# Beyond nutrients: sensory perception, dairy foods, and their role in enhancing sustainable diets


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*Institut Lyfe Research & Innovation Centre, Lyon, FR*

# Outline of the presentation

- *How sensory perception shapes food choices and eating behaviour*
- *The unique sensory properties of dairy*
- *Dairy's role in supporting nutrient adequacy in sustainable diets*
- *Health benefits of dairy within balanced, sustainable dietary patterns*

# Pick your healthy dish!

# Pick your healthy dish!

**Sweet Creamy Delight**

**Garden Vitality Bowl**

# Do the sensory properties of food influence food intake?

**“ *Food has no nutritional value until it is chosen, accepted, and consumed* ”**

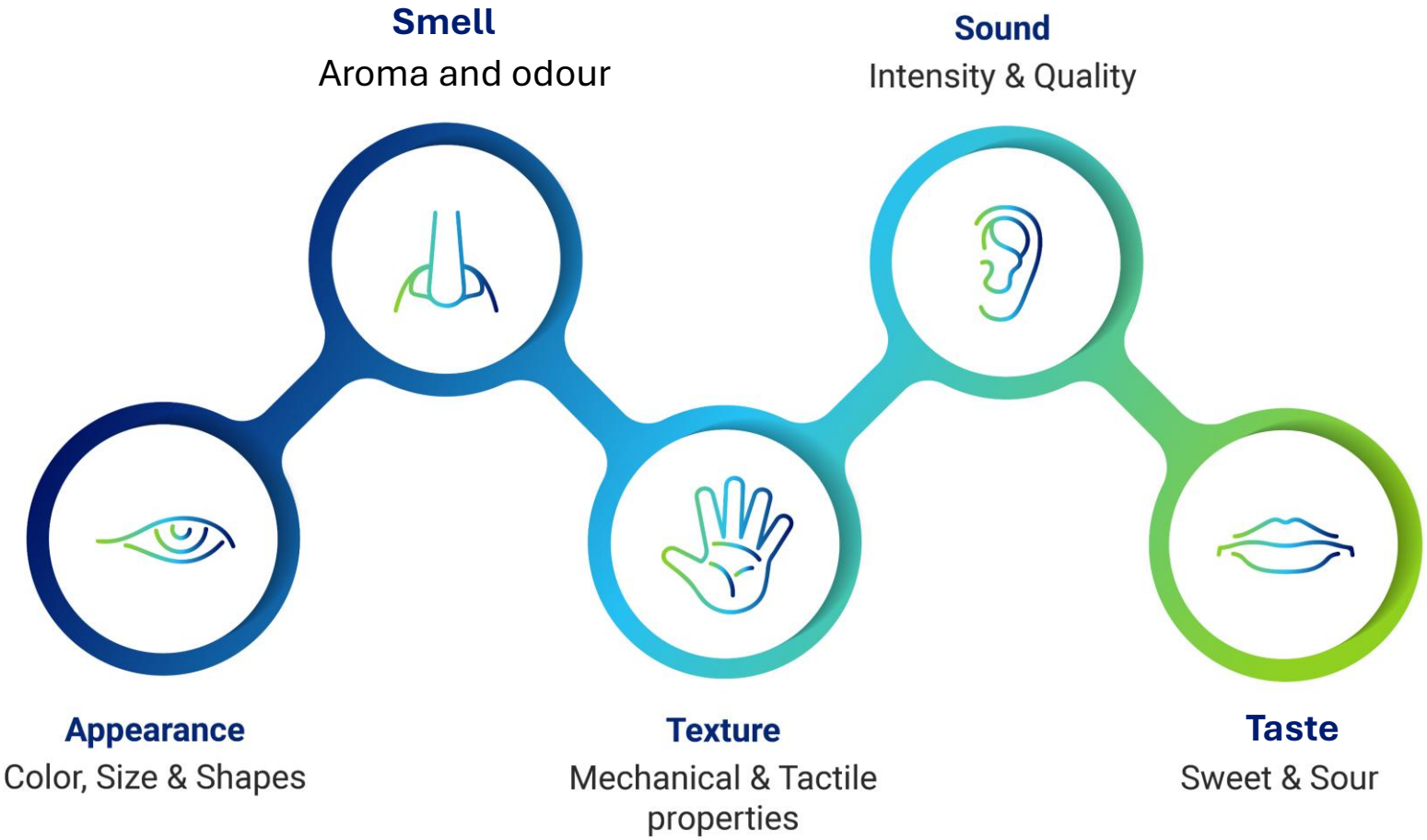
*(Forde & Delahunty 2004)*

- Increasing interaction between **sensory science** and **nutrition**

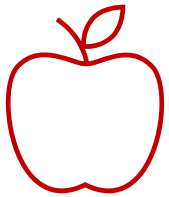
“***There is no health without pleasure***” (de Graaf 2023)

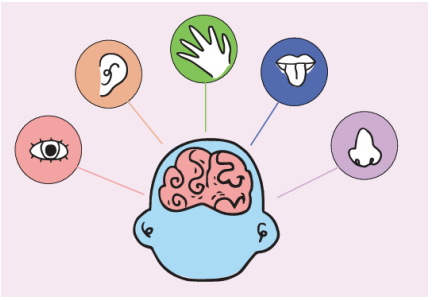
- **Palatability** (positive hedonic evaluation of food) influences **appetite** and **food intake** in humans *(Sorensen et al. 2003)*

# Food sensory properties



# How do we perceive things?



**Stimuli**

Sensory **properties** of food (e.g. colour, sound, tastants, odour molecules, texture/form)

**Sensation**

**Detection** of sensory **stimuli** using our **senses** (sight, hearing, taste, smell, touch) via different sensory receptors and **converting** them into **sensory signals**

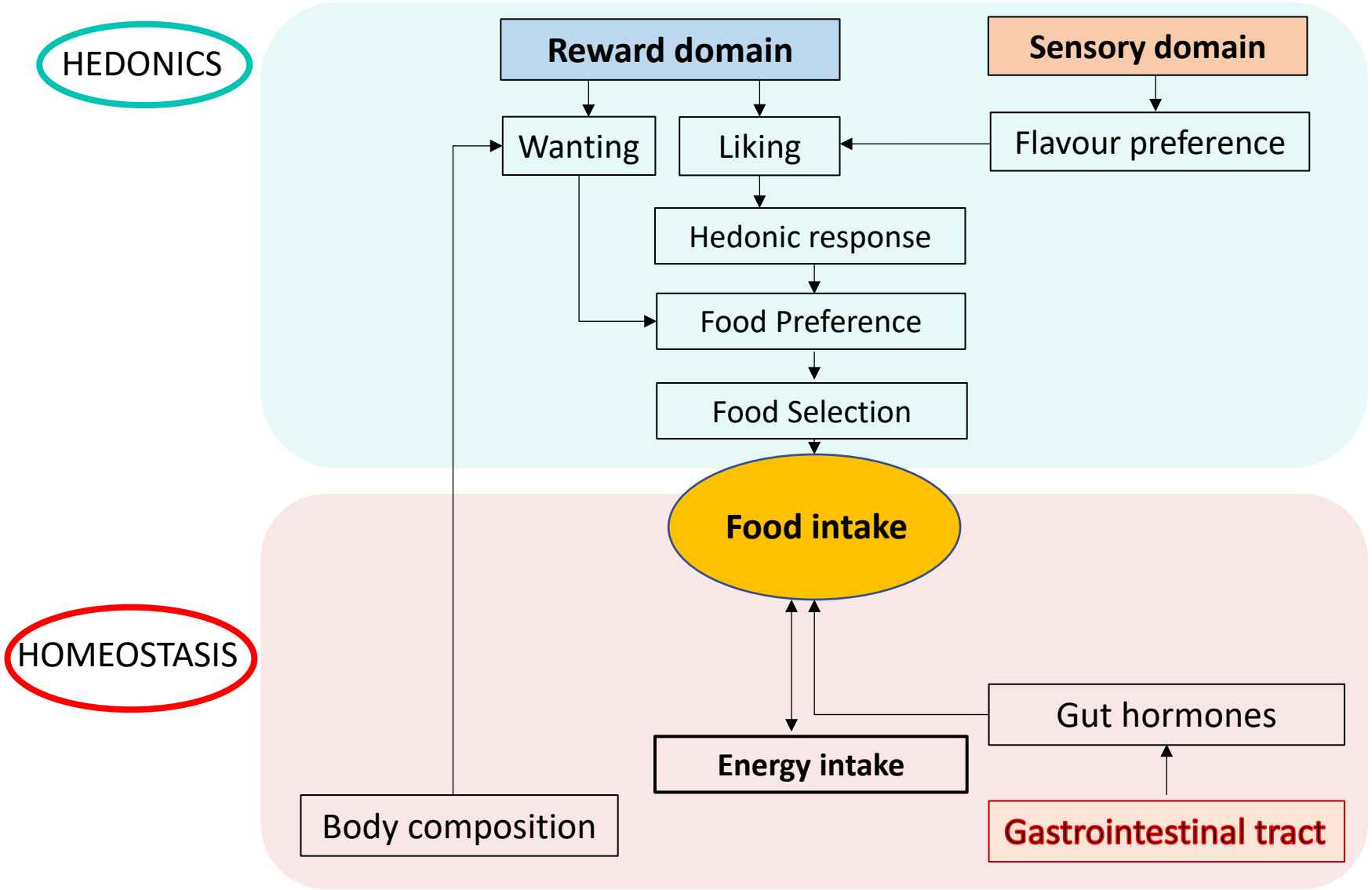
**Perception**

**Interpretation** of the **sensory signals** to create **meaningful experience**

**Flavour**: Taste, Odour and Somatosensory

**Food perception is a result of all senses**

# Homeostatic and hedonic food intake regulation



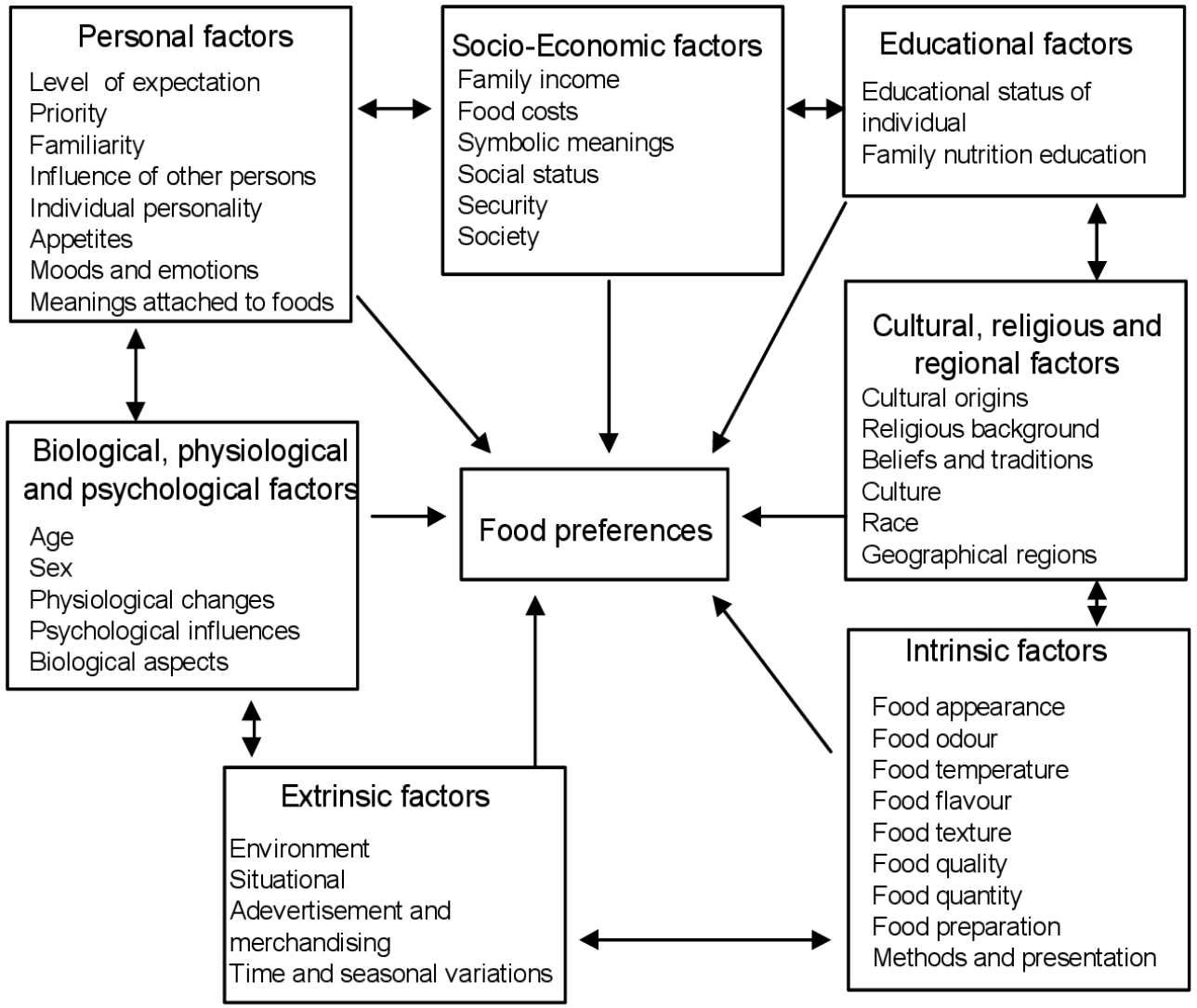

*(Guyot 2021; Drewnoski An Rev Nutr 1997; Blundell Dis. Mod. Mech. 2012, Finlayson et al. Cur. Obes. Rep 2012)*

# Factors influencing food preferences

**PHYSIOLOGICAL INFLUENCES**

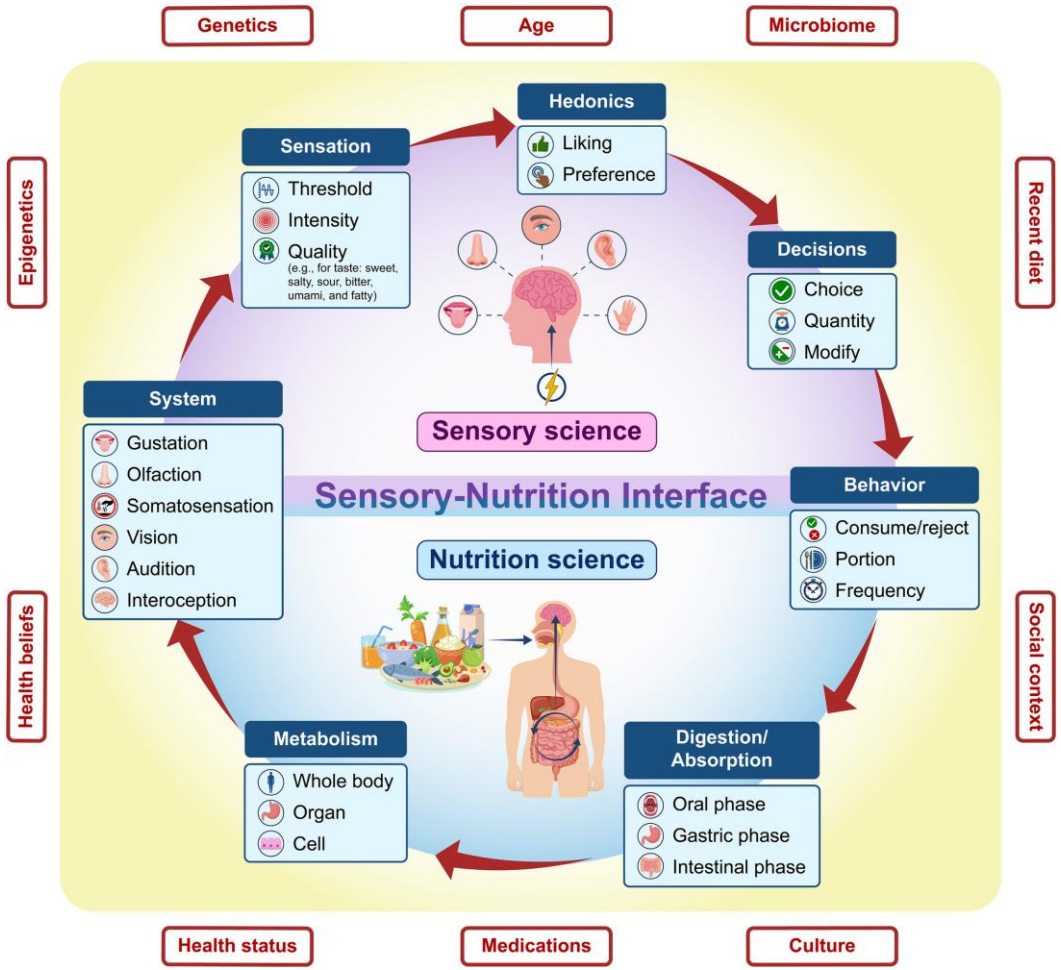
**PSYCHOLOGICAL INFLUENCES**

**ENVIRONMENTAL INFLUENCES**




*S. Sijtsema 2003*

# Opportunitites for sensory science to improve dietary behaviour




- **Undernutrition:** modifying food palatability. ↑palatability ↑intake (patients, elderly)
- **Overnutrition:** manipulation of food texture to influence satiation and satiety
- "**Sensory-nutrition** considers the interaction of '**food and eater**' and keeps eating pleasure at the heart of approaches to improve health" (*de Graaf 2023)*

*Mattes 2024 Obesity*

# SENSORY & CULINARY COMPLEMENTARITY

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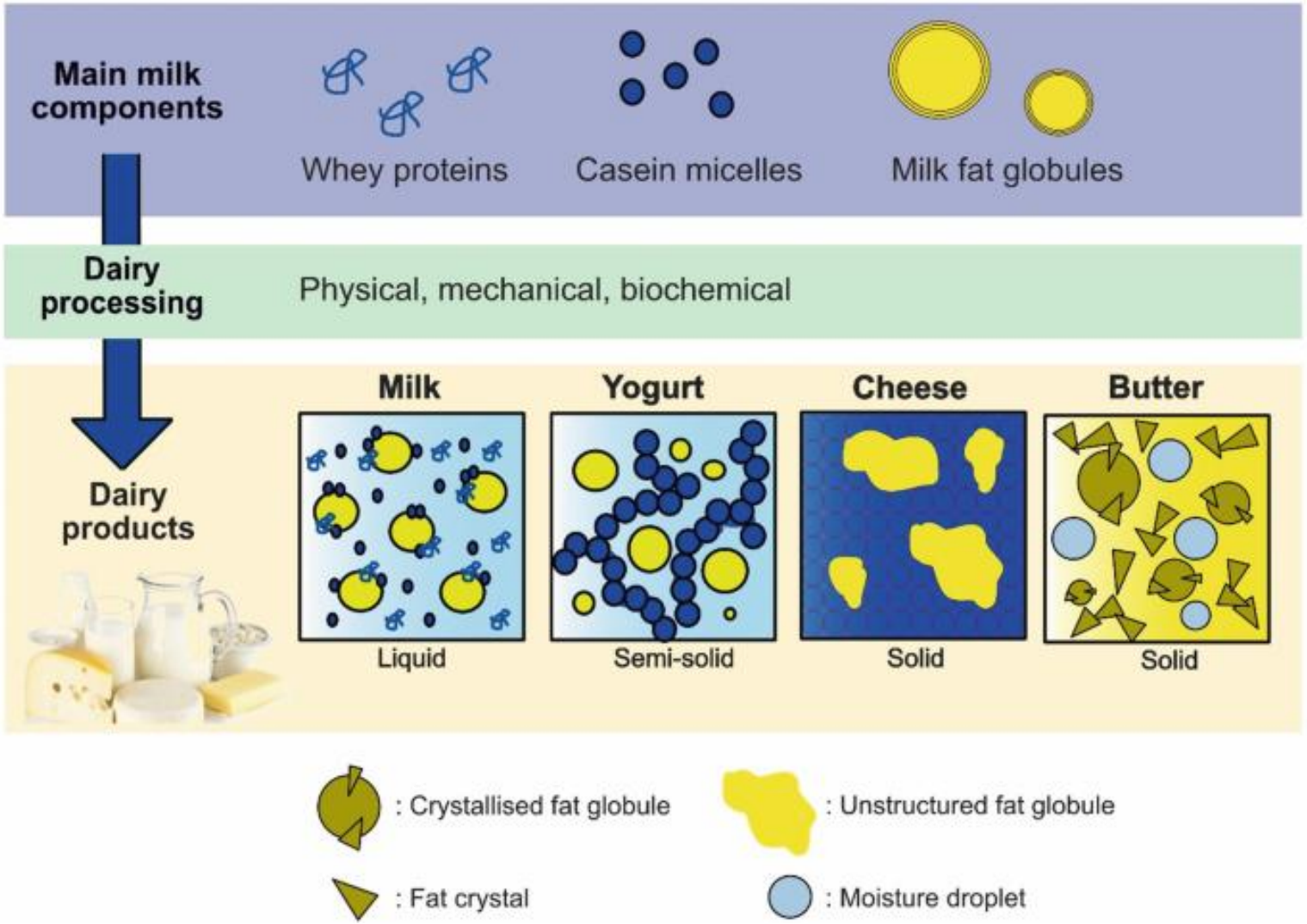
# Definition of the dairy matrix

‘The **food matrix** is not only the composition of nutrients, bioactive constituents, and other compounds present, but also how they are packaged and compartmentalised.’

*Weaver & Givens 2025 Cr Rev Food Sc & Nutr*

**Dairy matrix**: ‘describing the unique structure of a dairy food, its components (e.g., nutrients and non-nutrients), and how they interact.”

*Mulet-Cabero et al. 2025 Nutrients*

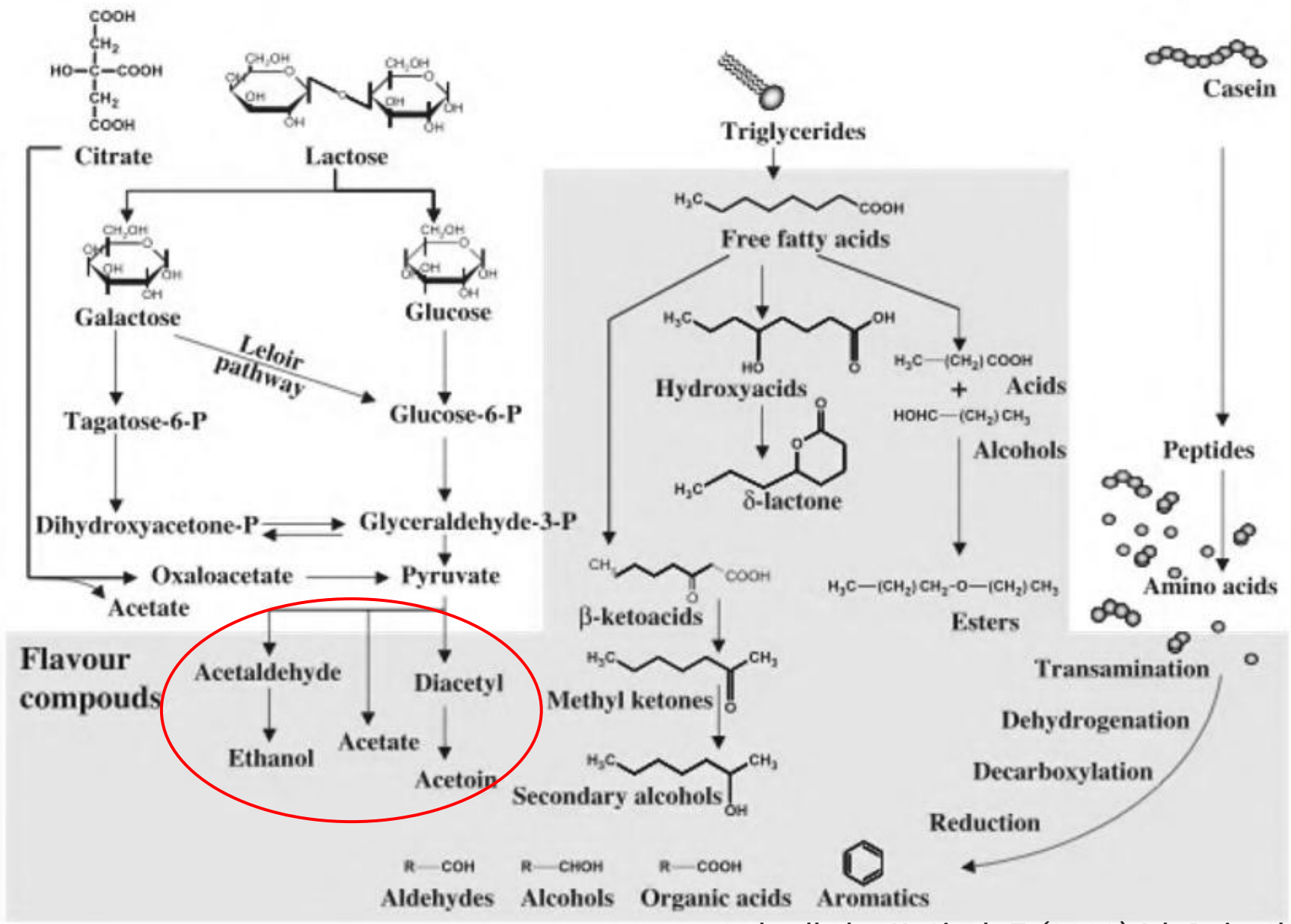



*Mulet-Cabero 2021, Bio Dig Lip from foods*
*Unger et al. 2023 Curr Dev in Nutr*

# Flavour compounds in dairy products

## Carbohydrates

- Diacetyl: Buttery flavour
- Acetaldehyde & Acetoin: Yoghurt flavour, freshness
- Acetate: stone fruity - too much, it turns pungent (nail polish)



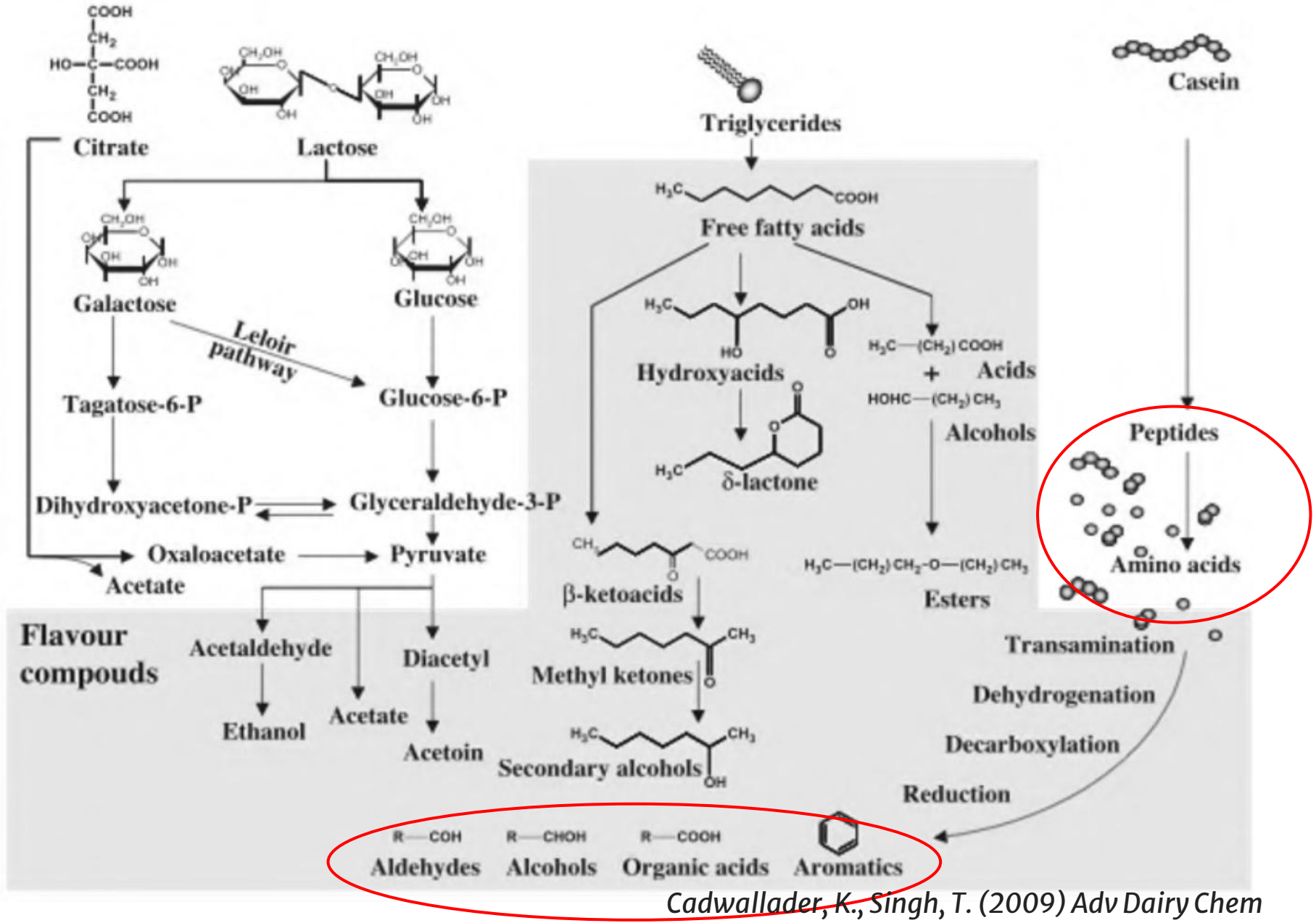

*Courtesy of Kostgroup.co*

*Cadwallader, K., Singh, T. (2009) Adv Dairy Chem*

# Falvour compounds in dairy products

**Proteins**

- Peptides and free amino acids: Glutamate, umami and γ-glutamyl; Kokumi
- Acids: Propionic acid is associated with nuts (e.g., Emmentaler)
- Aromatics: Phenols associated with dried species



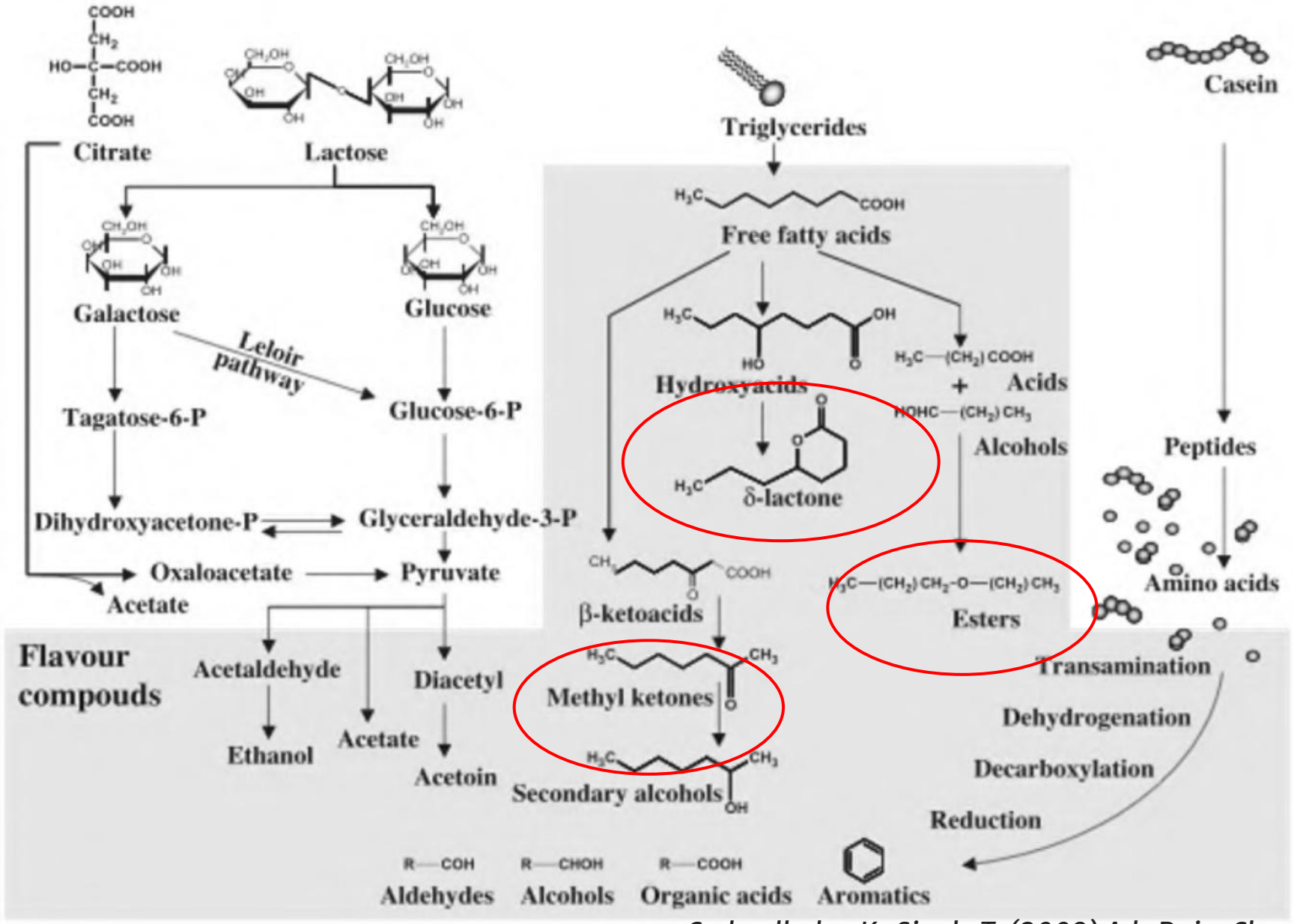

*Courtesy of Kostgroup.co*

*Cadwallader, K., Singh, T. (2009) Adv Dairy Chem*

# Falvour compounds in dairy products

## Lipids

- Short- and medium-chain Free fatty acids: Pungent, rancid, and cheesy, goaty, soapy aromas
- Methyl ketones: fruity and blue cheese notes
- Esters: Fruity & Floral Aromas
- Lactones: Creamy, Nuts & Coconut flavour




*Courtesy of Kostgroup.co*

*Cadwallader, K., Singh, T. (2009) Adv Dairy Chem*

# Flavour Wheel and Sensory profile of dairy

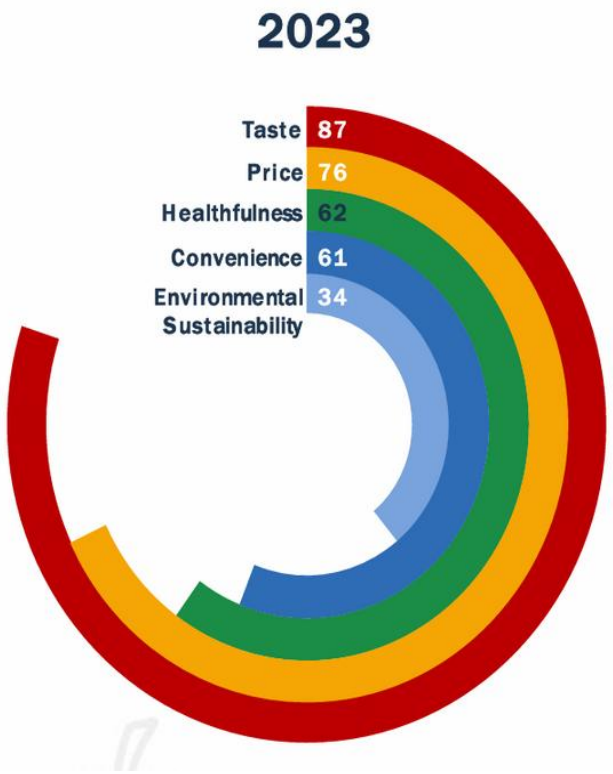


*Source: LinkedIn Prateek Mittal*

Credit: Cheese Science Toolkit https://cdr.wisc.edu/sensory-resources

*Drake 2007 J Dairy Sci.*

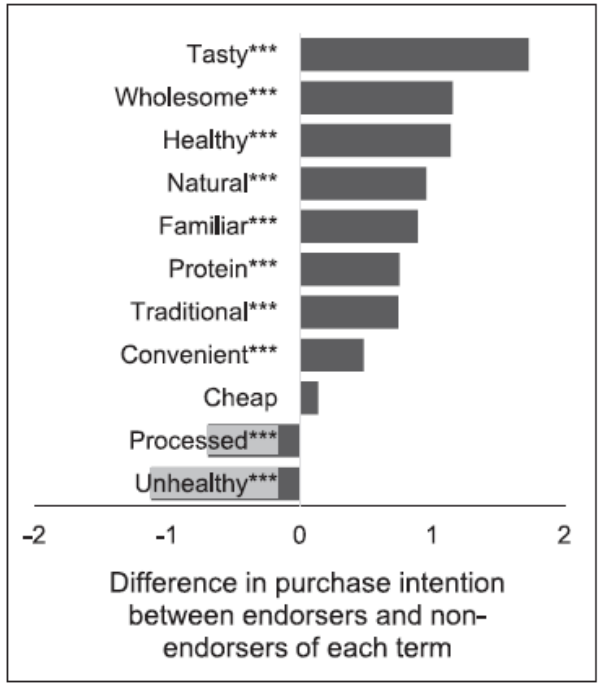
# Consumers' perceptions of plant-based alternatives relative to their animal-derived foods



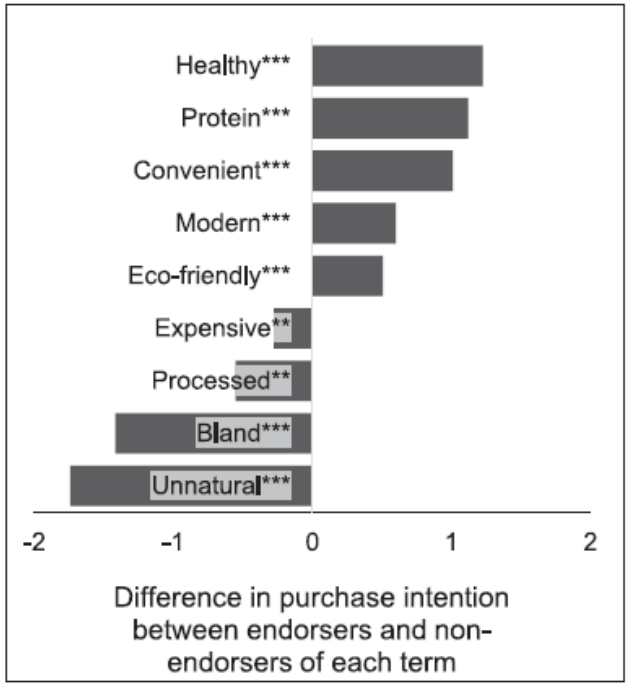

2023 Food and Health Survey
International Food Information Council

*Cardello et al. 2022 Food Qual & Pref*

Animal-derived



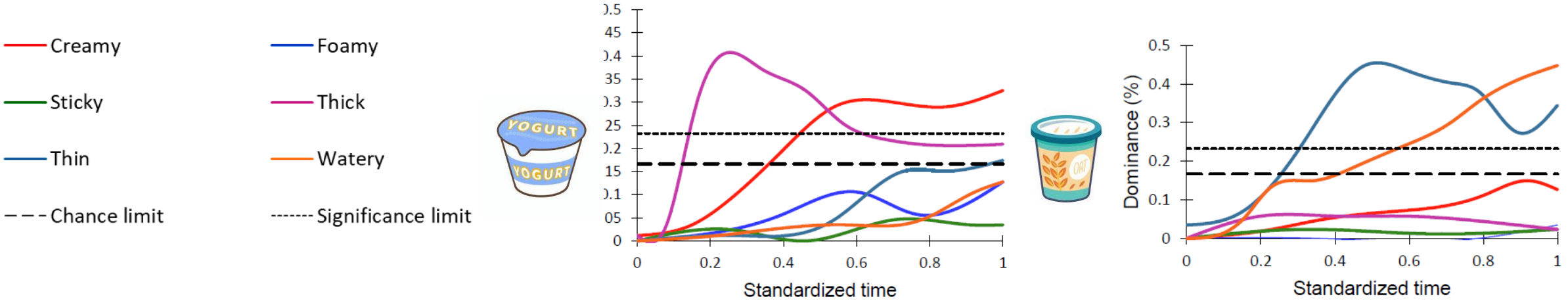

Plant-based




Penalty lift analysis: **unnatural** and **bland** were the greatest opposing drivers of purchase intention for PBA

*Kershaw et al. (2025) Food Qual & Pref*

# Overall liking and dynamic texture perception in plant-based yoghurt alternatives



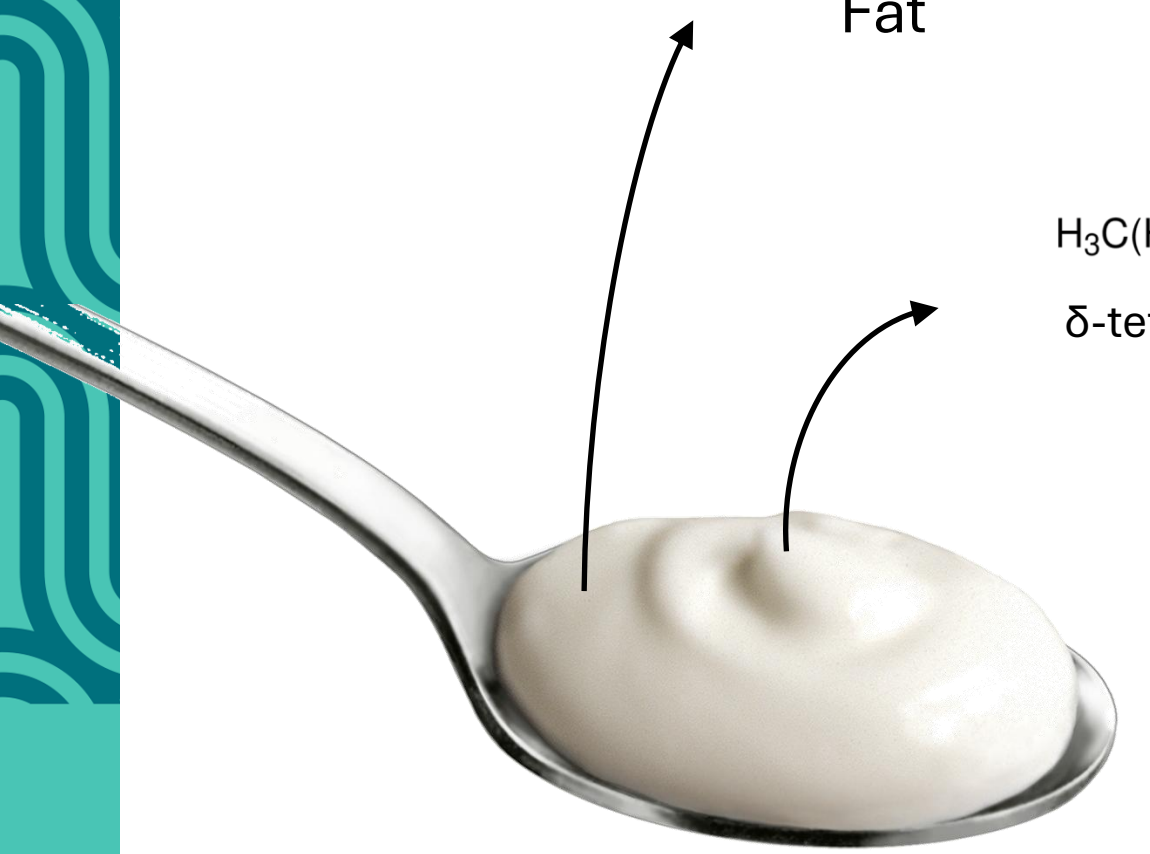

Dominance rates of each 6 attribute for each product

| Products | Overall liking | | | Mouthfeel liking | | |
|---|---|---|---|---|---|---|
| D1 | 5.2 | ± 1.4 | a | 5.6 | ± 1.2 | ab |
| D2 | 5.7 | ± 1.4 | a | 6 | ± 1.2 | a |
| P1 | 2.4 | ± 1.3 | c | 3 | ± 1.6 | d |
| P2 | 3.8 | ± 1.8 | b | 4.6 | ± 1.8 | c |
| P3 | 3.7 | ± 1.8 | b | 4.9 | ± 1.7 | bc |
| P4 | 3.3 | ± 1.6 | b | 4.3 | ± 1.5 | c |
| P5 | 3.3 | ± 1.7 | b | 4.4 | ± 1.5 | c |

*Greis et al. 2020 Food Qual & Pref*

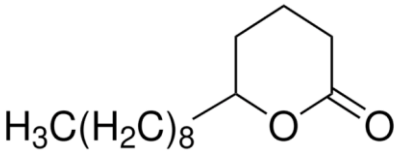
# Sensory functions of dairy

## Creaminess and Flavor Depth



Proteins
Fat

→ ↑ Creamy mouthfeel
(+ fat: melting and viscosity modulation)




δ-tetradecalactone

→ ↑ Retronasal creaminess perception

Dairy enhances **creaminess, flavor depth, and aroma release**

→ **Smoothing fibrous plant textures ?**

*Schlutt et al., 2007*

# Sensory functions of dairy

## Dairy Carrier for Fat-Soluble Flavors

Hydrophobic aroma compounds ← Matrice (protein + fat)

↑ Aroma perception ← Texture and viscosity

Dairy fat acts as a **carrier for fat-soluble flavours**, potentially improving plant flavour perception

*Lethuaut et al., 2005; Heilig et al. 2011*

# Plant-Dairy pairings in Europe

+

Viscosity, firmness

Antioxidant activity

Sensory acceptability (+50%)

↑ Consumer acceptance

Traditional pairings (yogurt+fruit, cheese+vegetables, milk+cereal) reflect a culinary logic of **sensory complementarity**

*Özcan et al., 2016; Garofalo et al., 2024; El-Sayed et al., 2025*

# Barrier reduction in plant-rich diets

Bland, astringent, or dry

↑ Mouthfeel, silkiness, and viscosity

**Dairy could reduce sensory barriers**, making plant-rich diets more palatable

**→ Integration of dairy + plants = enhanced sensory, nutritional, and culinary outcomes**

*Özcan et al., 2016; Garofalo et al., 2024; Song et al. 2024; El-Sayed et al., 2025*

# Visible cheese and consumption of encouraged food groups in middle schoolers

Table 1. *Food group servings consumed: Between group comparisons*

| | Study 1 | | Study 2 | |
|---|---|---|---|---|
| | VC | NC | VC | NC |
| Fruits | 0.14 ± 0.39 | 0.20 ± 0.54 | 0.42 ± 0.58 | 0.14 ± 0.29* |
| Vegetables | 0.33 ± 0.53 | 0.25 ± 0.51 | 0.33 ± 0.57 | 0.23 ± 0.51 |
| Whole grains | 0.72 ± 0.92 | 0.56 ± 0.95 | 2.84 ± 2.99 | 1.31 ± 1.95* |
| FGTE | 1.19 ± 1.28 | 1.0 ± 1.36 | 3.59 ± 3.28 | 1.68 ± 2.13* |

*Note.* Values are mean ± standard deviations. VC = visible cheese. NC = no cheese. FGTE = food groups to encourage.

*Significant between group difference ($p<0.05$).

*Donelly et al. 2010 J of Ch. Nutr Manag*

# NUTRIENT ADEQUACY WITHIN A SUSTAINABLE DIET

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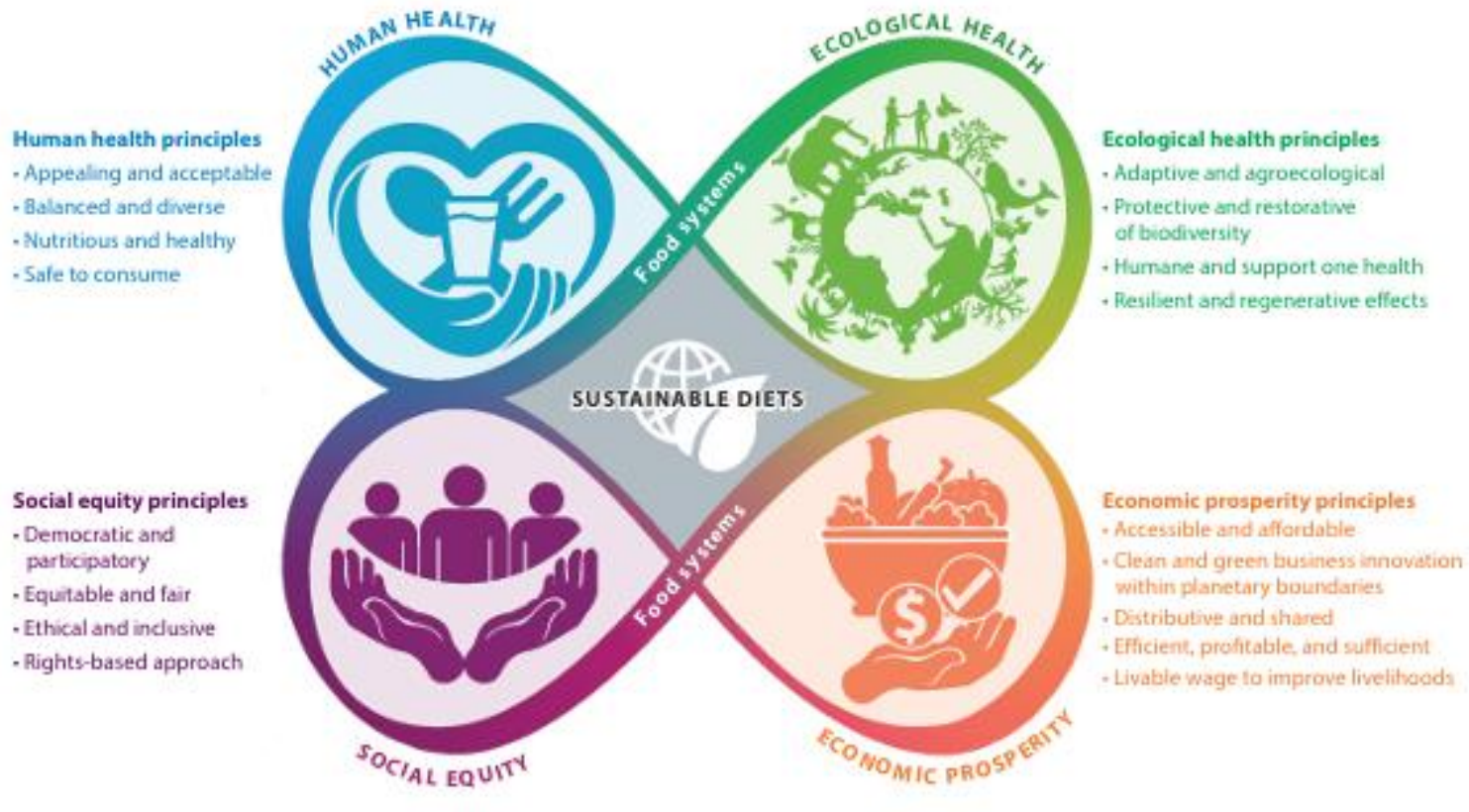
# Sustainable diets




*'Diets do not have to exclude entire food categories to be sustainable – studies have identified diets that are nutritionally adequate or 'healthy', while respecting food diversity, tolerating some meat and dairy foods, and having lower environmental impact'*

FAO and WHO. 2019. Sustainable healthy diets – Guiding principles

# Nutrient adequacy based on the EAT-Lancet

Estimated micronutrient shortfalls of the EAT–*Lancet* planetary health diet

*Ty Beal, Flaminia Ortenzi, Jessica Fanzo*

Editorial

Environmentally protective diets may come with trade-offs for micronutrient adequacy

Ty Beal

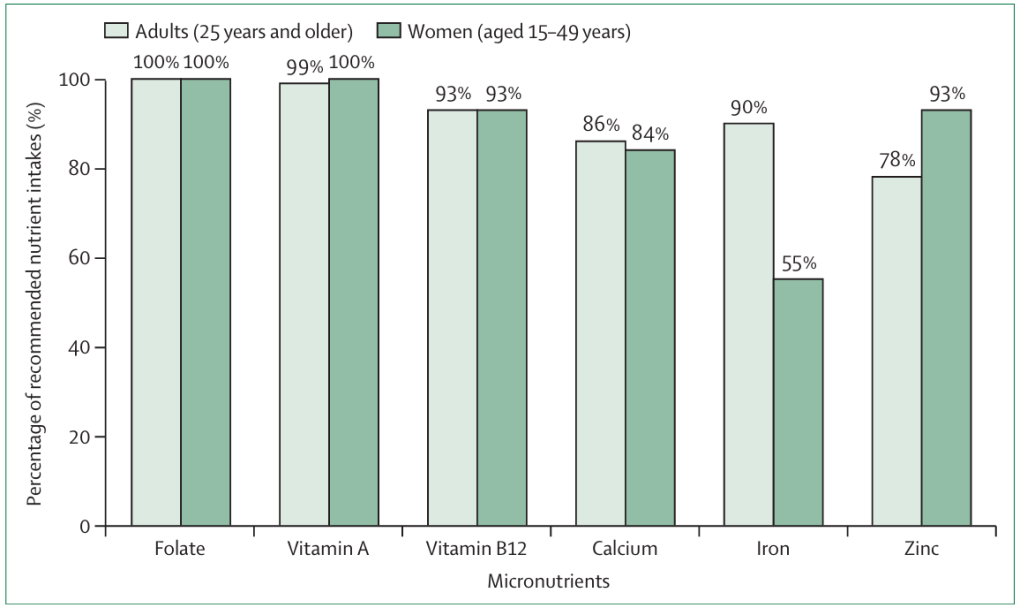


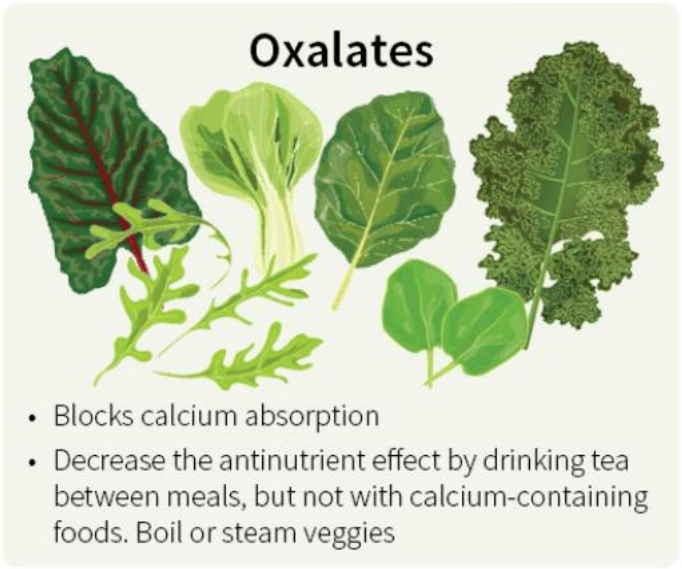

***Figure:*** **Percentage of recommended nutrient intakes for six micronutrients in the EAT–*Lancet* healthy reference diet**

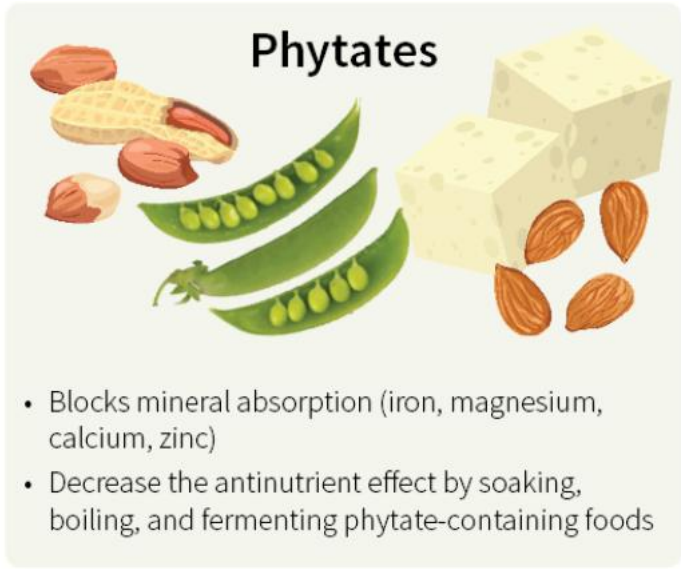
- ↑ **animal source foods** from **14%** to **27% of total kcal**
- ↓ **dietary phytate** from 1985 mg to **1021 mg** to ↑ Fe and Zn absorption
- Large-scale estimates show widespread global micronutrient inadequacies (e.g., **calcium, iron, iodine, B12**)

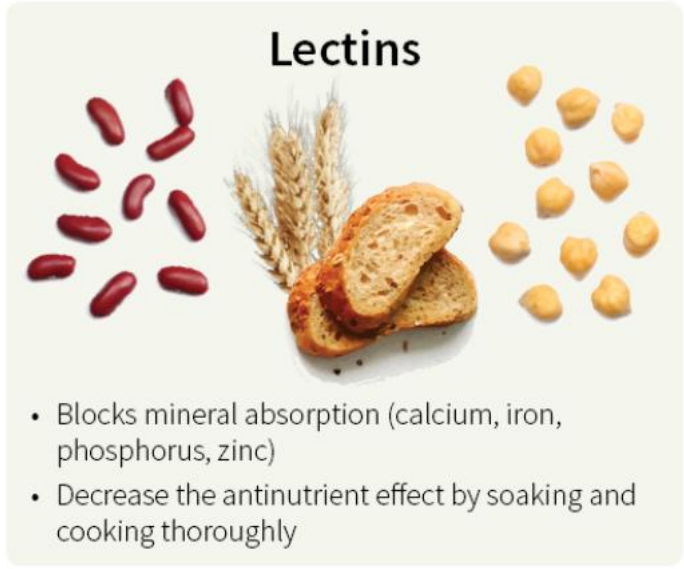
- One-size-fits-all framing critique
- Need to consider **local food systems, fortification and cultural acceptability**

*Passarelli S. et al 2024, Lancet Global Health*
*Stanton A. 2024. NPJ Science of Food*

# Dairy counteracts inhibitory factors in plant-rich diets




*Lopez_Moreno_et al. 2022 J Func Foods*

Dairy proteins
(Casein phosphopeptides (CPPs))

Fermented dairy
(Lactic acid, probiotics, phytase enzymes)

Improved mineral absorption (Ca, Zn, Fe, Mg) and vitamins (B2, B9,B12)

*Picciano et al 2004, Am J Clin Nutr*


*Talsma et al. 2017 J Nutr*

*Skhembi & Huppertz. 2021 Nutrients*

*Coudray et al. 2006 Br J Nutr; Hurrell RF 2003 Am J Clin Nutr*
*Bashir et al. 2025 Food Sci Anim Resour*

# Dairy supports fibre fermentation in plant-rich diets

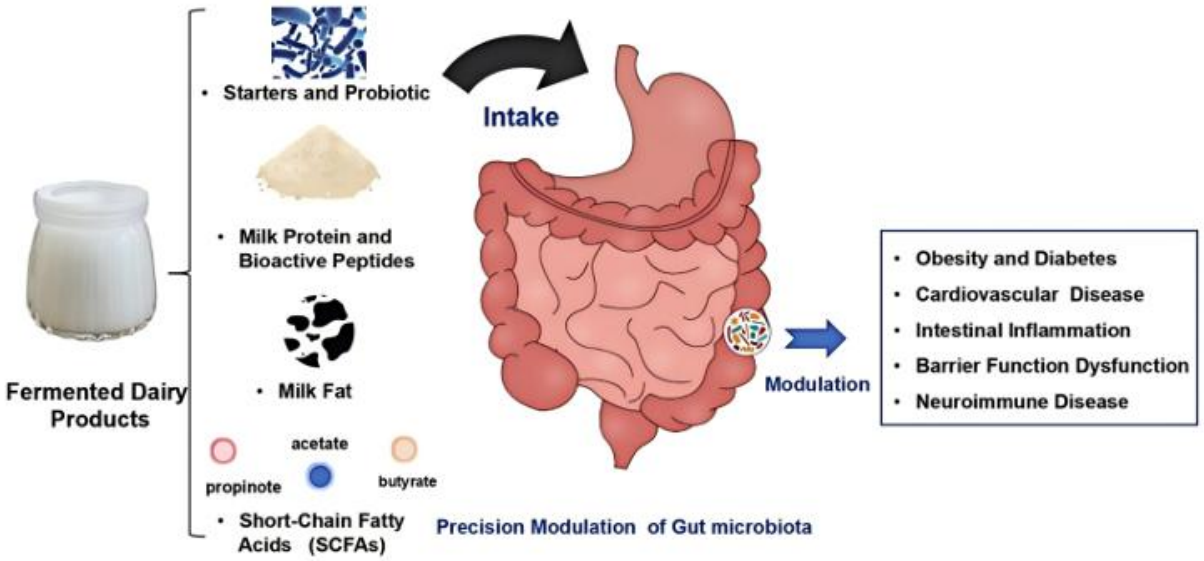



**Figure 1.** Overview of fermented dairy products as precision modulators of gut microbiota and host health.

- Probiotics in fermented dairy (Lactobacillus, Bifidobacterium) facilitate the fermentation of dietary fibers into SCFA

Nutrition & Diabetes www.nature.com/nutd

ARTICLE OPEN

Check for updates

The effect of a new developed synbiotic yogurt consumption on metabolic syndrome components in adults with metabolic syndrome: a randomized controlled clinical trial

Mohammad-Amin Zolghadrpour[1], Mohammad-Reza Jowshan[1], Mohammad Heidari Seyedmahalleh[2], Farzad Karimpour[3], Hossein Imani[1] and Somayyeh Asghari[1]✉

- Dairy–prebiotic synergy alters gut microbiota: human proof of concept

Better evidence is needed, especially linking modulated microbiota to actual improvements in fibre digestion and nutrient uptake in mixed diets

*Gao et al. 2025 Foods; Mukarromah et al. 2025 J Food Sci*

# HEALTH OUTCOMES – STATE OF KNOWLEDGE

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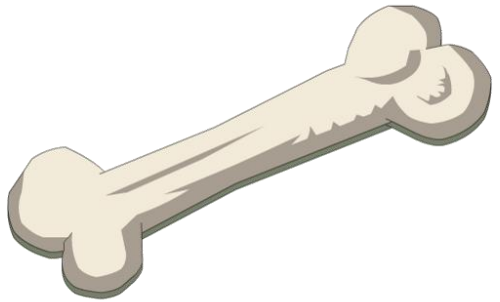
# Bone Health: Dairy & Plant nutrients

Risk nutrient inadequacy
+ inhibitory effect on
mineral absorption

Bioavalable calcium and
protein (matrix effect)

**Combination interest**



Dairy “secures” critical nutrients in plant-rich diets where calcium and high-quality protein may be limiting

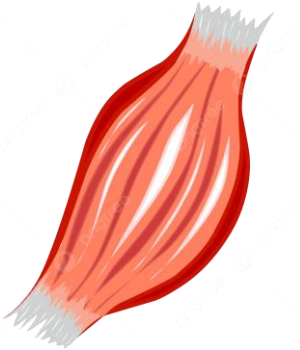
*Alcorta et al., 2021; Huppertz et al., 2022; Rizolli et al., 2021; Tremblay et al., 2025; Taormina et al., 2024*

# Protein Adequacy & Muscle Health

Lack of essential amino acids

Complete amino-acid profile + highly digestible → enhances protein utilization

**Combination interest**



Combining plant and dairy proteins can enhance amino acid adequacy and functional muscle support

# Satiety & Appetite regulation

Fibers: ↓ digestion
+ ↑ satiety

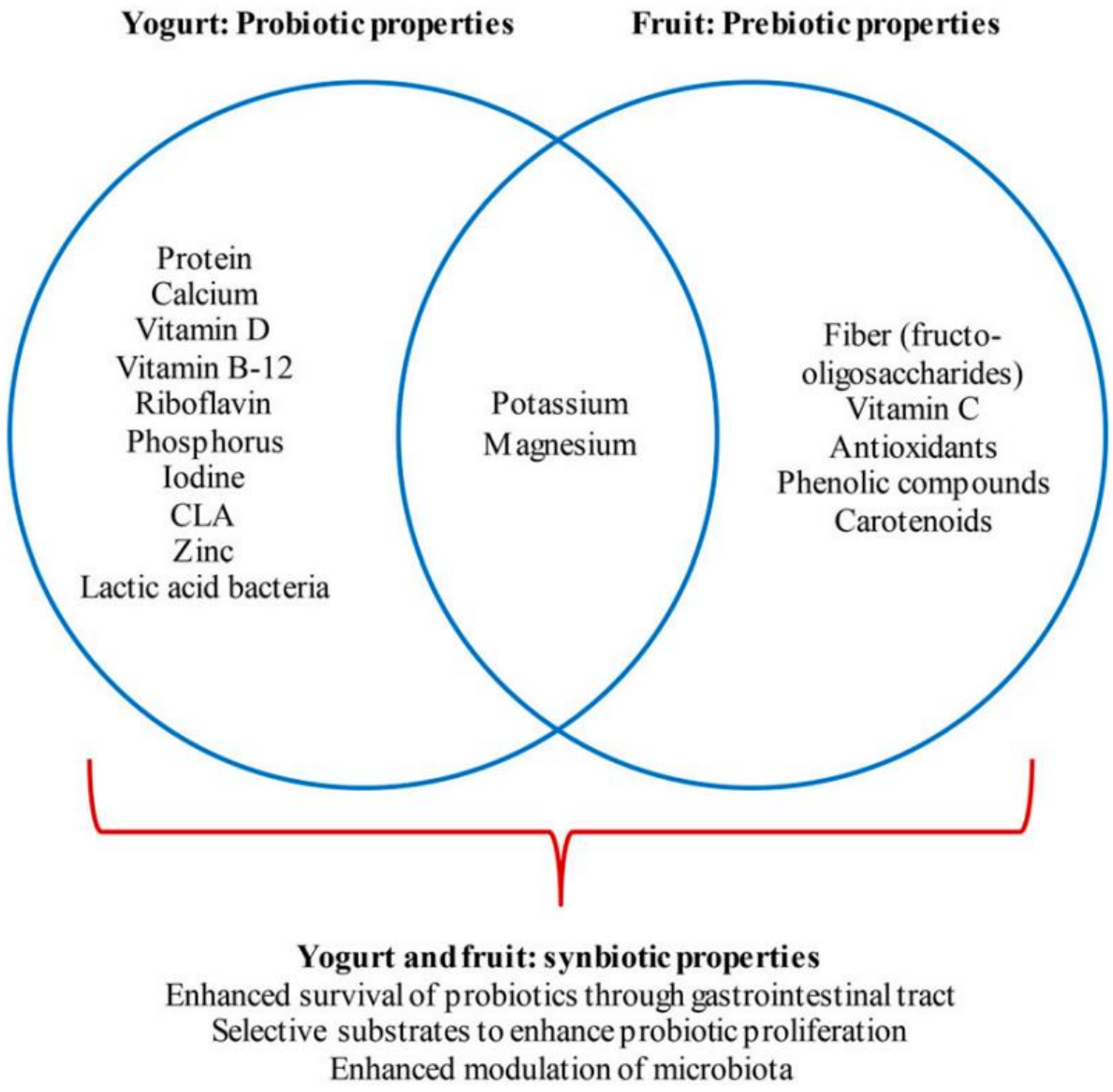
Trigger satiety hormones
+ preserve lean mass

**Combination interest:**
low-energy alternatives
to obesogenic snacks

Fiber + dairy protein synergy creates stronger and longer-lasting satiety signals

*Alcorta et al., 2021; Ignot-Gutiérrez et al., 2024; Huppertz et al., 2022; Fernandez & Marette, 2017; Elahikhah et al., 2024*

# Microbiota & Metabolism




**Combination interest:**

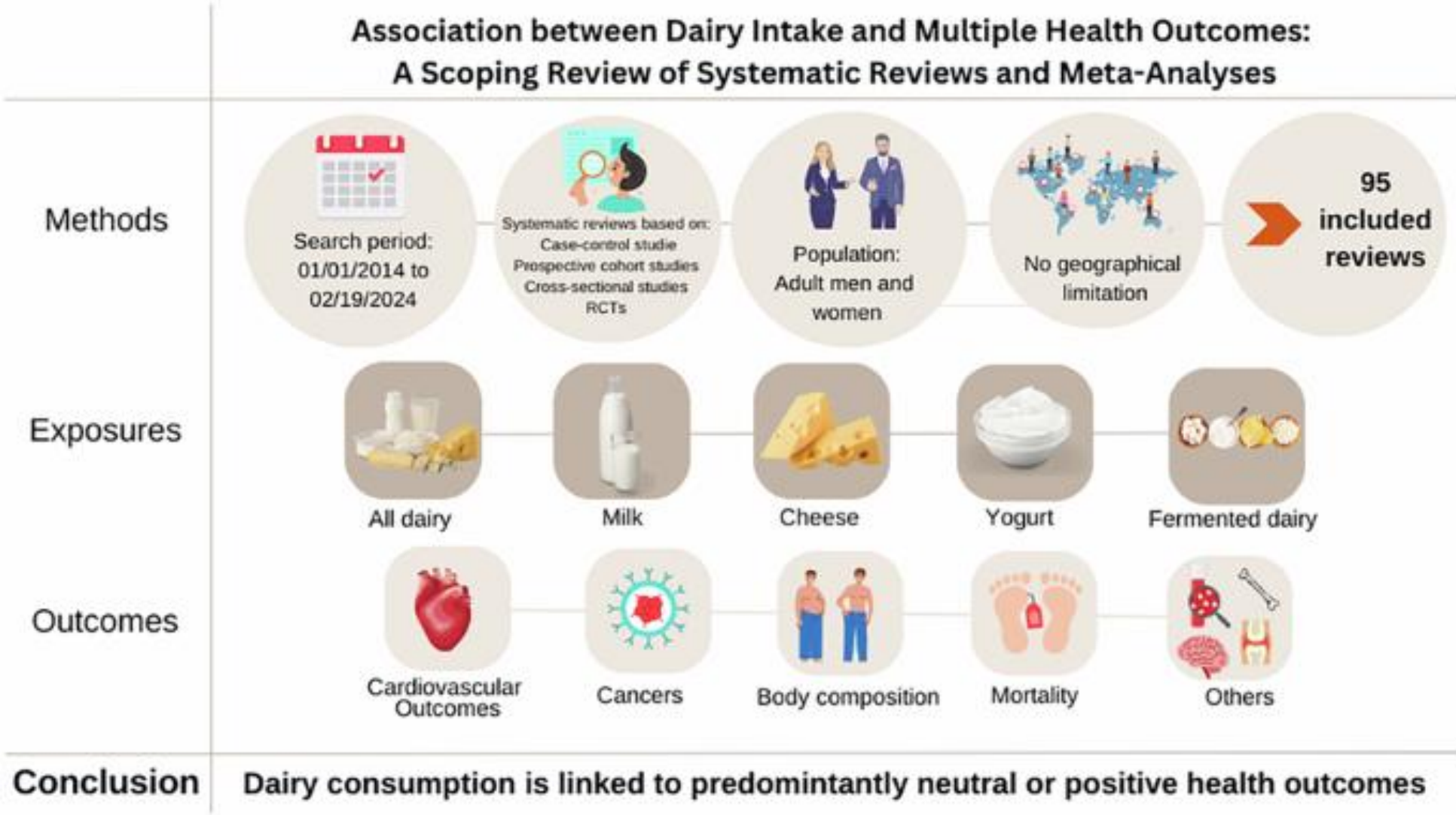
- dairy (probiotics, peptides, fermentation metabolites)
- fruits/vegetables (prebiotic fibers, antioxidants)

**→ Nutritional strategy to target the gut microbiome**

Dairy plus fruits synergistically enhance microbiota and metabolic regulation

*Tremblay et al., 2025; Fernandez & Marette, 2017*

# Overall evidence



# Health effects of sustainable dietary patterns

| Study | | Country | Sustainable diet type | Health indicator | Change in health indicator (95% CI)* |
|---|---|---|---|---|---|
| Sabate 2015 | 74 | US/Canada | Vegan | All-cause mortality rate | 19.2% |
| Soret 2014 | 50 | US/Canada | Vegetarian | All-cause mortality risk | 9% (0–17) |
| Tilman 2014 | 8 | Globally | Vegetarian | All-cause mortality risk | <1% (0–2)** |
| Sabate 2015 | 74 | US | Vegetarian | All-cause mortality rate | 15.9% |
| Aston 2012 | 21 | UK | Meat partially replaced by mixed food | CHD risk (men) | 9.7% (-3.5–22) |
| Aston 2012 | 21 | UK | Meat partially replaced by mixed food | CHD risk (women) | 6.4% (-1.8–14.3) |
| Aston 2012 | 21 | UK | Meat partially replaced by mixed food | Diabetes mellitus risk (men) | 12% (-4.5–22.7) |
| Aston 2012 | 21 | UK | Meat partially replaced by mixed food | Diabetes mellitus risk (women) | 7.5% (0.5–14.5) |
| Aston 2012 | 21 | UK | Meat partially replaced by mixed food | Colorectal cancer risk (men) | 12.2% (6.4–18.0) |
| Aston 2012 | 21 | UK | Meat partially replaced by mixed food | Colorectal cancer risk (women) | 7.7% (4.0–11.3) |
| Soret 2014 | 50 | US/Canada | Meat partially replaced by mixed food | All-cause mortality risk | 14% (4–23) |
| Sabate 2015 | 74 | US/Canada | Meat partially replaced by mixed food | All-cause mortality rate | 7.2% |
| Biesbroek 2014 | 25 | Netherlands | Meat partially replaced by plant-based food | All-cause mortality risk | 10% (3–16) |
| Biesbroek 2014 | 25 | Netherlands | Meat partially replaced by dairy | All-cause mortality risk | 6% (-4-14) |
| Tilman 2014 | 8 | Globally | Mediterranean | All-cause mortality risk | 18% (17–19) |
| Sabate 2015 | 74 | US/Canada | Pescatarian | All-cause mortality rate | 17.6% |
| Milner 2015 | 79 | UK | Healthy guidelines | Years of life lost+ | 6% |
| Milner 2015 | 79 | UK | Healthy guidelines + further optimisation | Years of life lost+ | 7% |
| Scarborough 2012 | 80 | UK | Meat, dairy partially replaced by plant-based food | Deaths averted | 6% |
| Scarborough 2012 | 80 | UK | Ruminants replaced by monogastric | Deaths averted | <1% |

*Percentages refer to reductions in health indicators, except for deaths averted

**Mortality risk reduction by cause: cancer 10%, coronary heart disease 20%, type 2 diabetes 42%

+Years of life lost, at year 30 (after adoption of the sustainable diet scenario)

doi:10.1371/journal.pone.0165797.t002

- 2025 UK Biobank: heart-protective diet incl. low-fat dairy → ↓ CVD incidence & mortality

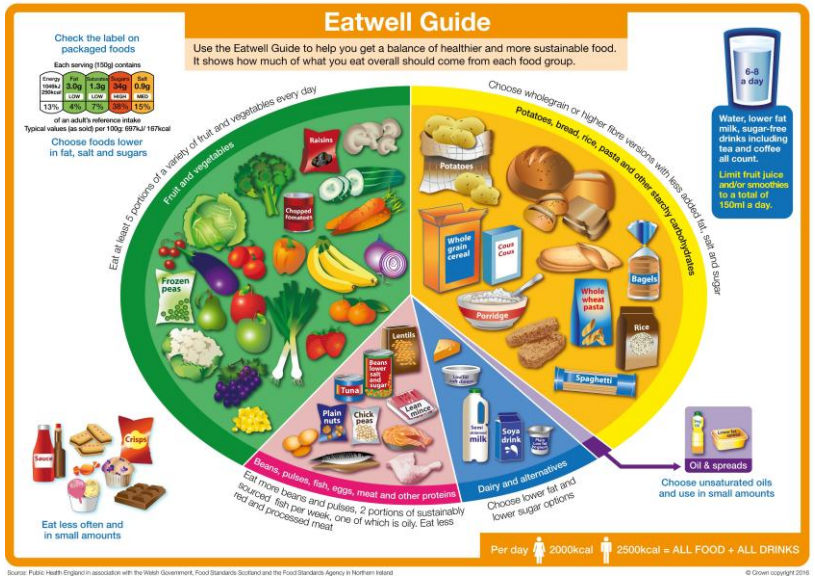
*Wang et al. 2025 Nutrients*

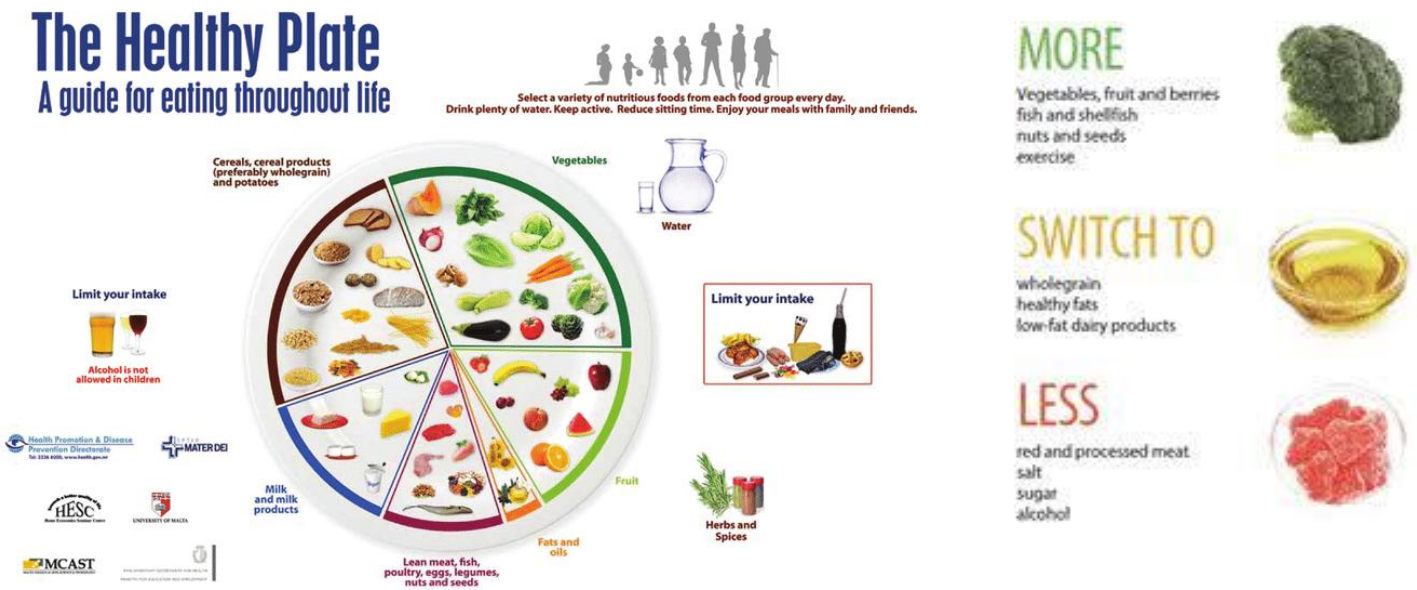
- Mortality risk did not differ much between vegans and lacto-ovo Vegetarians

*Grammatikopoulou et al. 2025 Maturitas*

*Aleksandrowicz et al. 2016 Plos One*

# Dairy in dietary guidelines and recommendations

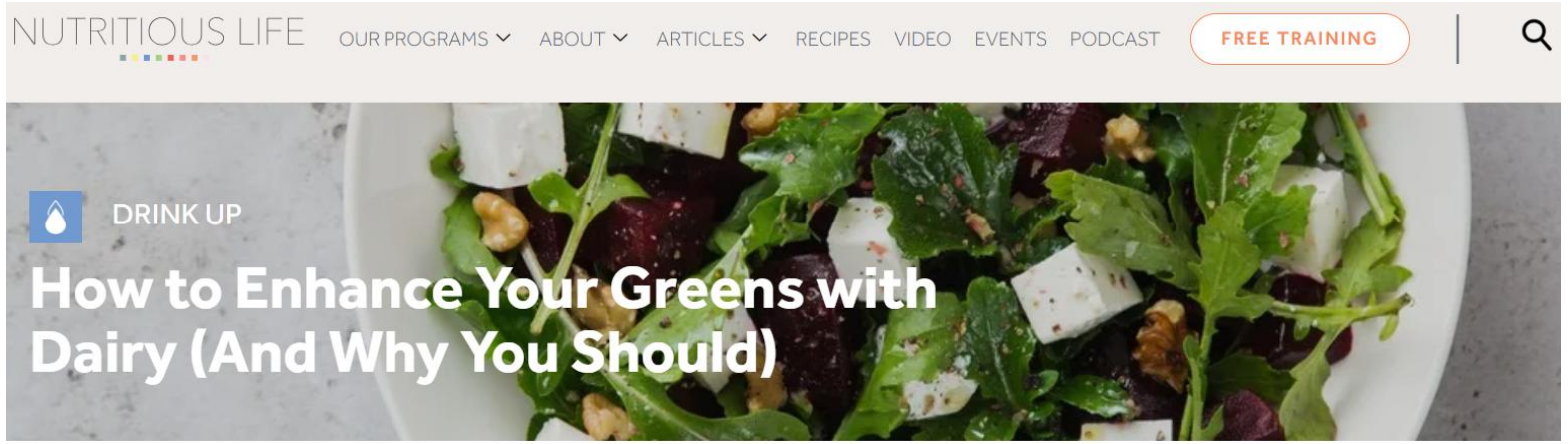



- This analysis revealed that more than 70% of FBDGs contain messaging regarding the consumption of dairy foods *Comerford et al. 2021 Front Nutr*
  *Herforth et al. 2019 Adv Nutr*
- Dairy foods have also been recognised globally for their accessibility, affordability, and acceptability, important parameters to the SDGs
- Recommended dairy intake is associated with healthy dietary habits

*Crichton et al. 2019 Int Dairy J*
*Campmans-Kuijpers 2016 BMC Pediatrics*
*Tambalis et al. 2025 BJN*

# Culinary complementarity




THE DAIRY ALLIANCE

Use Real Milk in These 7 Plant-Based Dinners

Dairy and Produce—A Perfect Pair

# CONCLUSIONS

# Conclusions

- Food choices are driven as much by pleasure as by nutrition—any sustainable dietary shift must account for sensory experience and enjoyment
- Dairy's sensory and culinary qualities and versatility can be a practical tool to help overcome acceptance barriers in plant-forward eating
- "Environmentally protective" dietary patterns risk lowering intakes of Ca, I, Vit B12, Zn; thus, dairy can serve as a bridge in the transition to sustainable, healthy diets
- Including dairy (e.g., milk, yogurt, cheese) within plant-rich diets does not diminish health benefits — and may further support multiple health outcomes
- Evidence gaps remain: Limited studies directly compare dairy-inclusive vs. dairy-exclusive plant-based diets on long-term health outcomes
- Integrating sensory science into nutrition strategies can help bridge the gap between what people should eat (dietary recommendations) and what they actually choose to eat

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