Overview of applications of radiation processing in combination with conventional treatments to assure food safety

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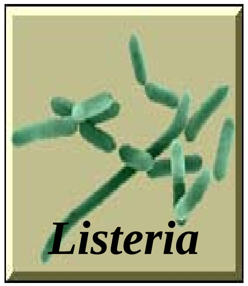
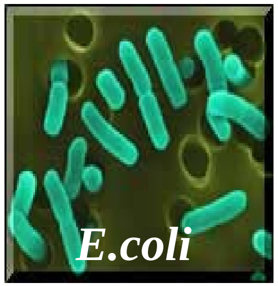
PROBLEMATIC ISSUES

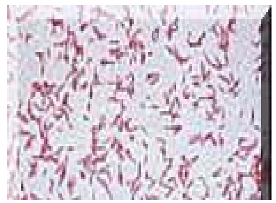
The Center for Disease Control and Prevention (CDC) estimates that 48 million people get sick due to foodborne diseases in USA annually.

In Canada, the foodborne illness is estimated as more than 11 million episodes/year

→ Therefore, controlling of food pathogens in food products are very important.







Campylobacter

Foodborne Illness in Canada

13 million cases/year

Salmonella choleraesuis **:**	**630 000 cases/year, $ 98 Million**
Staphylococcus aureus **:**	**100 000 cases/year**
Campylobacter jejuni **:**	**16 000 cases/year**
E. coli **O157:H7 :**	**13 000 cases/year**
Shigella **:**	**19 000 cases/year**
Listeria monocytogenes **:**	**2 800 cases/year**

Gélinas, P., 1995, La Fondation des Gouverneurs; (AgricultureCanada, 2006)

Cost of Food Loss in Canada

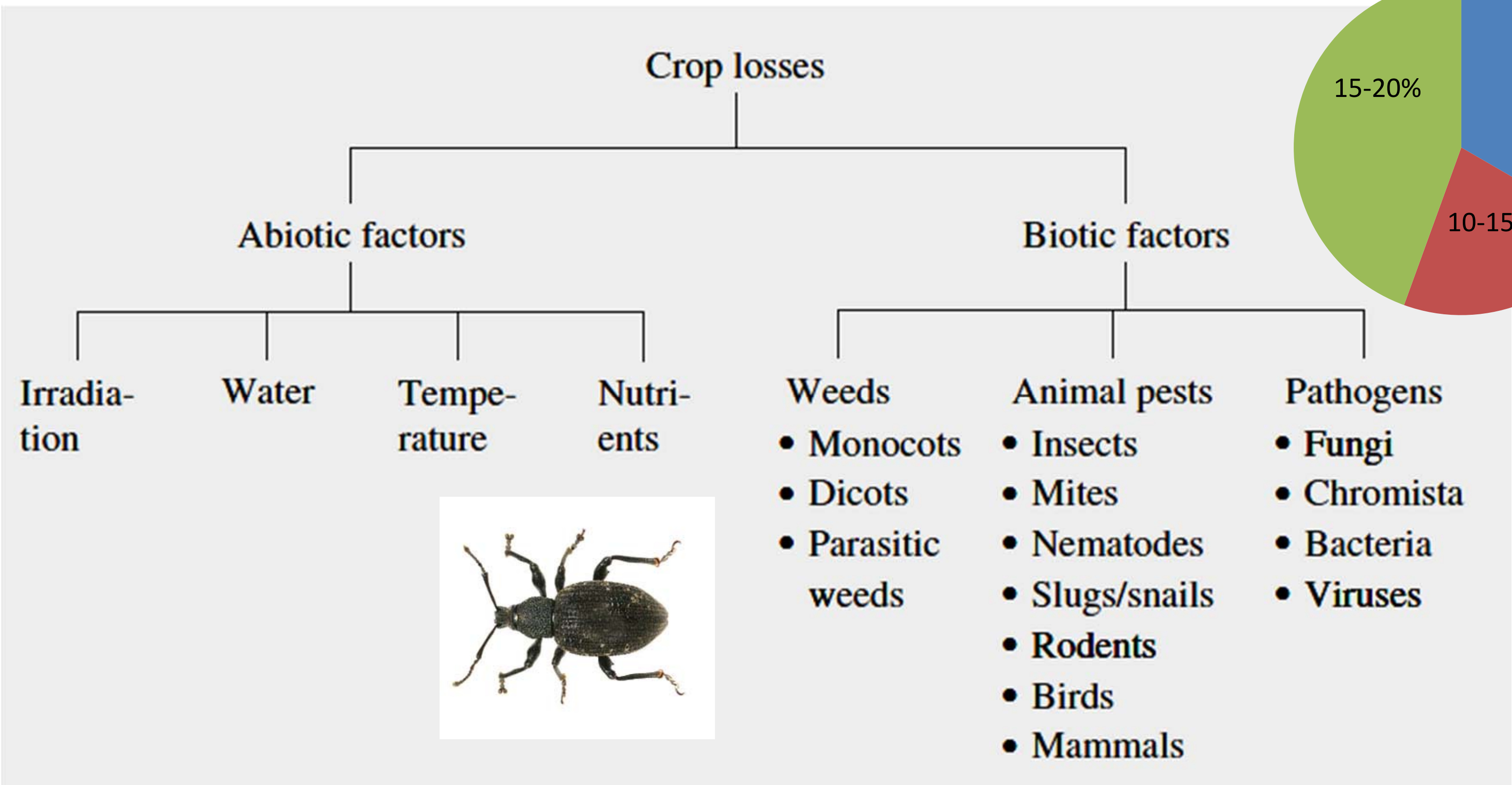
Meat, Poultry and Fishes: $200 Million/year

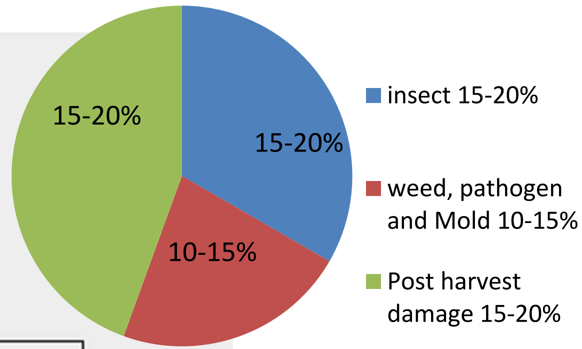
In Canada, 50% of the mortality related to alimentary diseases is due to poultry consumption

Foodborne illness: $ 1 Billion/year

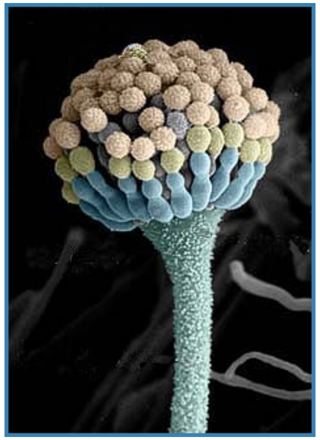
Crop pests - a serious concern….

1. More than 40% crops are destroyed each year due to pests.
2. Preventing this loss could feed 3 billion malnourished people.
   (Pimentel, D, 2009, Agricultural Sciences, Vol II, P-2)





More than 40% of food products could be rejected due to molds contamination



Aflatoxins produced by molds

- Toxic

- Mutagenic

- Carcinogenic

Occurrence of Aflatoxins in Food

Food	Country	Quantity	References
Rice	India	5-50 µg/kg	
	Chin	20 µg/kg	
Maize	USA	10-700 µg/kg	
	Denmark	5-174 µg/kg	Rubsom 1997. *Food Chem*.
	France	> 20 µg/kg	57-67.
Oat/wheat/bardy	Sweden	50-400 µg/kg	
Meat	Egypt	6-40 µg/kg	
Dried figs	UK	10-40 µg/kg	
Cotton seed	Argentina	20-200 µg/kg	
Peanuts	Mexico	700 µg/kg	
	USA	24 µg/kg	Andrea *et al*. 2012. *Food*
	Brazil	7.9-1496 µg/kg	*Addit. Contam*. 276-280.
Nuts shelled	Brazil	16.5-1972 µg/kg	
Peanuts butter	USA	20-100 µg/kg	
	UK	38-535 µg/kg	
Raw drugs	China	1.29 µg/kg	Bhat *et al*. 2010. *Food Sci*.
Medicine plant	China	10-160 µg/kg	*Food Safety*. 57-81.
Eggs	China	3300 mg/Kg	
Milk	UE countries	28-1012 ng/kg	
	India	50 ng/L	Rodriguez Valasco *et al*.
Red pepper	Ethiopia	250-525 µg/kg	2010. *Food Addit. Contam*.
	India	<10->100 µg/kg	276-280.
Red Paprika	Korea	5.40 µg/kg	Aydin *et al*. 2007. *Food*
Wallnut	Malaysia	17.5 µg/kg	*Cont*. 1283- 1288.
Bakery product		24 µg/kg	Leong *et al*. 2010. *Food*
Coated nut products		113.1-514.7 µg/kg	*Cont*. 334-338.

Irradiation of any food must satisfy two objectives

1- Adequate kill of target micro-organisms and insects

2-Retention of high quality of product

3-Avoidance of radiation-induced sensory detriment

Challenge is to ensure the simultaneous attainment of these goals

Irradiation is a non-thermal technologies are emerging technologies that have the advantage to assure food safety without affecting the nutritional value and when done in combination with other technologies (ex: addition of antimicrobials and modified atmosphere packaging), can protect the physico-chemical and sensorial quality by increasing the bacterial sensitivity.

However, the efficiency of the process should be demonstrated *in situ*

Microorganisms Sensibility

Temperature

Bacteria level

Presence of oxygen

Water availability

Media composition

Other factor to consider

The increase of the consumer demand to eliminate the addition of additives in food system represent a challenge for the scientists

Natural antimicrobials characteristics like essential oils (EOs)

Low solubility in water

High volatility

they need to be encapsulated in appropriate delivery systems

to promote their efficiency and assure a control release

The sensorial quality should be protected

Combination of Irradiation and EOs treatment

- **The ionizing radiation affects directly the microbial DNA molecules.**

- **The addition of EOs disintegrates the cell membrane, makes the cell impossible to repair the damage incurred by the action of both treatments (Oussalah et al., 2006 J. Food Prot. 69, 5, 1046-1055).**

- **Combined treatment lowers the doses required for individual treatment of EOs and Irradiation alone. (Takala et al., 2011, Rad. Phys. Chem., 80, 1414-18).**

→ **Novel Functional Ingredients for Enhancing the Effectiveness of Irradiation in Food Processing**

→ **Novel Encapsulation Technologies to Protect the Functional Ingredients and to Assure a control release of the functional ingredients**

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Main results of our studies on bacterial and insect radiosensitization using combined treatments

Protection of the natural antimicrobial compounds used

Future opportunities and needs

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Method used

↓

Fresh meat or ready-to-eat meat or vegetables or rice

↓

with additive and test organism.

↓

Irradiation to specified doses.

↓

Determine surviving microorganisms or insects as function of radiation dose.

↓

Plot radiation survival curves and calculate D_{10}.

Bacterial Radiosensitivity

D_{10} (control) / D_{10} (treatment)

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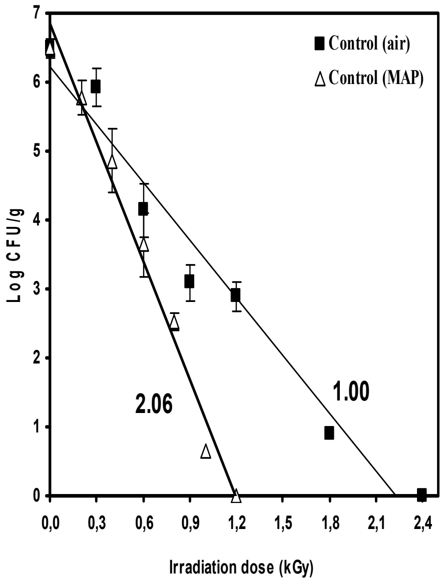
RESALA Laboratoire de Recherche en Sciences Appliquées à l'Alimentation

INRS Université d'avant-garde

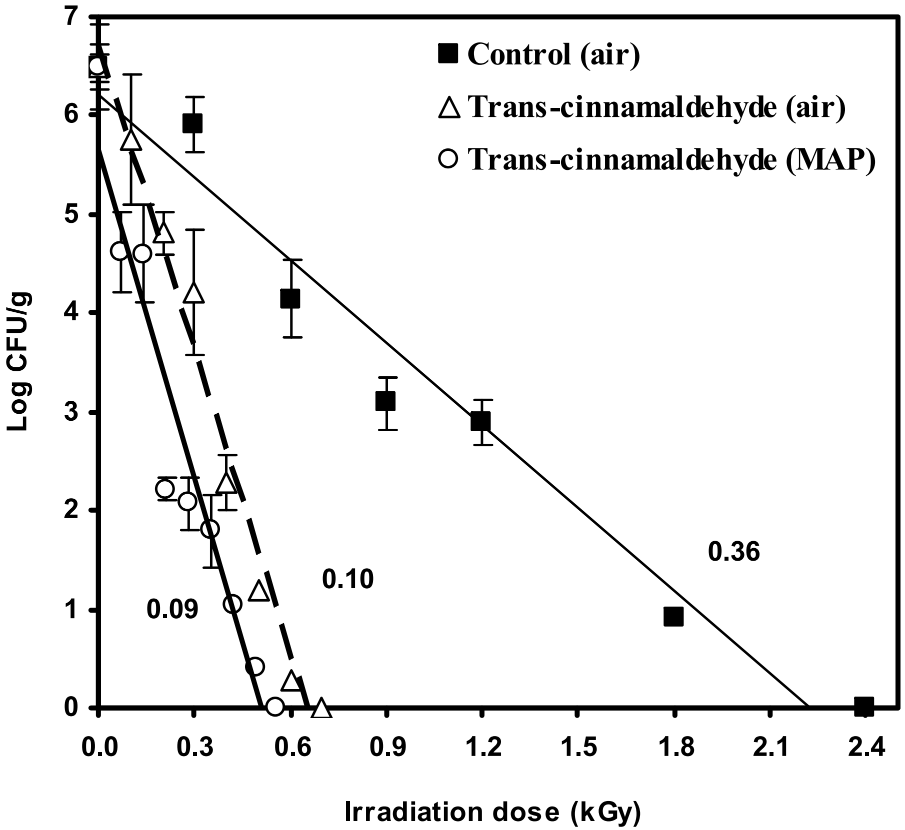
Modified atmosphere packaging (MAP) has been used to control bacterial populations in ready-to-used vegetables

Combination of MAP and irradiation without antimicrobial compounds can increase by 2 times the radiosensitization of *Listeria monocytogenes* in carrots



Caillet et al., 2006 J. Food Prot., 69, 1, 221–227

Listeria monocytogenes inhibition on ready to eat carrots in presence of natural antimicrobial compounds



HE + Ionisation

D_{10} (air) = 0.1 kGy

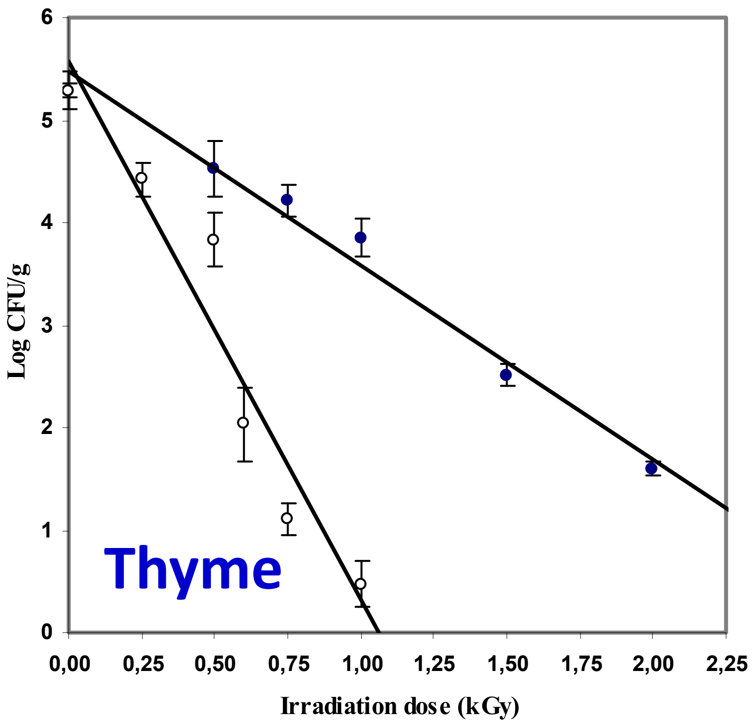
D_{10} (MAP) = 0.08 kGy

D_{10} in presence of HE

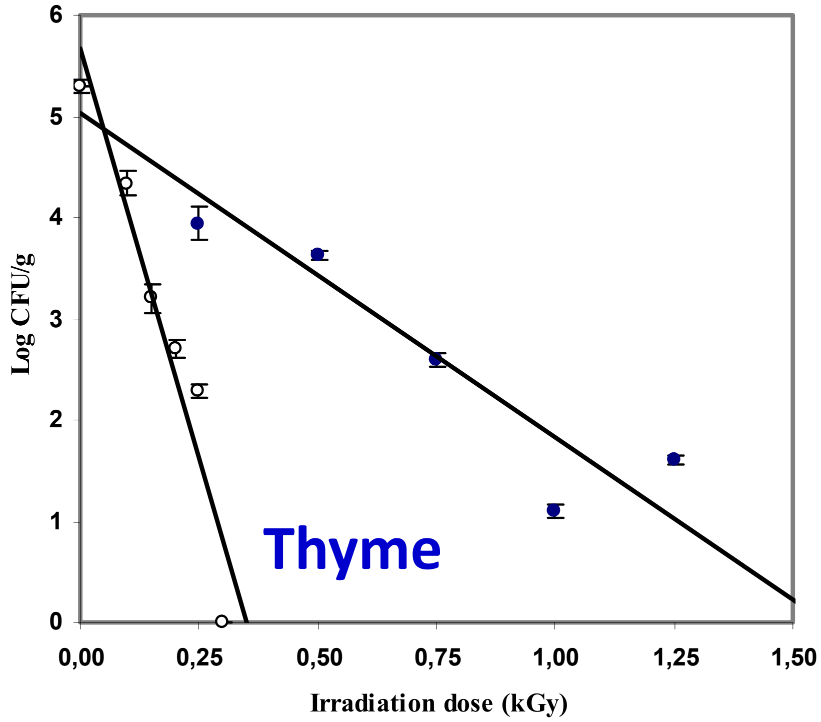
Air = 3.7 et MAP = 4

Salmonella in Beef
Bacterial Radiosensitization using spice extracts

Air



MAP



Combinaison MAP and carvacrol on ground beef

	E. coli		*S.*TYPHI	
	D10 (kGy)	Relative *Sensitivity*	D_{10} (kGy)	sensitivity
Contrôle	0.126	1.00	0.526	1.00
MAP	0.086	1. 9	0.221	4.15
Ess. oils + Air	0.055	2.29	0.254	2.2
Ess. oils + MAP	0.046	2.74	0.053	9.92

1. MAP : 60% O_2 - 30% CO_2 -10%N_2 ;
Ess. oils mix: Carvacrol (1 %) + TSPP (0.1%)}
3. Relative Sensitivity = ratio du D_{10}(contrôle) : D_{10}(treatment)

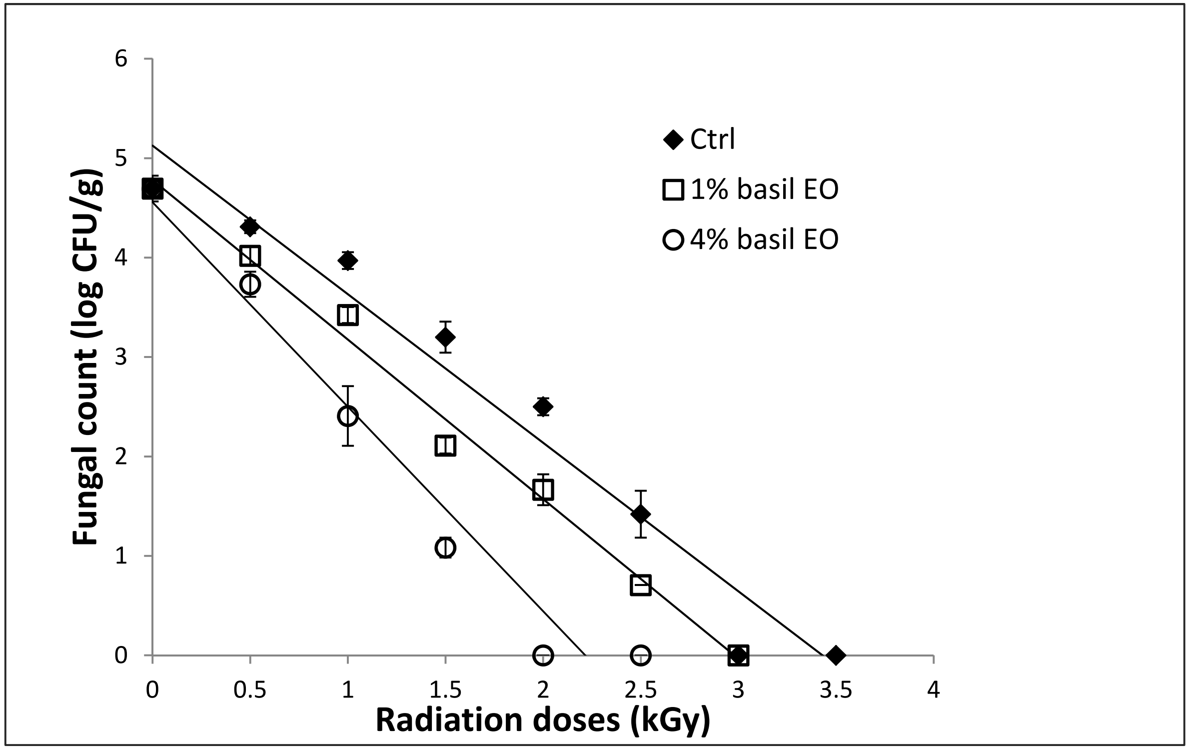
Shelf life extension of ground beef mesophilic aerobic count (log $_{10}$)

Treatment/Day	1	3	7	14
AIR				
0 kGy	7.3	>7	>7	>7
1.5 kGy	2.6 (4.7 log reduction)	3.5	4.3	>7
0 kGy Mustard 0.075%	7.4	>7	>7	>7
1.5 kGy Mustard 0.075%	2.6	2.4	3.8	>7
MAP				
1.5 kGy	<10	<10	<10	<10 even after 28 days of storage
0 kGy Mustard 0.075%	5.6 (1.7 log reduction)	7.1	>7	>7
1.5 kGy Mustard 0.075%	<1	<1	<1	<10 even after 28 days of storage

Listeria content in ready to eat carrots

Treatment	Day 1 (Log CFU/gr)	Day 7 (Log CFU/gr)
Control	3	3
0.25 kGy Air	2.6	2.4
0.50 kGy Air	1.9	1.15
0.25 kGy MAP	1.75	1.4
0.50 kGy MAP	<1	<1
Cinnamon 0.25 kGy Air	2.59	1.72
Cinnamon 0.5 kGy Air	2.04	<1
Cinnamon 0.25 kGy MAP	2.1	<1
Cinnamon 0.5 kGy MAP	<1	<1

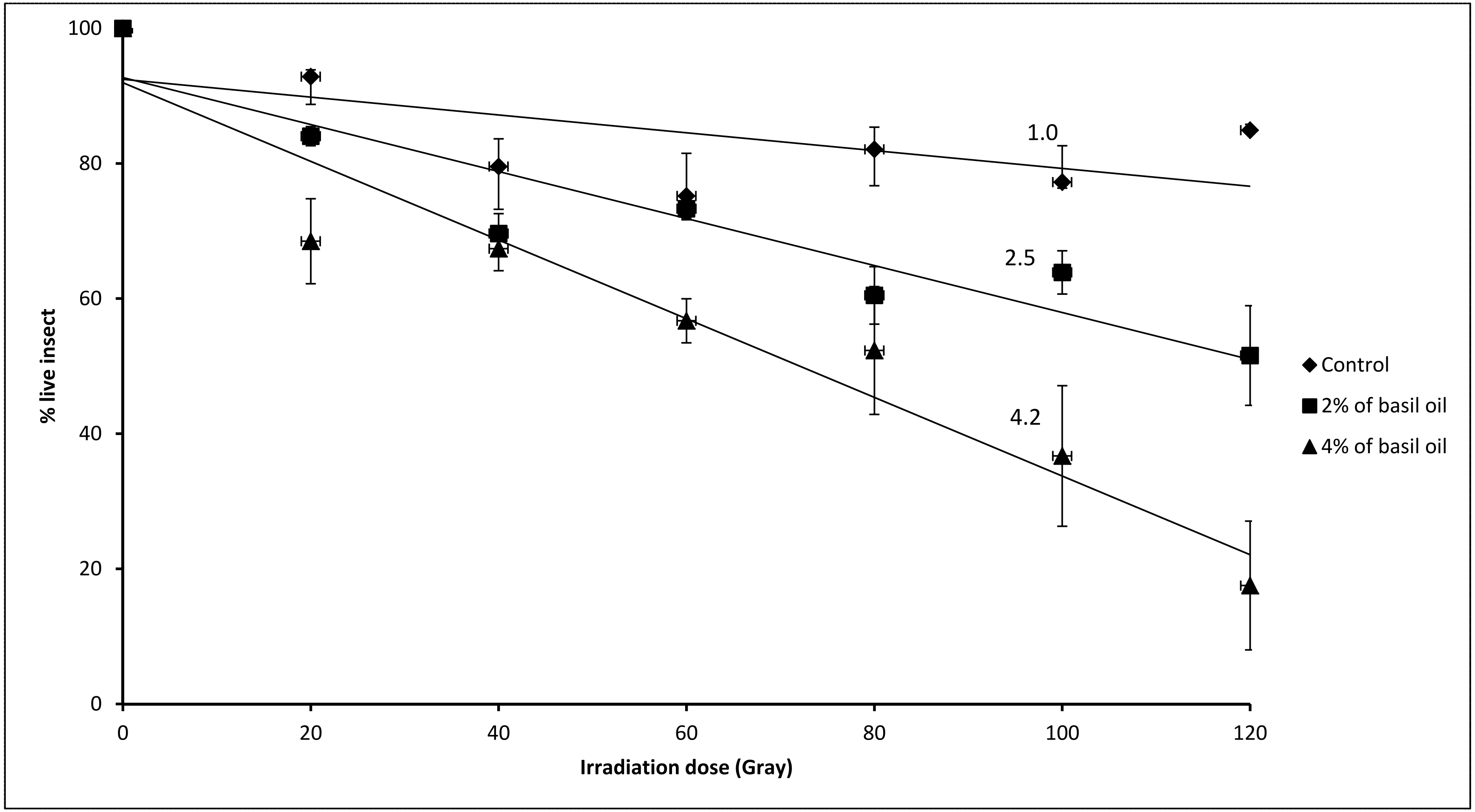
In situ Irradiation Experiment to Eliminate *A. niger* in rice



Relative sensitivity (RS) of *A. niger*

The D_{10} value decreased to 0.49 kGy and RS increased 1.38 times by combining 4% basil EO and irradiation treatment ($p \leq 0.05$) as compared to control.

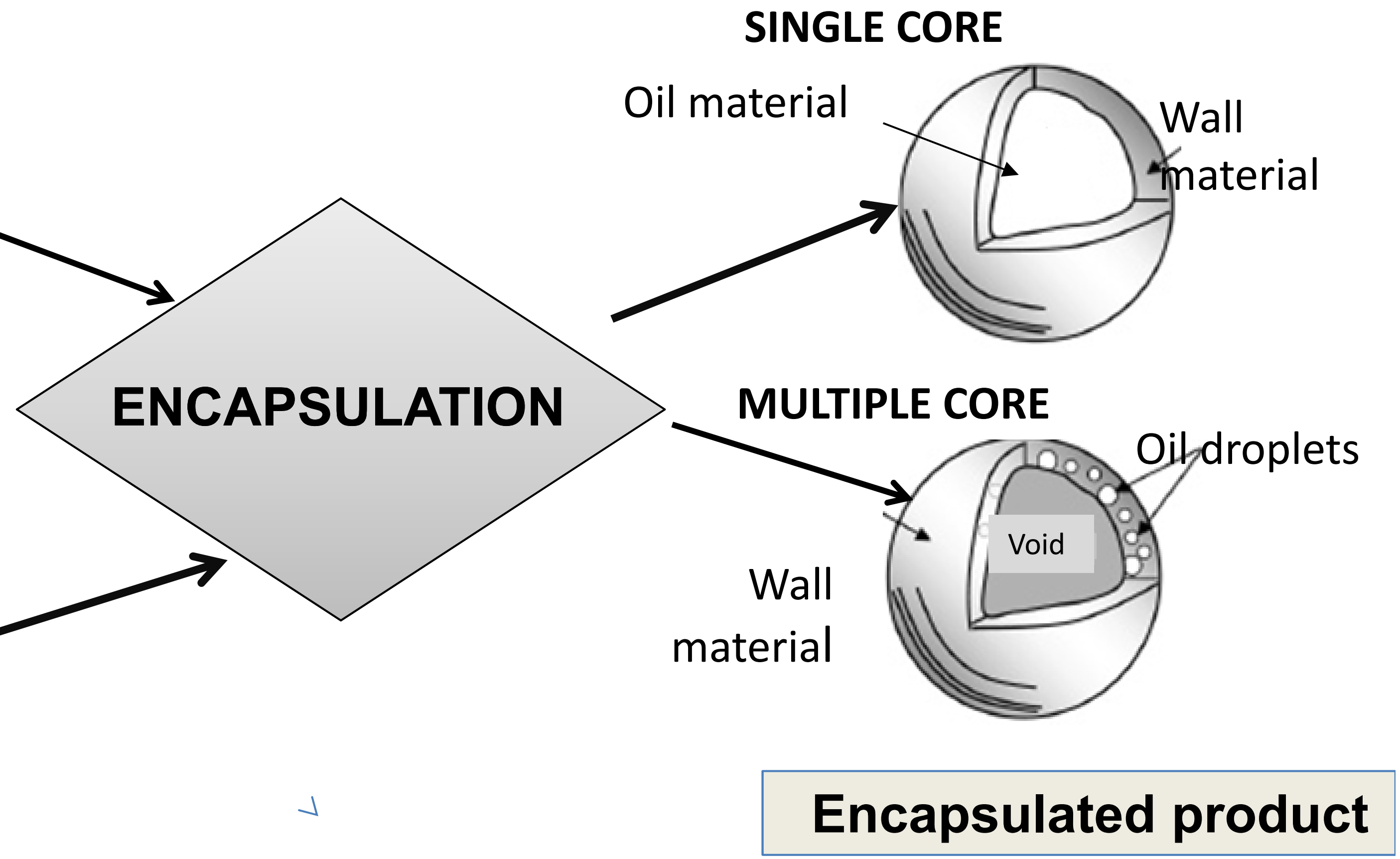
Radiosensitization of *Sitophilus oryzae* in rice



Encapsulation

Core materials
(bioactive agents
Flavor, antioxidant,
living cell)

Wall materials
➢Carbohydrate (starch, sucrose)
➢Protein(Gelatin)
➢Cellulose (MC, CMC)



Benefits:

➢Prevents degradative reactions
➢Allows mixing of incompatible components
➢Ensures control release to the target site.

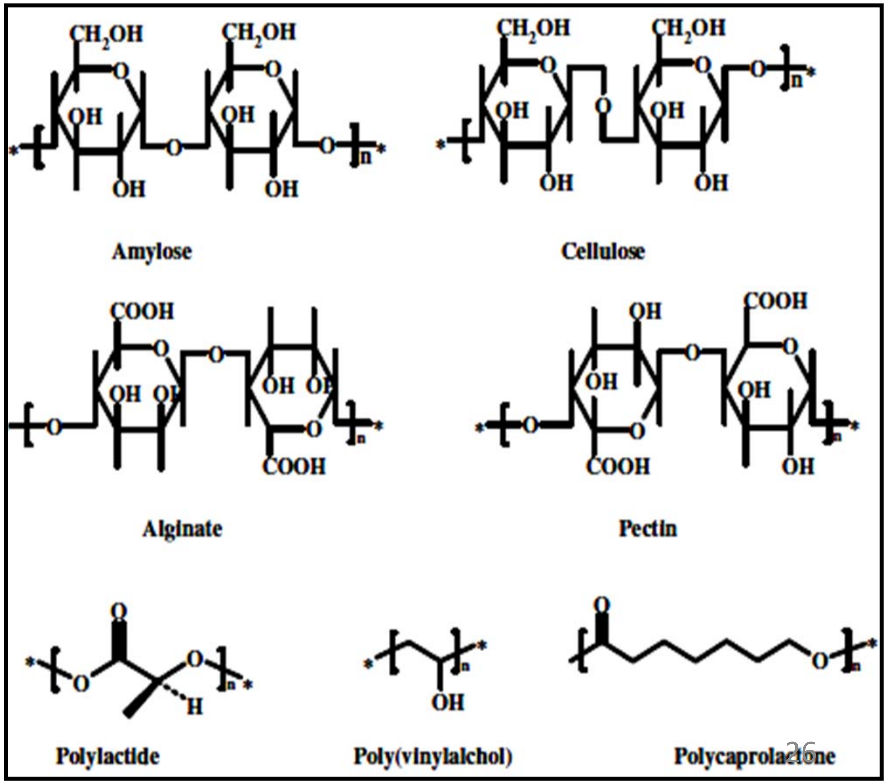
Natural polymer in agriculture.

- Natural polymers such as starches, chitosan, cellulose derivatives can be convenient for agricultural sector.

- Challenge
  The properties of these polymers do not fit specific applications.

- Alternative
  Blending, mixing and modifying with other polymers can regulate their morphologies and properties easily and efficiently.

(Puoci, et al., 2008, Am. J. Agric and Biol. Sci. V.3. 299-314)



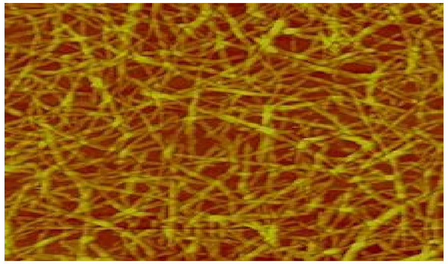
Active coating and Nanoscale encapsulation have been proposed as

Innovative approaches

Nanoscale encapsulation of natural antimicrobial compounds inside the active coating formulation can increase the concentration of bioactive compounds in food areas where microorganisms are preferably located

The active coating can be applied on vegetables to minimize or prevent the growth of pathogenic microorganisms

Crystalline nanocellulose (CNC)

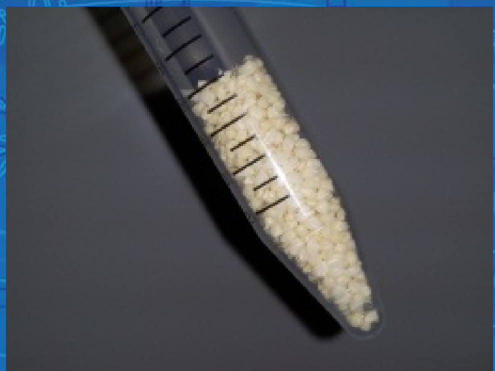

CNC

➢**Fillers for thermoplastic polymers due to their outstanding mechanical and barrier properties.**

➢**Can increase the stability of encapsulated bioactive agents into polymer matrices and ensure controlled release.**

(Khan et al., 2010. J. Agric. Food Chem., 58, 7878-85),
(Boumail et al., 2013. J. Agric. Food Chem. 61, 811-21),
Jamshidian et al., 2010, Comprehensive Reviews in Food Science and Food Safety, 9, 552-571)

Development of Cellulose Nanocrystal (CNC) Reinforced Bio polymeric Matrix for Encapsulation of Bioactive Compounds



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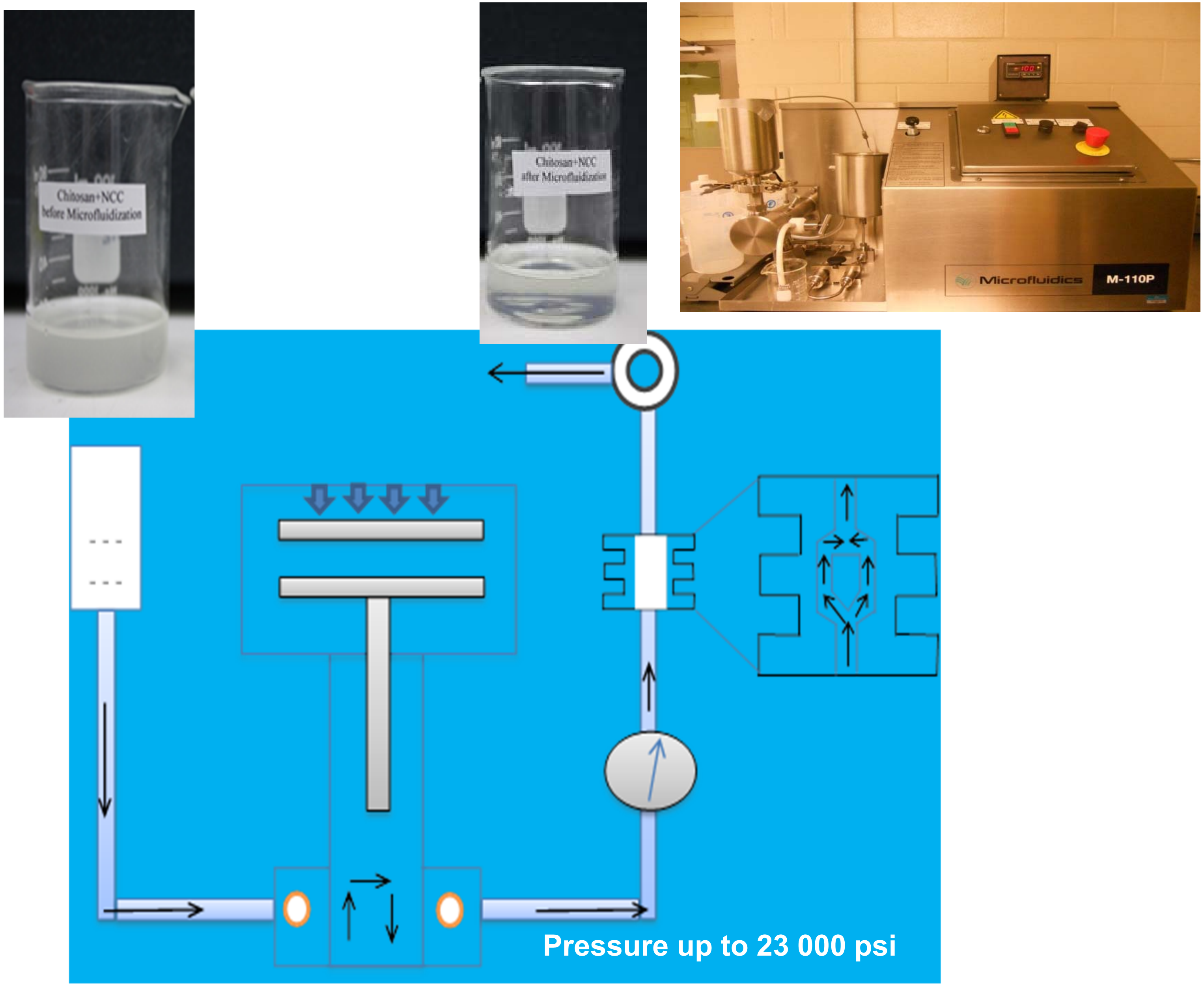
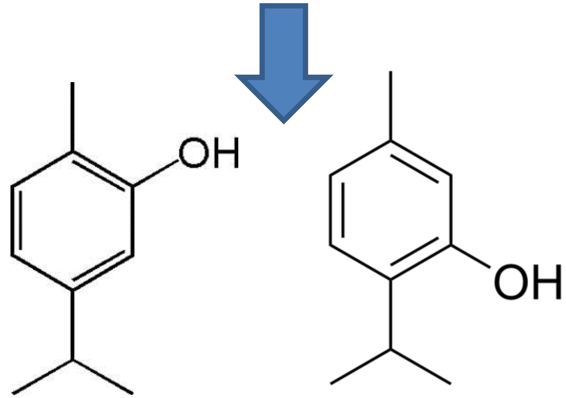

Chitosan+NCC before Microfluidization
Chitosan+NCC after Microfluidization
Microfluidics
M-110P
Pressure up to 23 000 psi

Essential Oils as antimicrobial compounds

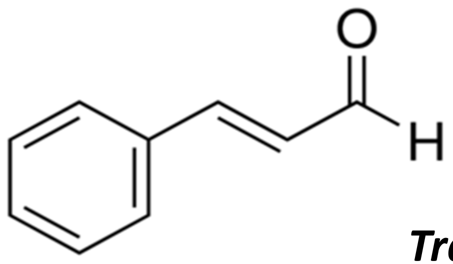
Origanum Compactum



Carvacrol **Thymol**

- **Aromatic oily liquids**
- **Extracted from plant**
- **Complex mixtures of comparatively volatile substances**
- **Widely used as an antimicrobial compounds against pathogenic bacteria**

Cinnamomum Cassia

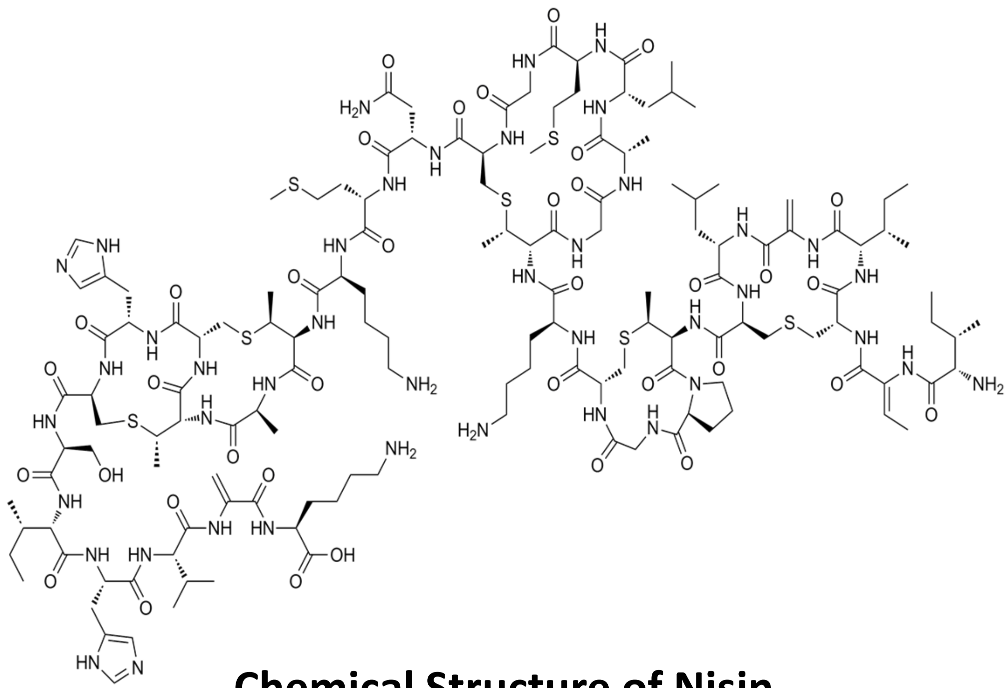


***Trans*-cinnamaldehyde**

Burt, 2004. *International Journal of Food Microbiology,* 94:223– 253

Nisin as an antimicrobial compound

- An antimicrobial peptide and produced from *Lactococcus lactis*
- Recognized as GRAS by the United States Food and Drug Administration (FDA)
- Showed antimicrobial activity against pathogenic bacteria (*Listeria monocytogenes*)



Chemical Structure of Nisin

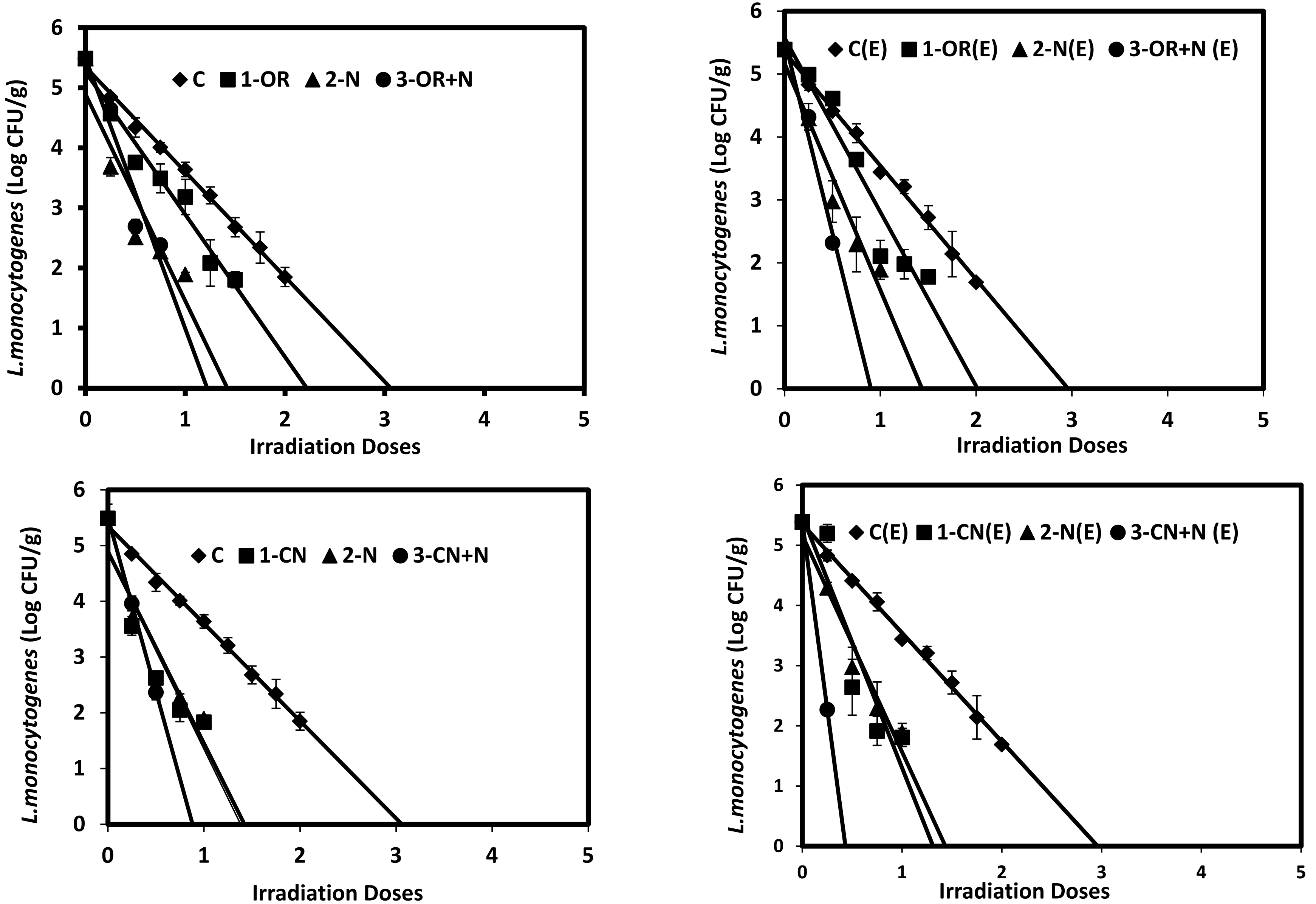
Cutter and Siragusa, 1997. *Food Microbiology* 14: 425–430.

In situ Analysis (Ready-to-eat, RTE Meat)

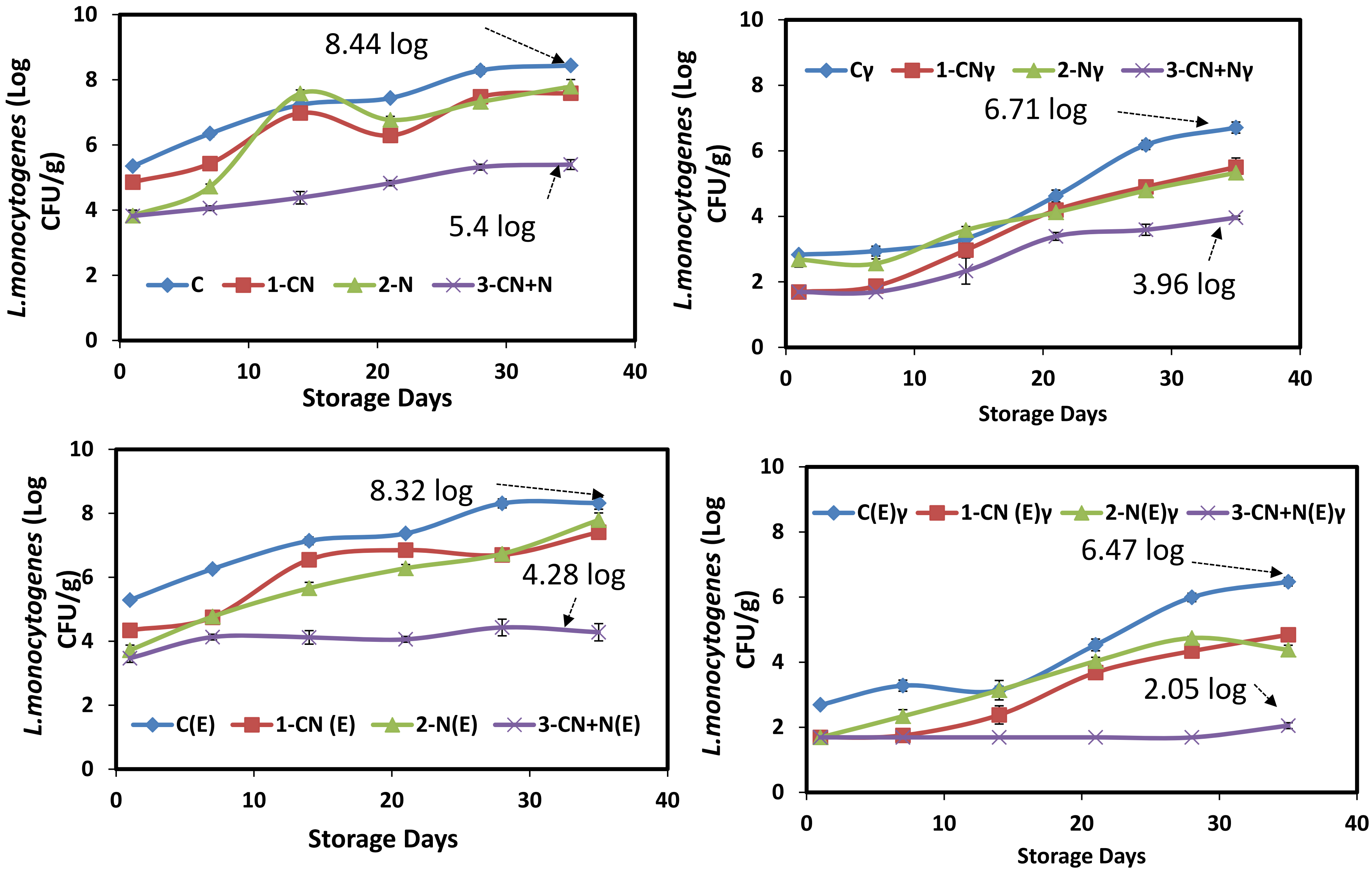
- **Ground lean pork**
- **Sodium chloride (13.95g), triphosphate (4.59g), erythorbate (0.80g) and nitrite salt (0.83g)**
- **Cooked at about 1hr at 162.7° C**

Without microencapsulated ham

Microencapsulated nisin In alginate/CNC based polymer



Radiosensitization of *L.monocytogenes* on RTE meat containing non and microencapsulated *Origanum Compactum* (0.25% w/v), *Cinnamomum Cassia* (0.25% w/v) and Nisin (0.125% w/w)



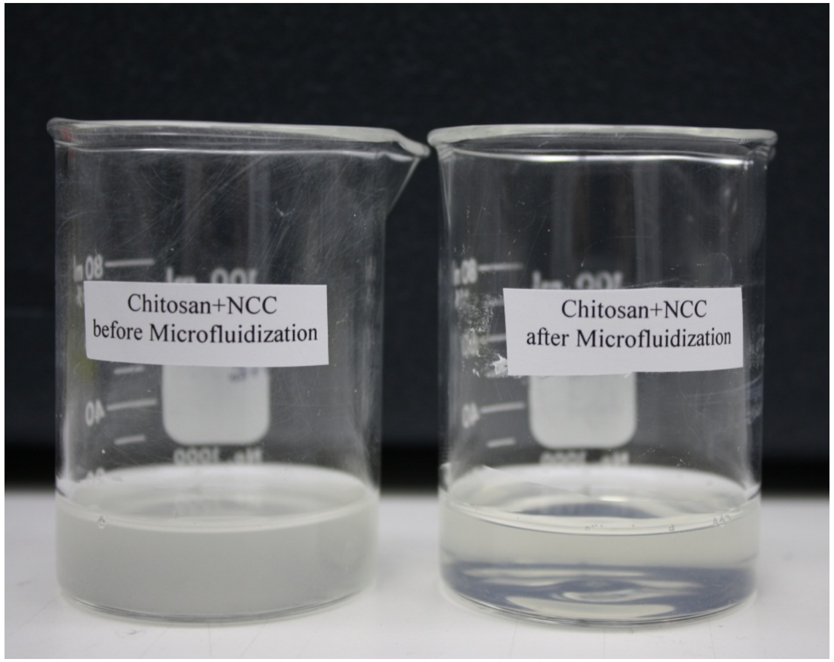
***L. monocytogenes* with and without microencapsulated essential oils and nisin with gamma irradiation (at 1.5 kGy) on RTE meat during storage against *L.monocytogenes*.**

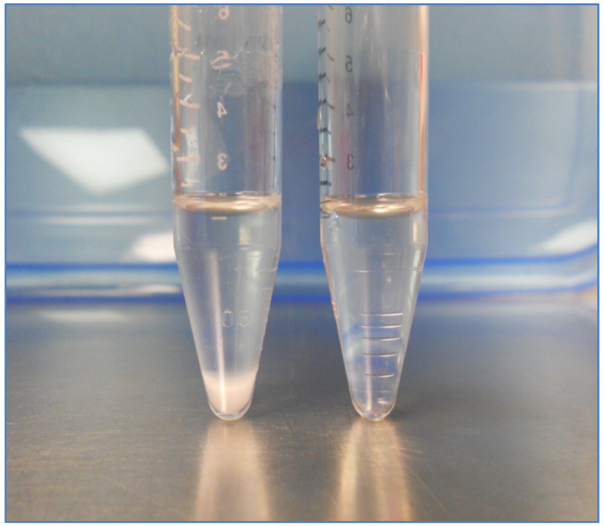
D_{10} and **Radiosensitivity (RS)** for non and microencapsulated antimicrobial microbeads against *L.monocytogenes*[*]

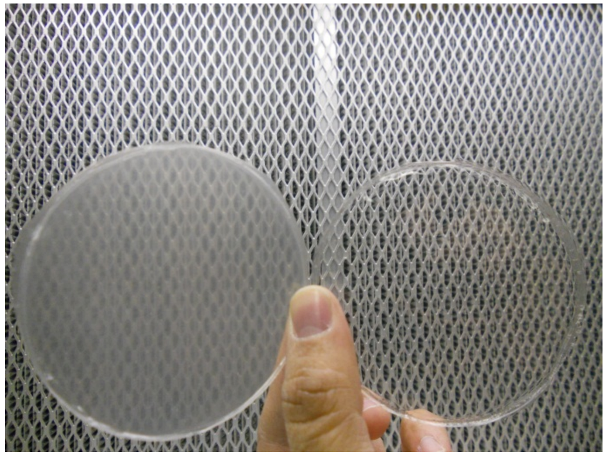
	D_{10} (kGy)	RS
C	0.57±0.031[a]	1±0.00[a]
OR	0.49±0.044[b]	1.16±0.09[ab]
CN	0.26±0.035[d]	2.18±0.28[cd]
N	0.29±0.018[cd]	1.94±0.06[c]
OR+N	**0.20±0.036[e]**	**2.91±0.74[ef]**
CN+N	**0.16±0.001[e]**	**3.57±0.15[g]**
C(E)	0.55±0.015[a]	1±0.00[a]
OR(E)	0.34±0.048[c]	1.65±0.30[bc]
CN(E)	0.21±0.028[e]	2.62±0.34[de]
N (E)	0.29±0.034[d]	1.95±0.26[c]
OR+N(E)	**0.16±0.003[e]**	**3.40±0.17[fg]**
CN+N (E)	**0.08±0.002[f]**	**6.89±0.30[h]**

[*]Values are means ± standard deviations. Means with the same letter are not significantly different ($P > 0.05$).

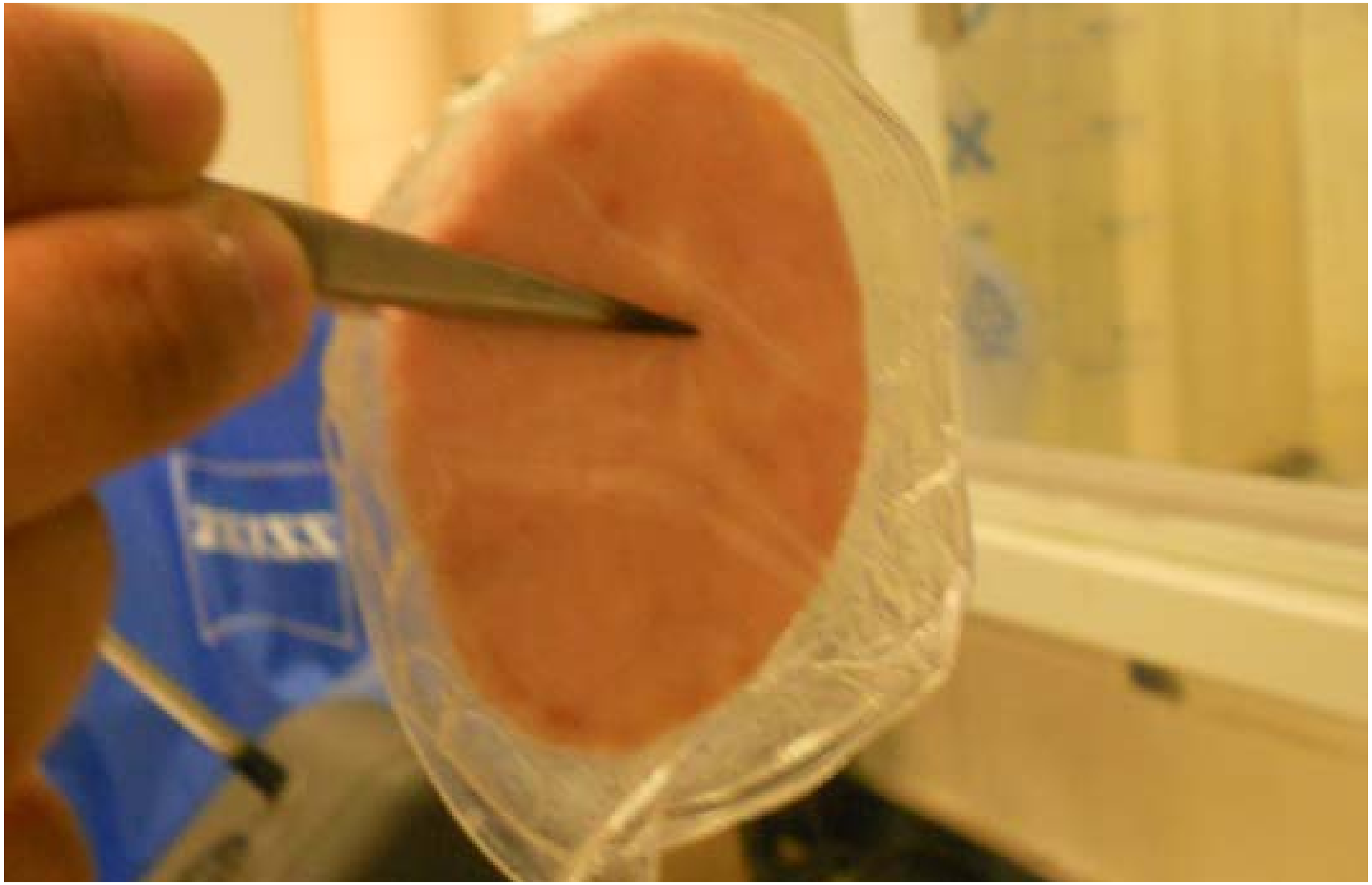
Microfluidisation of chitosan-NCC based solution and film formation



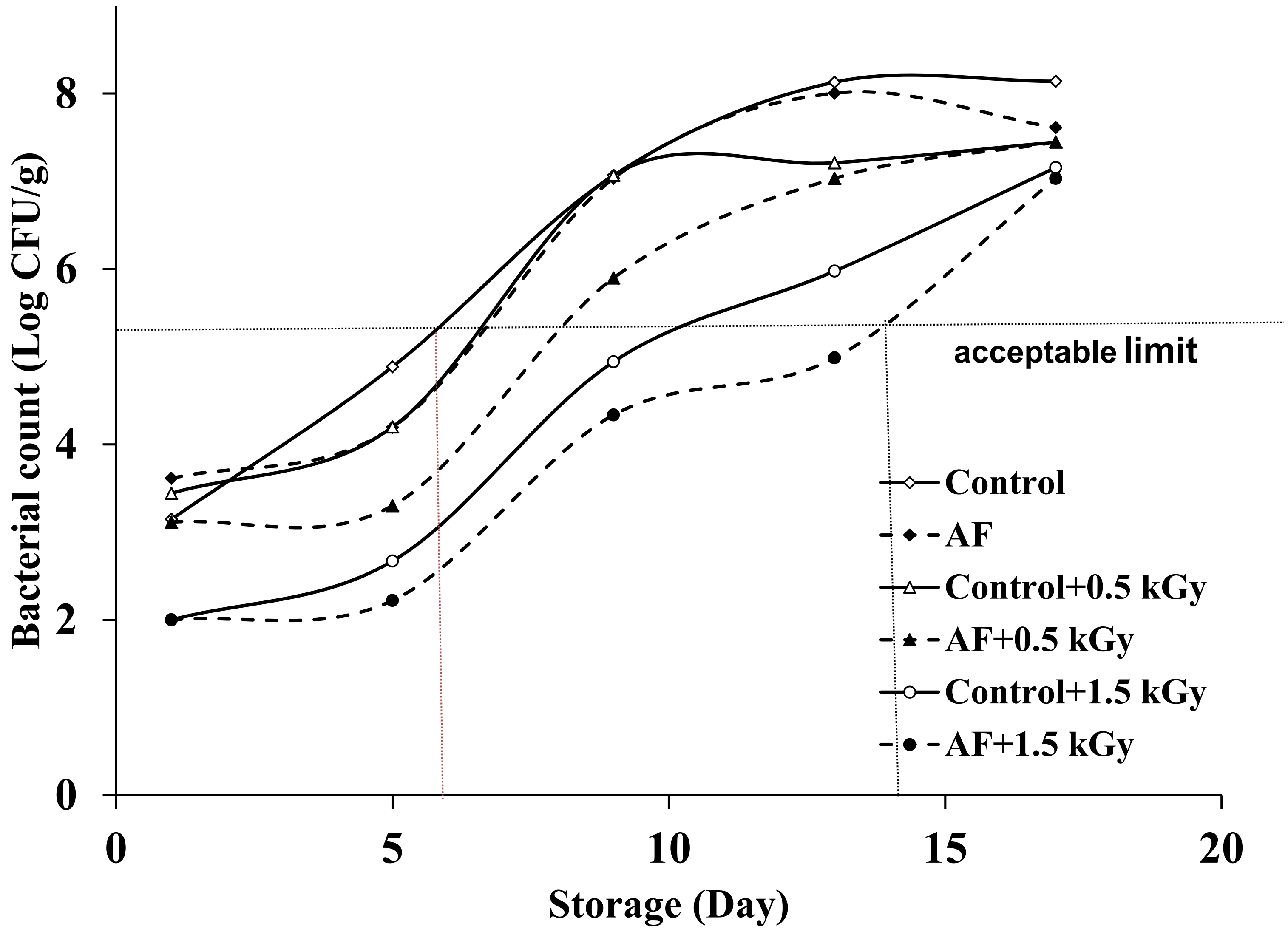




Active chitosan-NCC based film



Effect of active films based on chitosan-NCC and irradiation on mesophilic bacteria in RTE meat



Coating application on ready to eat vegetables and irradiation treatment

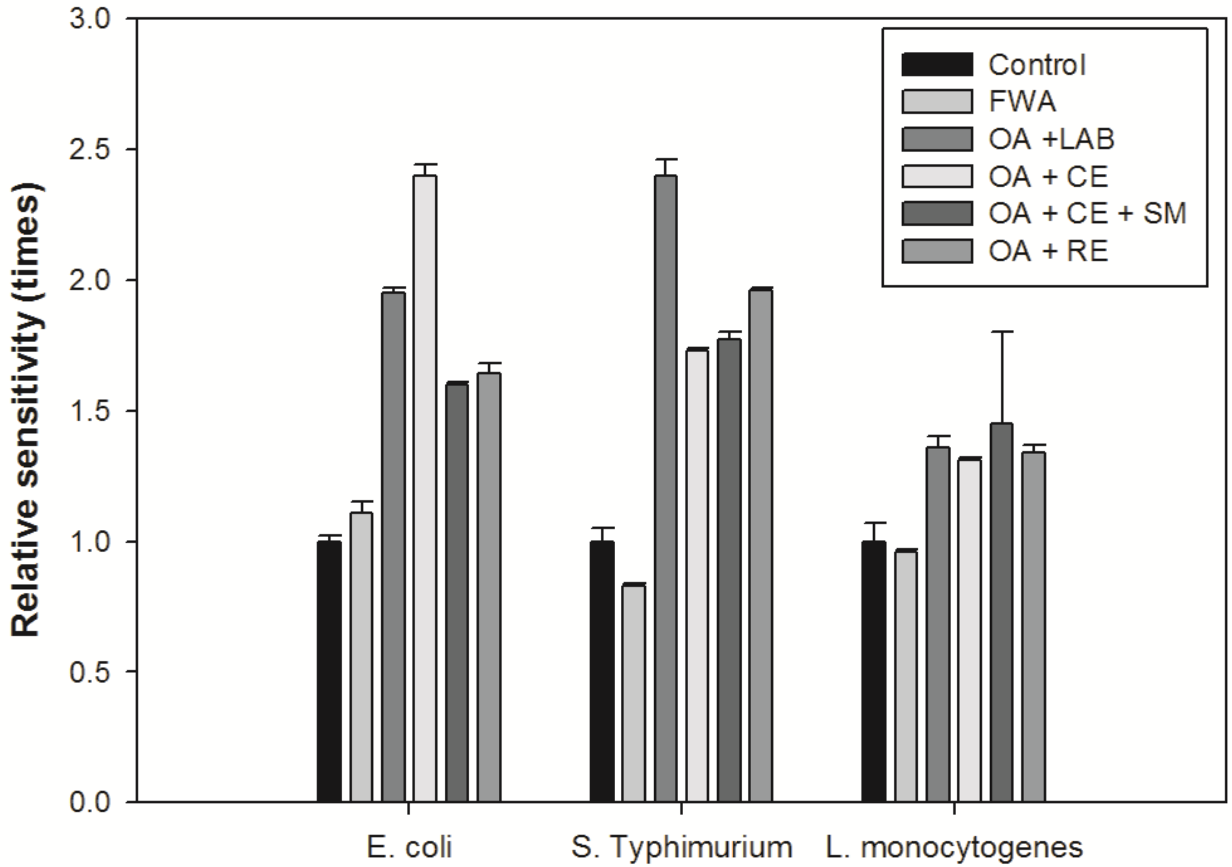
D_{10} values of selected pathogens and total microflora in broccoli florets coated with active coating

Bacteria	Control	OA/LAB metabolites	OA/FE	OA/FE/SM	OA/SE
L. monocytogenes	**0.4**	**0.29**	**0.3**	**0.27**	**0.3**
E. coli	**0.38**	**0.2***	**0.16***	**0.24**	**0.23**
S. Typhimurium	**0.50**	**0.2***	**0.29***	**0.28***	**0.25***
Aerobic flora	**0.57**	**0.36***	**0.32***	**0.38**	**0.33**

OA: organic acid mixture; LAB: mixture of LAB ferment; FE: fruit extracts; SM: spice mixture; SE: spice extract

Irradiation treatment from 0 to 3.3 kGy

Bacterial radiosensitization irradiation and active edible coatings



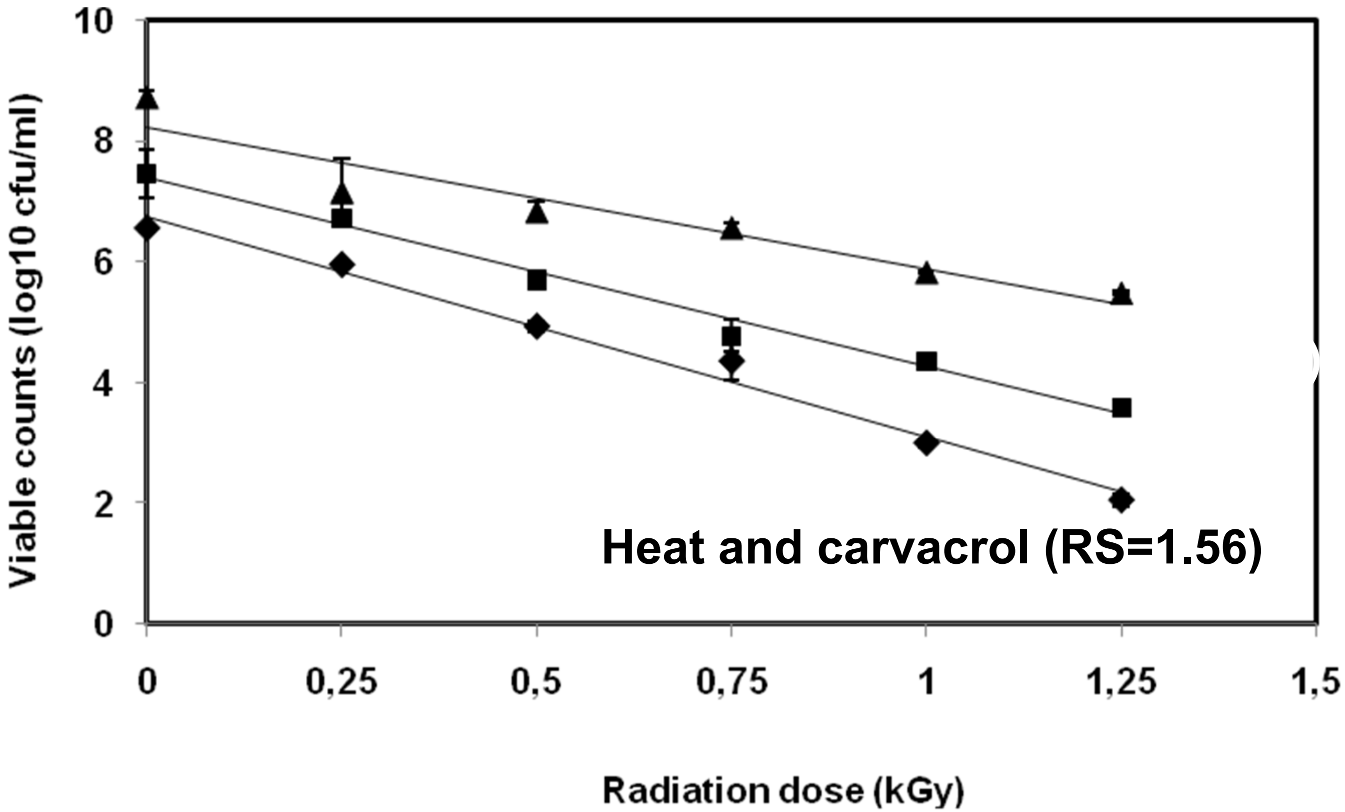
Takala et al., 2011 J. Food Prot. 74, 7, 1065-1069.

Effect of bioactive coating in combination with modified atmosphere packaging and gamma irradiation (0.25 kGy) on population of *E. coli* on green beans samples during storage at 4 °C

	Day 1	Day 3	Day 5	Day 7	Day 9	Day 11	Day 13
Control	2.98^{A}_{a}	3.03^{A}_{a}	3.10^{AB}_{a}	3.14^{AB}_{a}	3.18^{B}_{a}	3.41^{C}_{a}	3.95^{D}_{a}
MAP	3.02^{A}_{a}	3.19^{A}_{a}	3.05^{AB}_{a}	3.01^{ABa}	2.80^{B}_{b}	2.98^{AB}_{b}	3.01^{AB}_{b}
Coating (air)	2.45^{AB}_{b}	2.15^{A}_{b}	2.57^{B}_{b}	1.40^{C}_{b}	1.25^{C}_{c}	ND	ND
Coating+MAP	2.64^{A}_{b}	2.59^{AB}_{c}	2.30^{B}_{b}	1.66^{C}_{b}	1.19^{D}_{c}	ND	ND
γ (air)	1.71^{A}_{c}	1.26^{B}_{d}	1.18^{B}_{c}	ND	ND	ND	ND
γ +MAP	1.62^{A}_{cd}	1.45^{B}_{e}	1.19^{C}_{c}	ND	ND	ND	ND
γ+coating (air)	1.30^{A}_{d}	1.35^{A}_{de}	1.25^{A}_{c}	ND	ND	ND	ND
γ+coating+MAP	ND	ND	ND	ND	ND	ND	ND

Values are means ± standard deviations. Means with different lowercase letters within the same column are significantly different ($P \leq 0.05$), while means with different uppercase letters within each treatment lot are significantly different ($P \leq 0.05$)

Inactivation curve of *B. cereus in culture media* by gamma irradiation in combined treatments with mild treatment and natural antimicrobials



Control untreated cells (▲), cells treated with mild heat for 10 min at 45°C (■), cells treated with 312 ppm of carvacrol for 10 min at 30°C (♦).

CONCLUSIONS

Microorganisms and pests have the capability to develop significant increase of the relative radiation sensitivity (D_{10}) value in presence of natural antimicrobials and/or in combination with heat treatment.

Combination of irradiation and natural antimicrobials can be used to control pathogens, fungi and insect pest, in order to increase the shelf life and protect the safety and the quality of food.

Active edible coating or packaging can also act in synergy with irradiation treatment to protect food quality and safety but assure a better control of the safety during the whole storage.

Thank you

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