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Clean Label Ingredients for Food Safety

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Clean Label Ingredients for Food Safety

feeding the minds that feed the world

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July 14, 2018

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Objectives

- To review the factors that affect microbial growth in foods
- To present antimicrobial ingredients that may be considered “clean label”
- To present and discuss some of the challenges associated with “clean label” antimicrobials

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Agenda

- Microbial growth in foods
- Food parameters that impact microbial growth in foods
- Strategies for microbial control in foods
- Antimicrobials in foods
- “Clean label” antimicrobials
- Current challenges of “clean label” antimicrobials

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Microbial Growth in Foods

- **Spoilage Microorganisms**
  - Reduction of keeping quality and shelf-life → economic losses; food waste; loss of consumer confidence and trust
- **Pathogenic Microorganisms**
  - Consumer discomfort, illness or death → human pain, loss and grief; lost productivity; ↑ health care costs; ↓ consumer confidence and trust in food industry and food supply
- Except post-package sterilized foods, <u>all foods</u> are subject to food spoilage or loss of microbiological safety if ideal microbial growth conditions are present.

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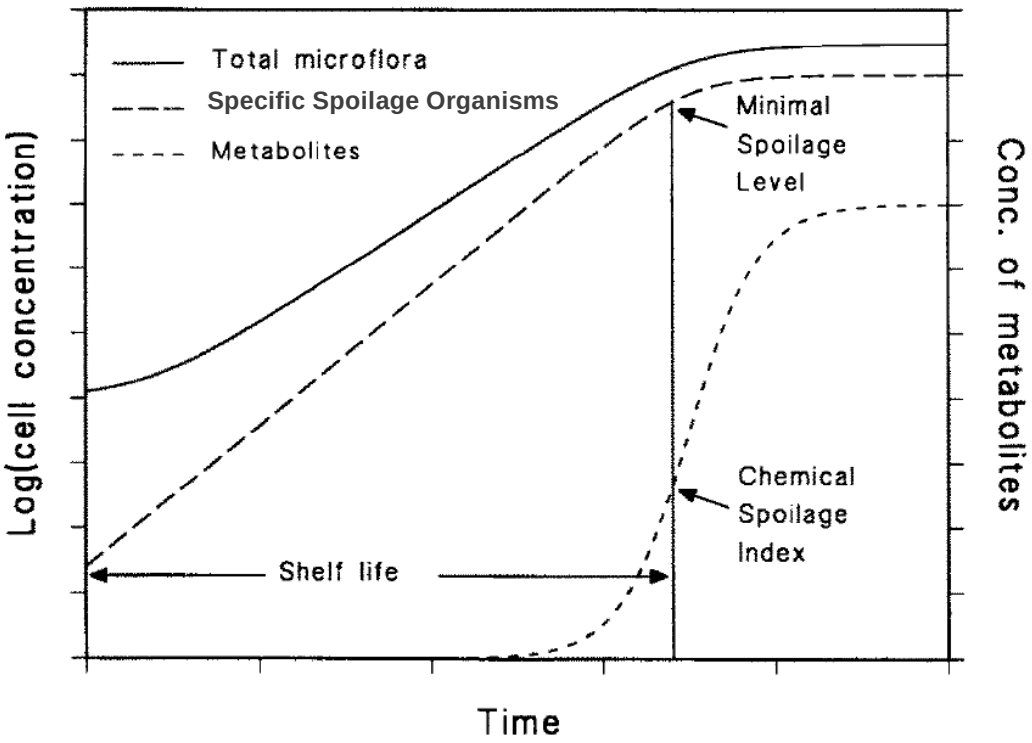
General Pattern of Microbial Spoilage



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Source: Huis in't Veld JHJ. 1996. Int J Food Microbiol. 33:1–18.

Food Parameters that Influence Microbial Growth

Intrinsic Parameters	Extrinsic Parameters
pH	Inactivation temperature
Available Moisture	Storage temperature
Nutrients	Storage atmosphere
Antimicrobial constituents	
Oxidation-Reduction (O/R) Potential (Eh)	
Biological structures	

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pH

pH = -log [H^+]

Microbes try to maintain pH within narrow range → “homeostasis”

Intracellular pH typically near neutral

Microbial classification by optimal pH range:

- Acidophiles → pH 0.5–5
- Neutralophiles → pH 5–9
- Alkaliphiles → pH 9–13

Major deviations from optimal pH disrupt pH homeostatic mechanisms

Cytoplasmic membrane relatively impermeable to H^+ and ^-OH ions

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Available Moisture

Described by water activity (a_w)

$$a_w = \frac{p}{p_o}$$

(vapor pressure of food)

(vapor pressure of pure water)

Related to equilibrium relative humidity (ERH) above the food

$$ERH = a_w \times 100$$

Describes degree to which water is bound in food

Measures availability of water to support microbial growth and participate in chemical/biochemical reactions

a_w not same as moisture (or water) *content*, or percent moisture

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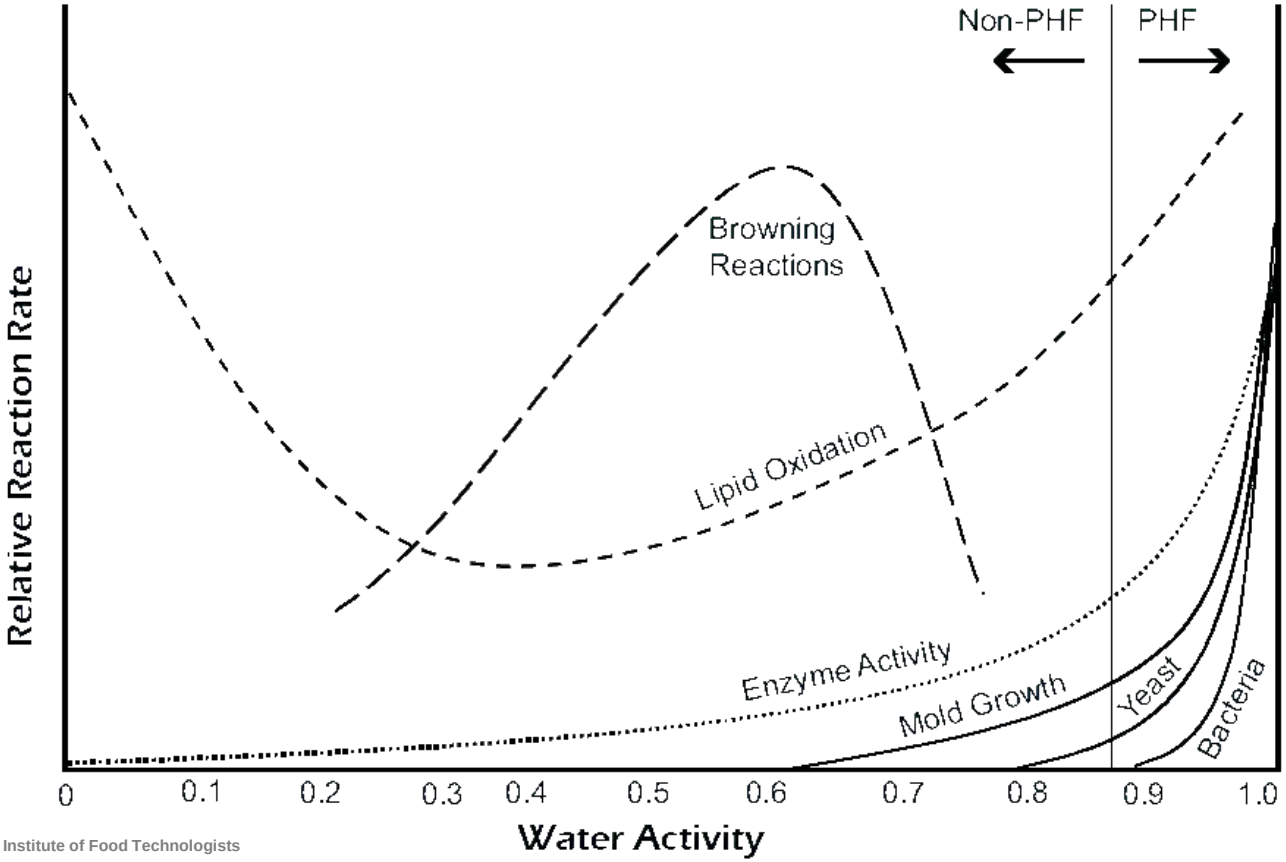
Effect of a_w on chemical and microbial stability of foods



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Minimum a_w requirements for microbial growth

Type of Microorganism	Water Activity (a_w)
Bacteria	0.85–1.00
Most yeasts	0.87–0.91
Molds	0.80–0.87
Certain yeast and molds	0.71–0.86
Certain yeasts	0.60–0.70
None	<0.60

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a_w of Selected Foods

Fresh meat and fish	0.99–1.00	Baked cake	0.90–0.94	Fruit cake	0.73–0.83
Fresh fruits & vegetables	0.97–1.00	Jams and jellies	0.75–0.94	Hard salami	0.82
Natural cheeses	0.95–1.00	Bean paste	0.93	Beef jerky	0.78–0.82
Fluid milk	0.99	Caviar	0.92	Soy sauce	0.80
Pudding	0.97–0.99	Summer sausage	0.88	Dried fruit	0.55–0.80
Bacon	0.97	Uncooked rice	0.80–0.87	Honey	0.75
Cooked Ham	0.97	Flour	0.67–0.87	Peanut butter, 15% moist	0.70
Eggs	0.97	Aged cheddar cheese	0.85	Dried whole egg	0.40
Pork sausage	0.97	Maple syrup	0.85	Cookies	0.30
Frankfurter	0.96–0.97	Fruit juice concentrates	0.79–0.84	Instant coffee	0.20
Liverwurst	0.96–0.97	Cake icing	0.75–0.84	Dried whole milk	0.20
Bread, white	0.94–0.97	Fudge sauce	0.83	RTE breakfast cereal	0.10–0.20
Cheese spread	0.95	Sweetened cond. milk	0.83	Crackers	0.10

Nutrients

Nutrient requirements of microorganisms

1. Water
2. Energy → primarily sugars, alcohols, amino acids
3. Nitrogen → amino acids
4. Vitamins and growth factors
5. Minerals

Requirements, least to highest:

- Molds → yeasts → gram-negative bacteria → gram-positive bacteria

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Oxidation-Reduction (O/R) Potential (Eh)

Ratio of oxidizing vs. reducing power of a substance

Measured in mV (pH 7.0; 30°C)

↓O_2 ➔ ↓Eh

Can be extrinsic parameter also (i.e., packaging atmosphere)

Classification of microorganisms based on Eh requirements:

	Eh range (mV)	Example
Aerobes	[+500] – [+300]	*Aeromonas* hydrophila
Facultative anaerobes	[+300] – [-100]	*Escherichia coli*
Anaerobes	[+100] – [<-250]	*Clostridium botulinum*
Microaerophiles		*Campylobacter jejuni*

Biological Structures

Natural protective coverings of foods

- e.g., egg shells, nut shells, fruit peels, seed coats, animal hides/skin

In intact form, provide physical barrier to entry of microorganisms

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Temperature

Classification of microorganisms based on temperature requirements:

	Growth range (°C)	Growth optima (°C)
Psychrophiles	[-5]–20	10–15
Psychrotrophs	>0	n/a
Mesophiles	10–45	35–40
Thermophiles	45–70	55–60

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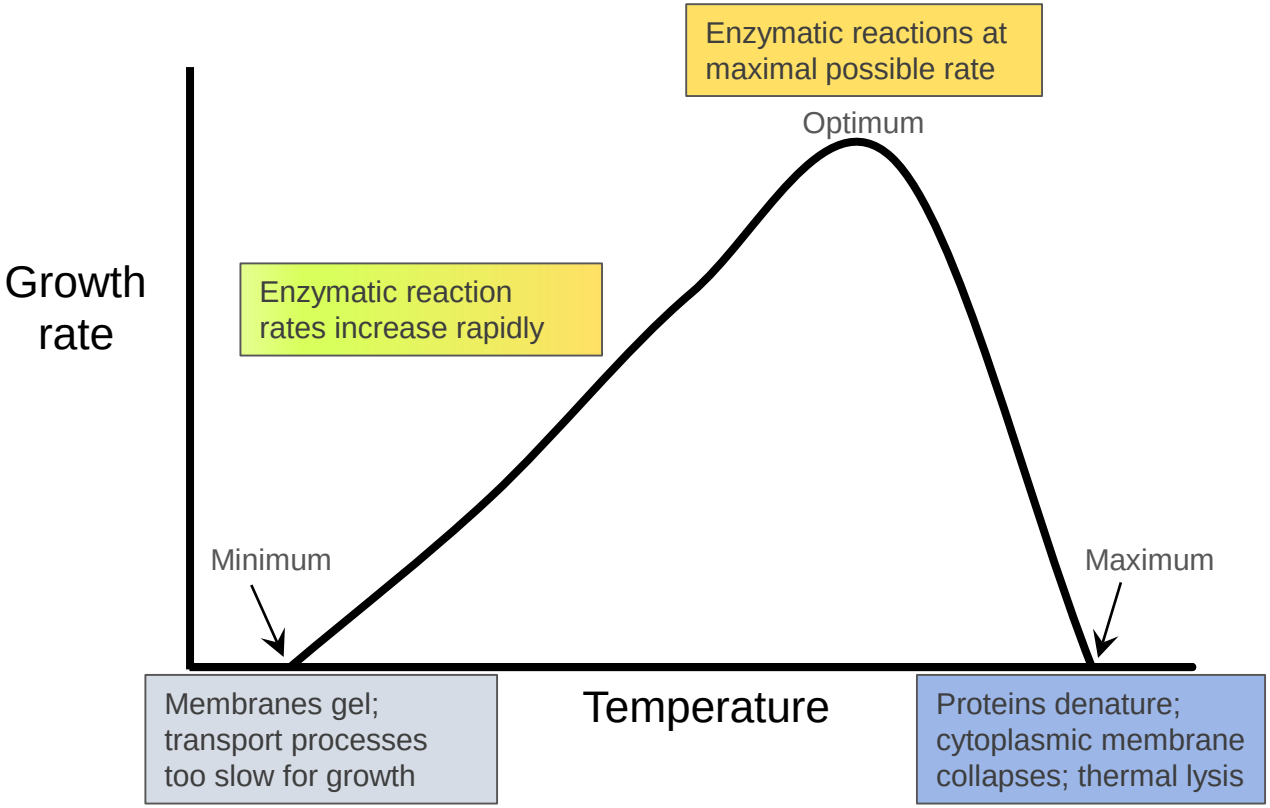
Effect of temperature on growth rate of microorganisms



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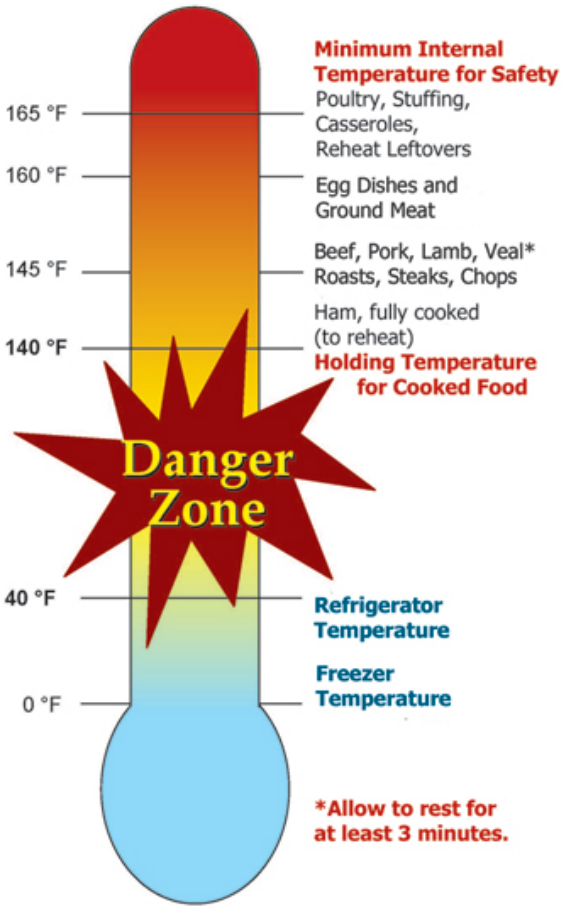
Temperature

Ways to control microorganisms:

- High temperature: cooking, canning, etc.
- Low temperature: refrigeration, freezing, etc.
- Avoid temperature “danger zone” (40–140°F)



Graphic source: https://www.fsis.usda.gov/wps/portal/fsis/topics/food-safety-education/get-answers/food-safety-fact-sheets/safe-food-handling/danger-zone-40-f-140-f/CT_Index

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Antimicrobial Constituents

- May be:
  - Naturally-present
  - Produced by competitive microflora
  - Deliberately added as food additives

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Microbial growth control strategies

Control barrier	Objective	Example strategies
Inactivation temperature	↑	Cooking; canning
Storage temperature	↓	Refrigeration; freezing
pH	↓	Fermentation; acidification
O/R Potential (Eh)	↓	Vacuum or modified atmosphere
Water activity (a_w)	↓	Dehydration; addition of salt or sugar
Antimicrobial ingredients	↑	Lactate; sorbate; diacetate; vinegar; fermentates; etc.
Competitive microflora	↑	Starter cultures
Non-thermal processes	↑	High pressure; irradiation; pulsed light; ultrasound; etc.

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Antimicrobials in Foods

- Classified as “preservatives”
- Definitions:
  - Chemical preservatives (21 CFR 101.22(a)(5)):
    - “…any chemical that, when added to food, tends to *prevent or retard deterioration* thereof, but does not include common salt, sugars, vinegars, spices, or oils extracted from spices, substances added to food by direct exposure thereof to wood smoke, or chemicals applied for their insecticidal or herbicidal properties.”
    - “[P]revent or retard deterioration” can refer to both biological and chemical deterioration
  - Antimicrobial agents (21 CFR 170.3(o)(2)):
    - “Substances used to preserve food by preventing growth of microorganisms and subsequent spoilage, including fungistats, mold and rope inhibitors,...”

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Antimicrobials in Foods

- General considerations
  - **Microorganism(s) to control**
    - Desired antimicrobial spectrum of action

    } Type of antimicrobial

  - **Length of shelf-life**
  - **Characteristics of food product**
    - a_w, pH, Eh, temperature, package, etc.

    } Usage level

  - **Cost-in-use** = Usage level x price

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“Clean Label” Antimicrobials

- **Identity criteria:**
  - Less/minimally processed
  - Recognizable and/or easy to pronounce name (not chemical)
    - ∴ isolated ingredients at disadvantage if chemical name must be used
    - “‘*Tis but thy name that is my enemy.*” (*Romeo and Juliet*, Act 2, Scene 2)
  - Sourced from nature / not synthetic
  - Preferably multi-use ingredient (e.g., flavoring <u>and</u> antimicrobial)
    - Helps shortening of ingredients statements
  - Other criteria:
    - e.g., organic, country of origin, local, environmental footprint

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“Clean Label” Antimicrobials

- Many currently-used antimicrobials are found in nature
  - e.g., acetic acid (vinegar), benzoic acid (cranberries), propionic acid (Swiss cheese), lactic acid (many fermented foods)
- However, even when isolated and purified from natural sources or produced by processes that could be considered natural (e.g., fermentation), the use of their chemical names in food labels may exclude them from “clean label” consideration

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“Clean Label” Antimicrobials

Animal	Plant	Microbial
Lysozyme Lactoferrin Lactoperoxidase system Chitosan	Spices and essential oils Berries Olives Hops Mustard Alliums Lemon juice Cherry powder	Bacteriocins Fermentates Protective cultures Vinegar

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Organic Acids and Salts

Short-chain organic acids

Weak acids

Antimicrobial activity is pH-dependent

- Increases as environmental pH approaches pKa
- When pH = pKa, half of the acid molecules are dissociated
- At pH < pKa, more of the acid is undissociated (and thus more effective)

In undissociated state, organic acids enter cell, dissociate and decrease cytoplasmic pH. In effort to maintain homeostasis, cellular ATP is depleted

Organic acids are lipophilic and therefore difficult to solubilize in water phase; therefore they are more commonly added in their salt forms

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Commonly-used organic acids

Organic acid	MW	pK_a
Acetic	60.50	4.75
Propionic	74.08	4.88
Lactic	90.08	3.08
Phosphoric	98.00	2.21
Sorbic	112.13	4.80
Fumaric	116.70	3.03
Benzoic	122.12	4.19
Malic	134.09	3.40
Caprylic (octanoic)	144.21	4.89
Citric	192.12	3.14

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Organic Acids and Salts

Combinations of organic acids (or with other antimicrobials) can sometimes be more effective than a single one

Commercial applications:

- Decontamination of fresh meat or carcasses
- Processed meats

Lactate (usage ≈ 2–3%), sometimes in combination with diacetate, has been used effectively in processed meats for many years

Recently benzoate and propionate have gained popularity due to their lower cost-in-use (usage ≈ 0.2–0.3%)

Most are approved as GRAS

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Organic Acids and Salts

Final word:

- Although generally not consumer-friendly due to their chemical name, they constitute the basic antimicrobial components of many natural or “clean label” antimicrobial ingredients

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Lysozyme

Muraminidase enzyme that breaks down peptidoglycan of bacterial cell walls

- Active against gram-positive bacteria (*Clostridium*, *Bacillus*, *Micrococcus*, specific strains of *Lactobacillus* spp. and *L. monocytogenes*)
- By itself, ineffective against gram-negative bacteria
- Activity can be enhanced by combining with other antimicrobials

Commercially obtained from egg white albumin and milk

Approvals

- FDA: affirmed GRAS; approved for direct addition to foods
- USDA: casings; cooked RTE meat and poultry products

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Lactoferrin

Iron-binding transferrin protein

Commercially obtained from whey protein

Levels increased in:

- Unmilked animals
- Udder infection

Effective against bacteria, fungi and viruses

Competes with bacteria for available iron

Approved in U.S. for decontamination of beef carcasses and parts

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Lactoperoxidase system

System components:

- Lactoperoxidase: enzyme found in mammalian secretions (raw milk, saliva, colostrum, etc.)
- Thiocyanate: found in secretions; derived from the diet
- Hydrogen peroxide: produced by bacteria

LP catalyzes reaction of thiocyanate ion with H_2O_2 to produce antimicrobial compound *hypothiocyanate*, which disrupts bacterial inner membrane

$$SCN^- + H_2O_2 \longrightarrow \mathbf{OSCN^-} + H_2O$$

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Lactoperoxidase system

Bactericidal to many gram-negatives (e.g., *E. coli* and *Salmonella)*; bacteriostatic vs. gram-positives; antifungal activity

Promoted for preservation of raw milk

Also tested in vegetable juices, liquid whole egg and beef

Not very effective *in vivo*; must add thiocyanate and H_2O_2 to increase effectiveness

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Chitosan

Derived from shellfish chitin via deacetylation

Effective against bacteria, yeasts and molds, although MIC varies widely (0.01%–5.0%)

Mode of action not totally understood

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Spice Extracts and Essential Oils

Efficacy demonstrated in extracts and essential oils obtained from various plants

- Most active: cinnamon (cinnamaldehyde, eugenol), oregano (carvacrol), cloves (eugenol), thyme (thymol, carvacrol)
- Also active: rosemary, sage, basil, coriander, nutmeg, lemongrass, marjoram, cumin, others

General susceptibility

- Fungi > gram-positives > gram-negatives

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Spice Extracts and Essential Oils

Efficacy can be affected by high protein and fat

Efficacy favored by low a_w, high NaCl, organic acids

Chemical types:

- Phenols: eugenol, isoeugenol, carnosol, rosmanol, isorosmanol, rosmarinic acid, borneol
- Aldehydes: cinnamaldehyde
- Terpenes: thymol, carvacrol
- Thiosulfinates: allicin

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Berries

Rich in antimicrobial polyphenolics and organic acids

Cranberry, raspberry, strawberry, bilberry, cloudberry

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Olives

Olea europae

Rich in biophenols, such as oleuropein and others

Oleuropen active against gram+ and gram– bacteria, several fungi and enveloped viruses

Mode of action not yet fully understood

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Hops

Used to impart bitterness in brewing

Two types of bitter compounds:α-acids and β-acids

β-acids have antimicrobial activity against *L. monocytogenes*, *Streptococcus* spp., and *E. coli*

Work by disrupting cell membrane

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Mustard

Active component: isothiocyanates (R–N=C=S)

- R side group = allyl, ethyl, methyl, benzyl, phenyl
- Inhibit gram-positives, gram-negatives and fungi
- Low flavor threshold, but effective at very low concentrations (ng/L)
- Mechanism of action believed to be related to inhibition of sulfhydryl-containing enzymes

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Alliums

Garlic (*Allium sativum*) and onions (*Allium cepa*)

Active component: allicin (garlic); thiopropanal-S-oxide (onion)

Inhibit growth and toxin production by numerous microorganisms (*C. botulinum* type A, *B. cereus*, *E. coli*, *L. plantarum*, *Salmonella*, *Shigella* spp., *S. aureus*, *A. flavus*; *C. albicans*, *Saccharomyces*, *Torulopsis*)

Mechanism of action (allicin) believed to be related to inhibition of thiol-containing enzymes

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Lemon Juice

Active components: citric acid, ascorbic acid

Not considered a preservative

Available as lemon juice solids and lemon powder

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Cherry Powder

Obtained from Acerola cherries

Active components: malic acid, ascorbic acid

Not considered a preservative

Primary use in meat products is as replacement for erythorbate or ascorbate

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Vinegar

Active component: acetic acid

Very significant antimicrobial activity, but not considered a preservative

Available in liquid and powdered form

Buffered vinegar typically used to mitigate effects on product pH

Popular in meat products as replacement for sodium diacetate

Quintessential pantry ingredient → very “label-friendly”

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Bacteriocins

Heat-stable antimicrobial peptides produced by bacteria (lactic acid bacteria and others)

Advantages

- Can be used when fermentation conditions are not desired
- Permit more exact dosification

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Bacteriocins, cont.

Nisin

- Class I bacteriocin (lantabiotic) produced by *Lactococcus lactis* subsp. *lactis*
- Inhibits growth of wide number of gram-positives as well as germination of spores of *Clostridium* and *Bacillus*
- Inhibits cell wall biosynthesis and forms pores in cytoplasmic membrane, leading to disruption of proton motive force
- First bacteriocin approved for food use
- GRAS status in U.S.; approved in pasteurized process cheese, cooked RTE meat & poultry products & soups, egg products

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Bacteriocins, cont.

Natamycin

- Antimycotic produced by *Streptomyces natalensis*
- Affects cell membrane permeability, resulting in leakage of ions and peptides and, ultimately, cell lysis
- Approved in U.S. as mold inhibitor in cheese

Other bacteriocins

- e.g., pediocin, lacticin, lactocin, lactococcin, leuconocin, sakacin
- LAB bacteriocins are of special interest due to potential GRAS status

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Fermentates

Products of fermentation of ingredients such as sugar, dextrose, milk, whey, by lactic acid bacteria

Active components: organic acids (e.g., lactic, propionic, acetic) and/or bacteriocins

Activity dependent on fermenting culture used

Many commercial preparations for meat & poultry products consists of blends with vinegar

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Protective (antagonistic) cultures

LAB (primarily *Lactobacillus* spp.) or other bacteria (primarily *Bifidobacterium* spp.)

Work by:

- Production of antibacterial components such as bacteriocins, enzymes, organic acids, diacetyl, ethanol, free fatty acids, H_2O_2
- Outcompeting other microorganisms

As opposed to fermentates, production of active component(s) takes place in the food

Generally GRAS

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Current Challenges of “Clean Label” Antimicrobials

- **Cost-in-use**
  - Generally higher than synthetic
  - Must weigh CIU vs. need/desirability of ingredient
- **Toxicological/allergenic aspects**
  - Natural ≠ Safe
  - How safe are they at levels required for antimicrobial activity?
- **Activity validation and predictive modeling**
  - Valid results require consistent concentration of antimicrobial component(s)
  - Natural variations may make this difficult or impossible

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Current Challenges of “Clean Label” Antimicrobials

- **Sensory effects**
  - Two main issues:
    - Lack of refinement may leave sensory-objectionable components
    - May require high usage level for antimicrobial effectiveness

    → May lead to negative sensory attributes (flavor, color, odor, texture) at concentrations required for desired antimicrobial activity
- **Interaction with other food components**
  - Sometimes activity level observed *in vitro* is not observed in food product

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Is it approved?

simple truth Kroger

Simply balanced TARGET

Panera BREAD

Wholesome Pantry Organic SO SIMPLE. ShopRite

wild HARVEST SUPERVALU

WILD OATS MARKETPLACE

FDA

USDA

H-E-B

Select Ingredients

Nature's Promise Ahold Delhaize

NOODLES & COMPANY World Kitchen

OPEN NATURE 100% natural SAFEWAY

WHOLE FOODS MARKET

true goodness by meijer meijer

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References

- Davidson PM, Sofos JN, Branen AL. 2005. Antimicrobials in food. 3rd ed. Boca Raton (FL): CRC Press.
- Huis in’t Veld JHJ. 1996. Microbial and biochemical spoilage of foods: an overview. Int J Food Microbiol. 33:1–18.
- Slonczewski JL, Fujisawa M, Dopson M, Krulwich TA. 2009. Cytoplasmic pH measurement and homeostasis in bacteria and archaea. Adv Microb Physiol. 55:1–79.
- [IFT] Institute of Food Technologists. 2001. Evaluation and definition of potentially hazardous foods. A Report of the Institute of Food Technologists for the Food and Drug Administration of the United States Department of Health and Human Services. IFT/FDA Contract No. 223-98-2333; Task Order No. 4. Chicago (IL): Institute of Food Technologists.
- Taylor TM. 2015. Handbook of Natural Antimicrobials for Food Safety and Quality. Cambridge (UK): Woodhead Publishing.

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