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Emerging Food Safety Risks
Thermal Process Contaminants

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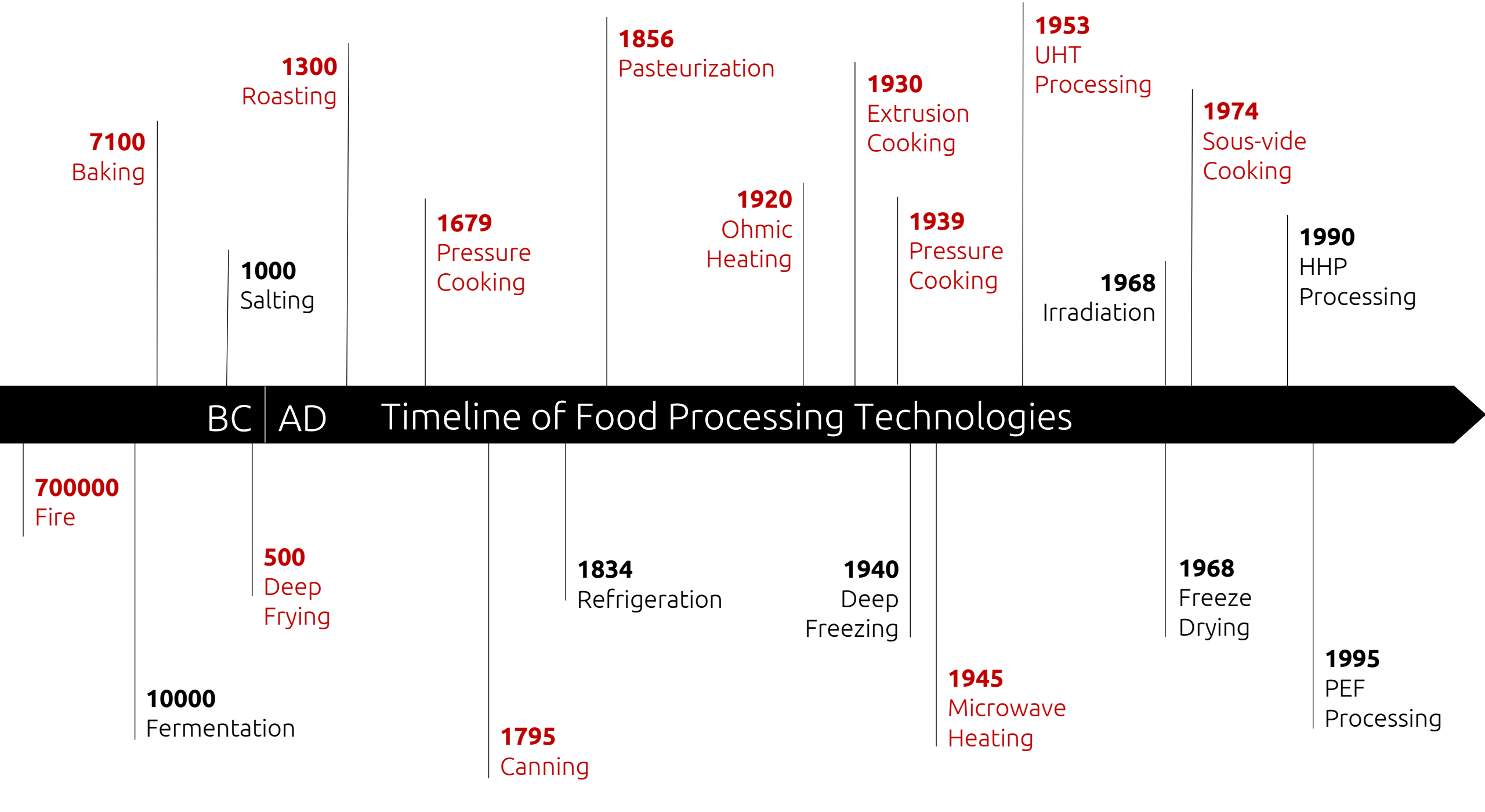

7100
Baking
1000
Salting
1300
Roasting
1679
Pressure
Cooking
1856
Pasteurization
1920
Ohmic
Heating
1930
Extrusion
Cooking
1939
Pressure
Cooking
1953
UHT
Processing
1968
Irradiation
1974
Sous-vide
Cooking
1990
HHP
Processing
BC
AD
Timeline of Food Processing Technologies
700000
Fire
10000
Fermentation
500
Deep
Frying
1795
Canning
1834
Refrigeration
1940
Deep
Freezing
1945
Microwave
Heating
1968
Freeze
Drying
1995
PEF
Processing

Thermally Processed Foods

Baking
150-250ºC

Roasting
150-250ºC

Frying
170-190ºC

Pasteurization
70-100ºC

Sterilization
110-130ºC

Pasteurization
70-100ºC

Pasteurization
70-100ºC
Sterilization
110-130ºC

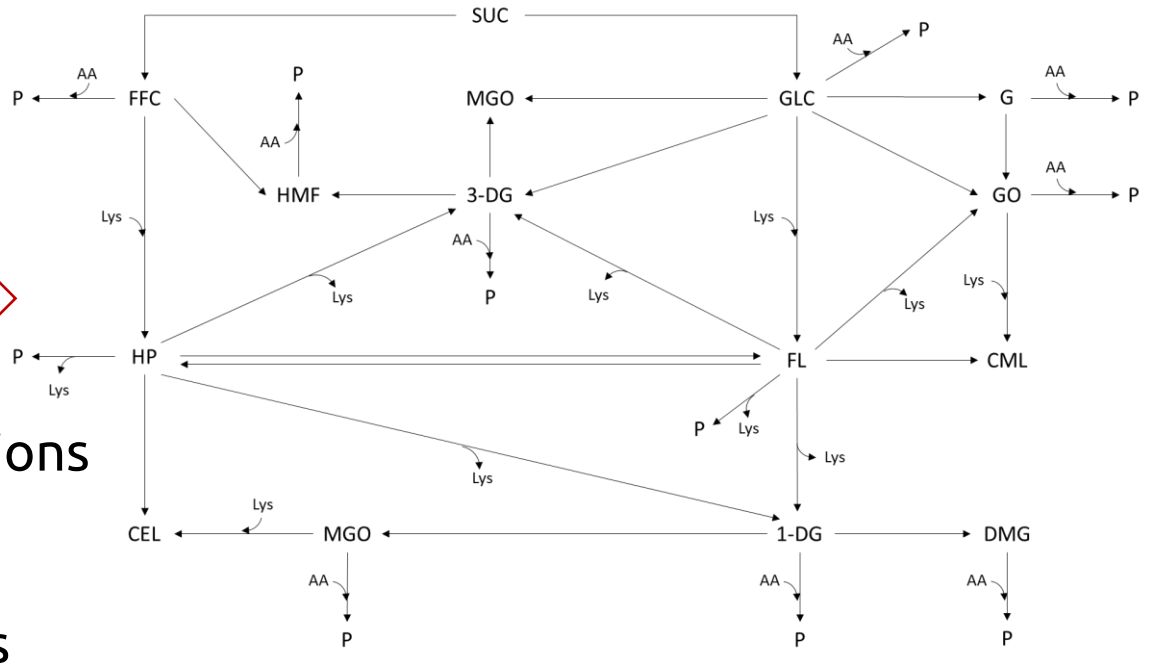
Deodorization
150-260ºC

Roasting
150-200ºC

Food Composition (Reaction Mixture)

- Carbohydrates
- Proteins
- Lipids
- Minerals
- Vitamins
- Water

Heating / Cooking



- T/t induced complex chemical reactions
- Changes in food composition
- Effects on food quality and safety
- Considerations on risks and benefits
- Need for product reformulations and/or process modifications

Thermal Process Contaminants

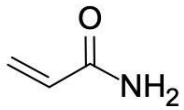
Precursors Naturally Found in Foods

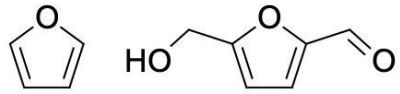
- Asparagine
- Ascorbic acid
- Sugars
- Polyunsaturated fatty acids
- Acylglycerols
- Creatin(in)e

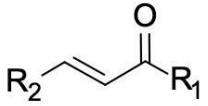
Thermally Processed Food Products

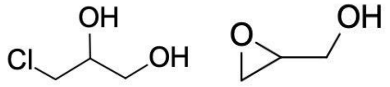
Bakery Products | Coffee Products | Potato Products | Honey Products | Baby Foods | Juice Products | Milk Products | Vegetable Oils | Meat Products

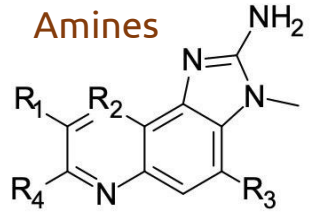
- Acrylamide
- Furan Derivatives
- Dicarbonyl Compounds
- Chloropropanols and Glycydil Esters
- Heterocyclic Amines











Acrylamide

Maximum limits are not regulated in EU.

French fries
Mean 338 µg/kg
Max 2174 µg/kg

Biscuits, crackers, crisp bread
Mean 680 µg/kg
Max 3307 µg/kg

Soft bread
Mean 53 µg/kg
Max 563 µg/kg

Potato crisps
Mean 675 µg/kg
Max 4533 µg/kg

Breakfast cereals
Mean 155 µg/kg
Max 2072 µg/kg

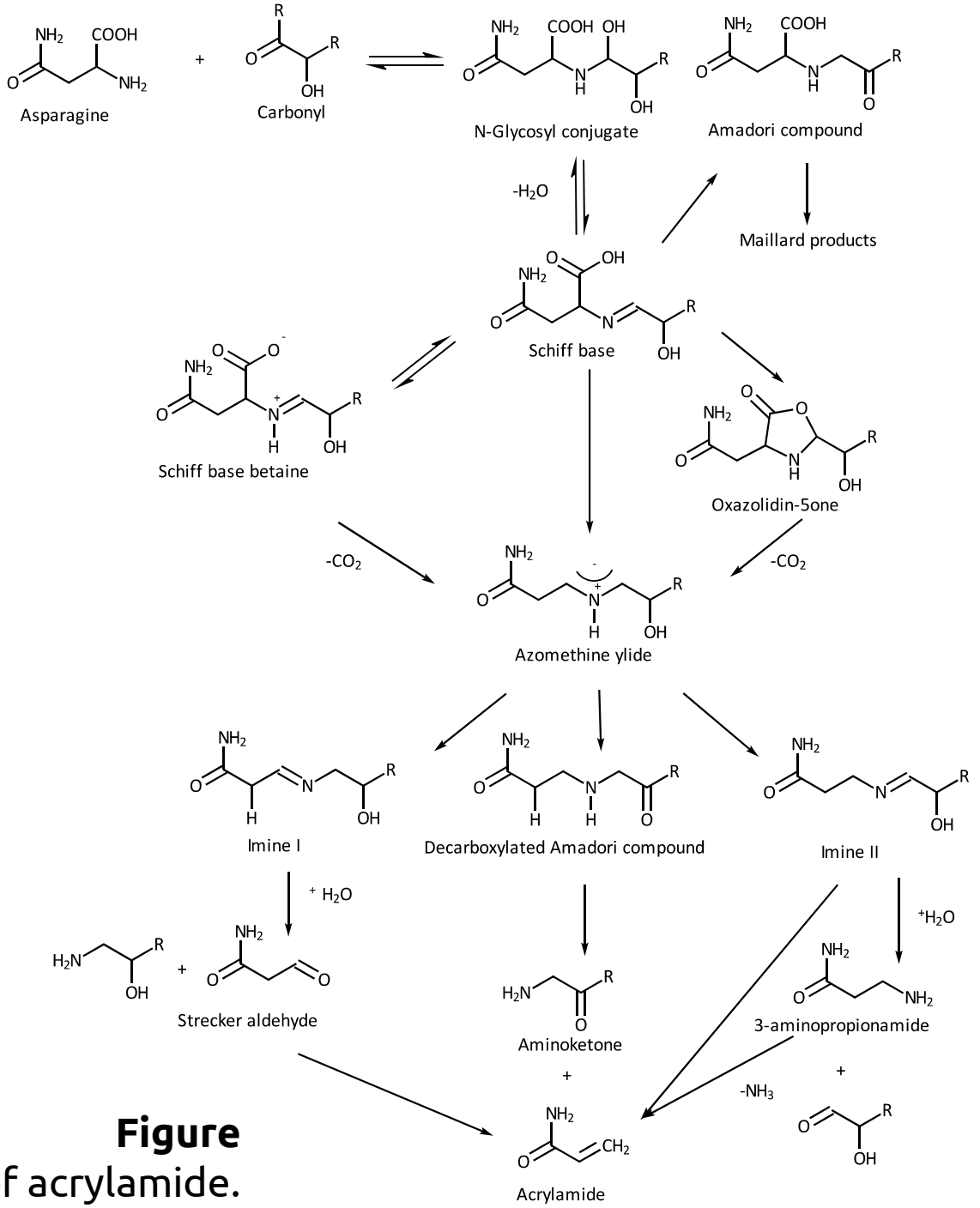
Processed cereal based foods for infants and young children
Mean 69 µg/kg
Max 1200 µg/kg

Coffee and coffee substitutes
Mean 393 µg/kg
Max 7095 µg/kg

The Benchmark Levels

Acrylamide

- The **Maillard reaction** is responsible for the formation of acrylamide in foods during heating at elevated temperatures.
- **Asparagine** which is a **major precursor** of acrylamide occurs naturally in plants.
- Asparagine concentration is considered as **the limiting factor** for acrylamide formed in foods. In practice, the foods rich in free asparagine and reducing sugars have the highest potential to form acrylamide.
- **Carbonyl compounds** are known to **accelerate** acrylamide formation during heating. Foods may be considered as a pool of carbonyl compounds.



Figure

Formation mechanism of acrylamide.

Mechanistic Basis of Mitigation

Asparagine + Carbonyls + Heat → Acrylamide

Targeting asparagine as the limiting factor

- Decreasing asparagine level as low as possible by selecting cereals with low asparagine, diluting with low asparagine cereals, using asparaginase, extending fermentation time where possible
- Blocking carboxyl group of asparagine by adding divalent cations

Targeting carbonyl/dicarbonyl compounds as the accelerating factor

- Avoiding or minimizing reducing sugars, replacing fructose with glucose, using glucose oxidase, extending fermentation time where possible
- Limiting sugar fragmentation reactions leading to α-dicarbonyl and α-hydroxy carbonyl compounds by replacing ammonium bicarbonate with alternatives where feasible
- Trapping sugar fragmentation products by adding thiol and/or phenolic compounds
- Addition of amino acids to compete with asparagine for carbonyl compounds

Targeting thermal load and T/t history of the baking process

- Decreasing overall thermal load by adjusting T/t during baking
- Decreasing surface-to-volume ratio of product
- Avoiding very high baking temperatures and maintenance of uniform control of the color

Furan

Maximum limits are not regulated in EU.

Boiling point
31.3°C

Roasted Coffee & Jarred Baby Purees

Furan is a volatile compound formed mostly during the thermal processing of foods. The toxicity of furan has been well documented previously, and it was classified as “possible human carcinogen (Group 2B)” by the International Agency for Research on Cancer.

Furan

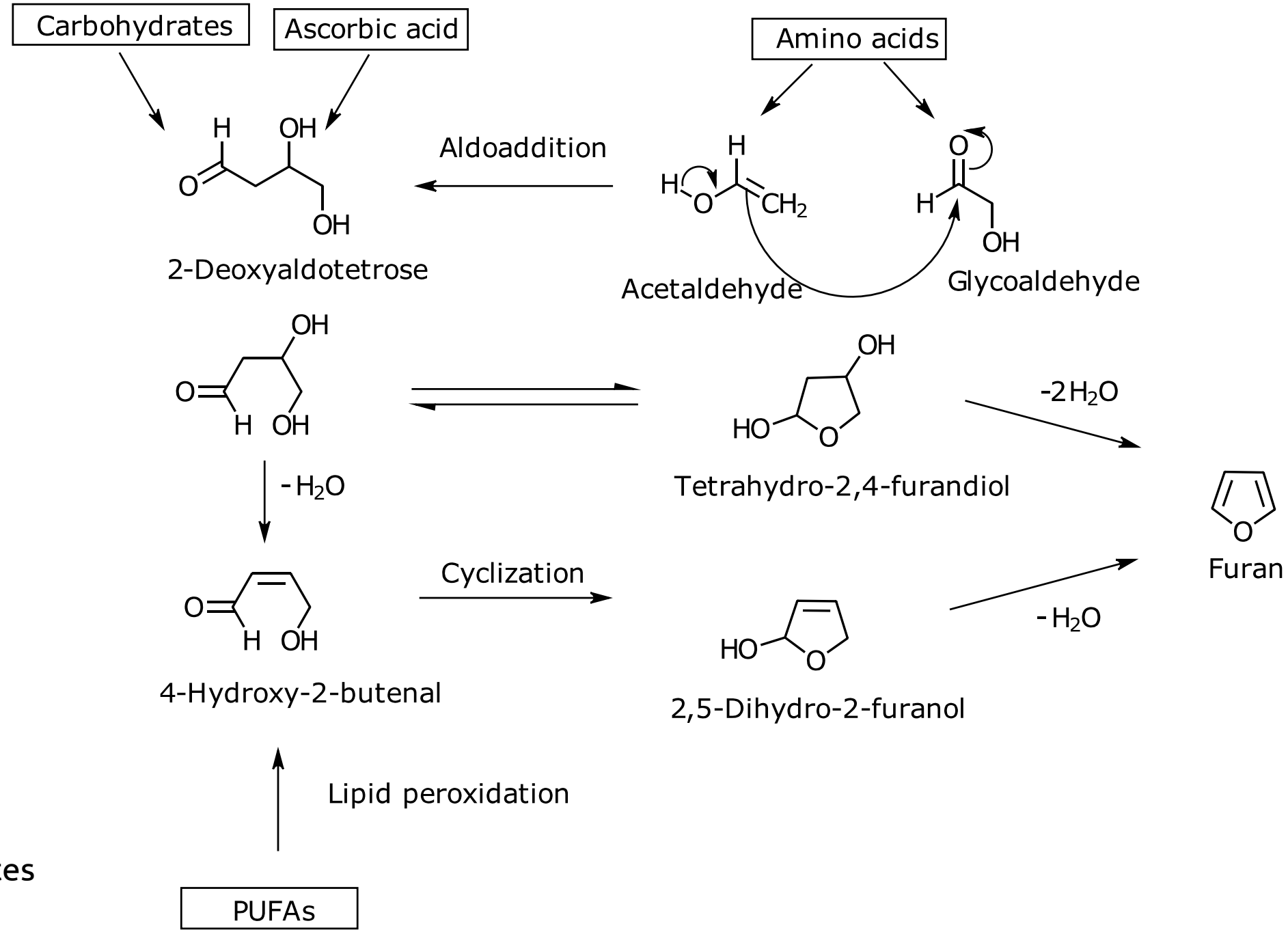


Figure
Summary of possible routes for furan formation

Chloropropanols

Maximum limits are regulated in EU.

3-MCPD and its esters

- 20 µg/kg in hydrolyzed vegetable protein and soy sauce
- 1250 – 2500 µg/kg in vegetable oils and fats
- 15 µg/kg in infant formula

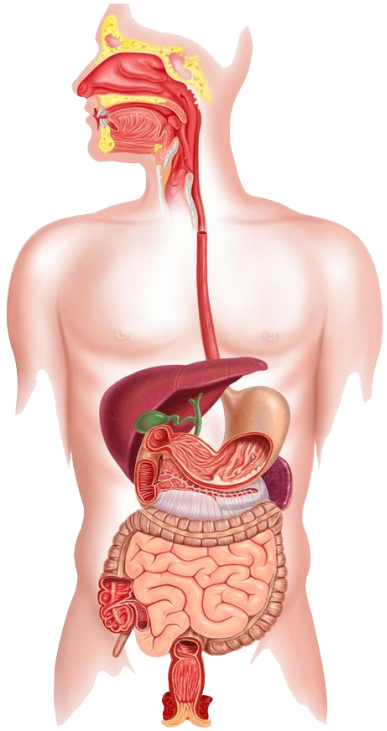
Glycidyl esters

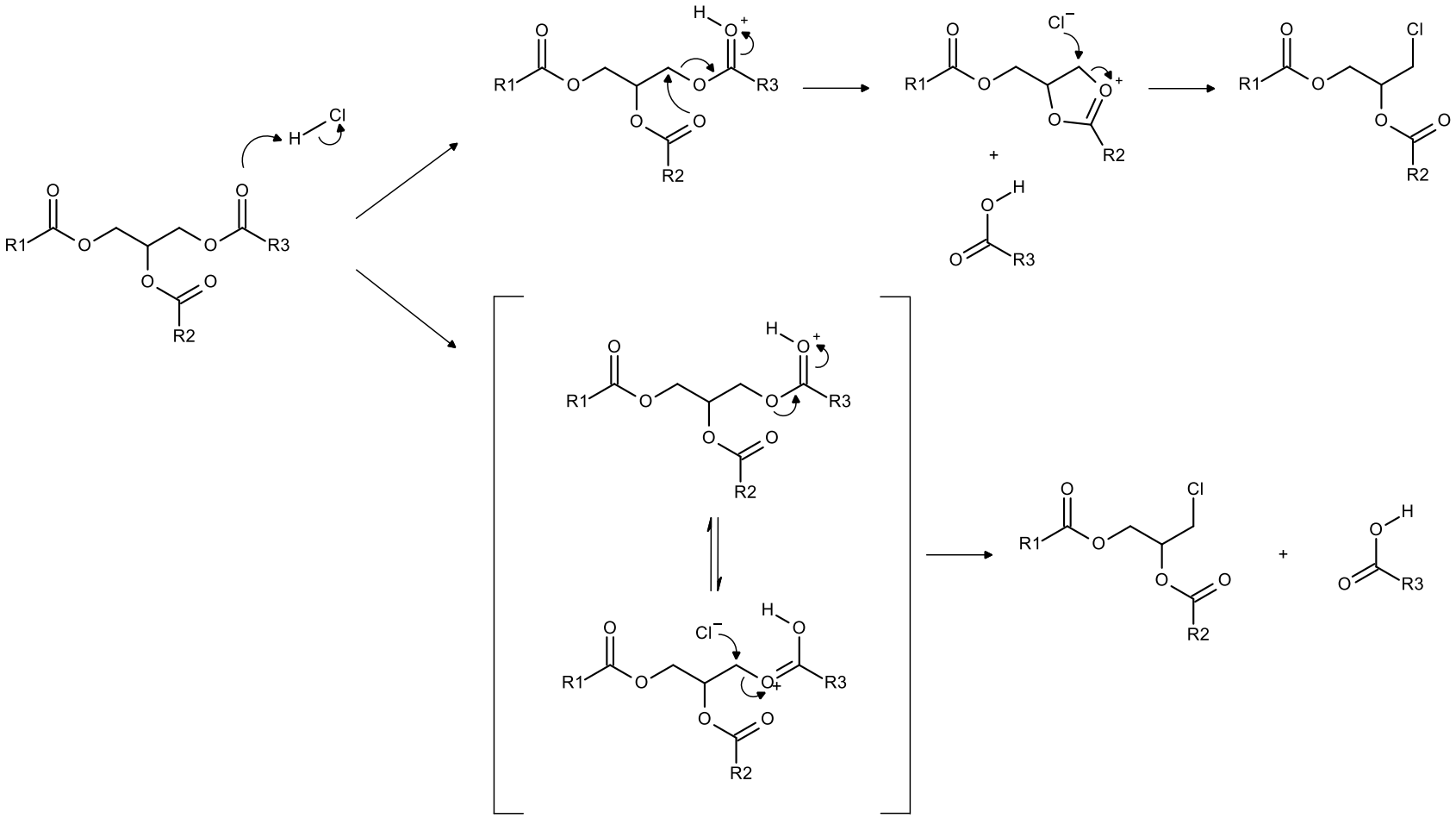
- 500 – 1000 kg in vegetable oils and fats
- 6 µg/kg in infant formula

Fats and Oils

Chloropropanols and related substances are contaminants that can be formed during food processing, particularly when high temperatures are applied to fats and oils. The original maximum levels for 3-MCPD and its esters in specific food products for infants and young children were established by Regulation (EU) 2020/1322.

Chloropropanols





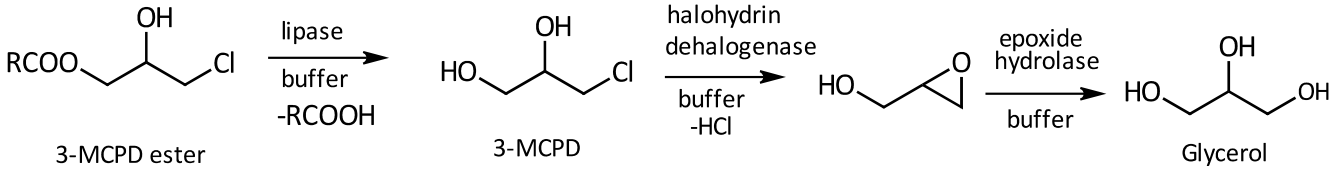
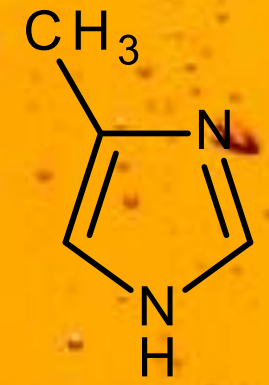


Figure
Mechanism of the formation of chloropropanols and related substances from acrylglycerols

Methylimidazole



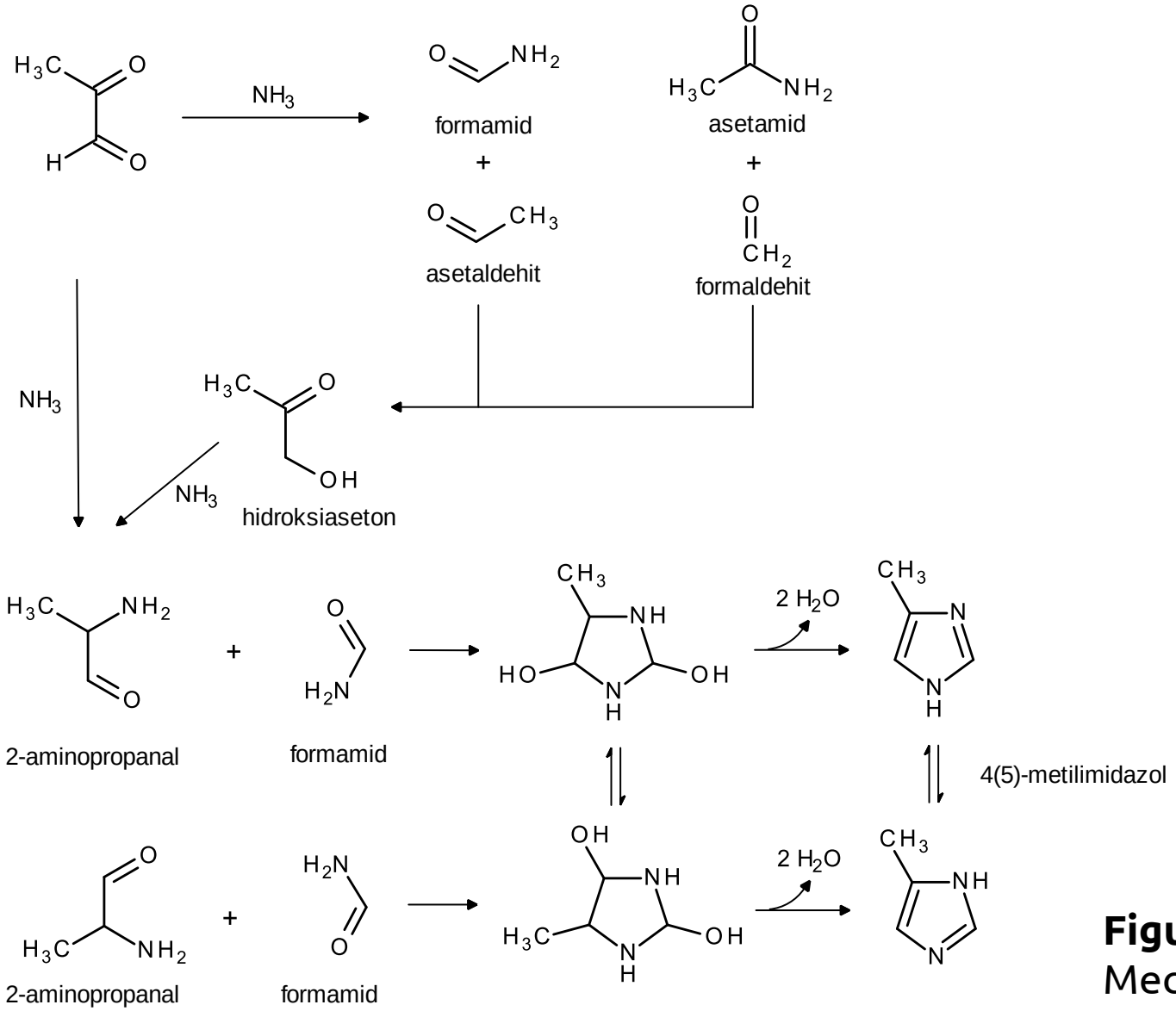
Maximum limits are not regulated in EU.

- Caramel Color I (also known as plain or spirit caramel)
- Caramel Color II (caustic sulfite caramel)
- **Caramel Color III** (ammonia or beer caramel, baker's and confectioner's caramel)
- **Caramel Color IV** (known as sulfite-ammonia, soft drink caramel or acid-proof caramel)

Coke, Beer, Candy, Bakery Products

The International Agency for Research on Cancer classified methylimidazole (-4-MEI) as Group 2B indicating sufficient evidence of carcinogenicity in experimental animals while no human data were available. In 2011, California listed 4-MEI as a carcinogen under the Proposition 65.

Methylimidazole



Ammonia Caramel

Figure
Mechanism of the formation of methylimidazole

AGEs in Foods

Maximum limits are not regulated in EU.

- In vitro
- In vivo

UHT-Treated and Powdered Milk Products

Advanced glycation end products (AGEs) are proteins that become glycated as a result of exposure to sugars.

They are a biomarker implicated in aging and the development or worsening of many degenerative diseases, such as diabetes, atherosclerosis, chronic kidney disease, and Alzheimer's disease.

Maillard Reaction in Foods

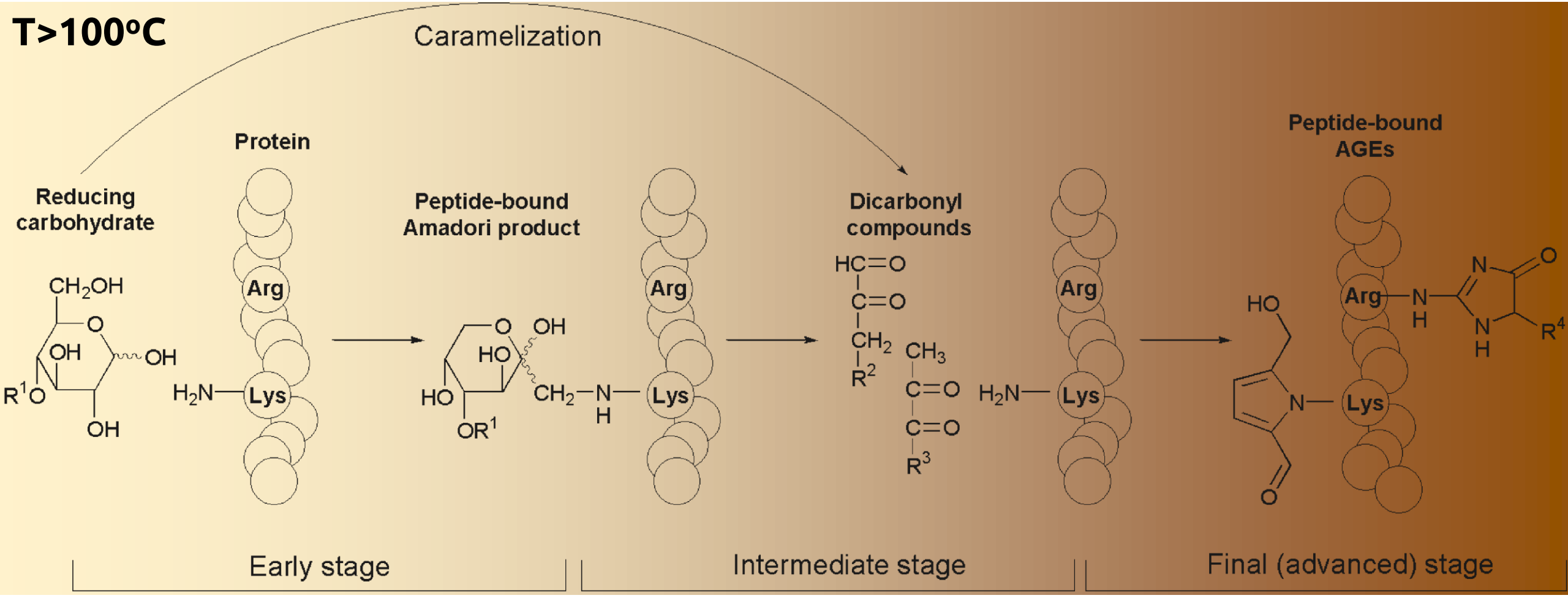
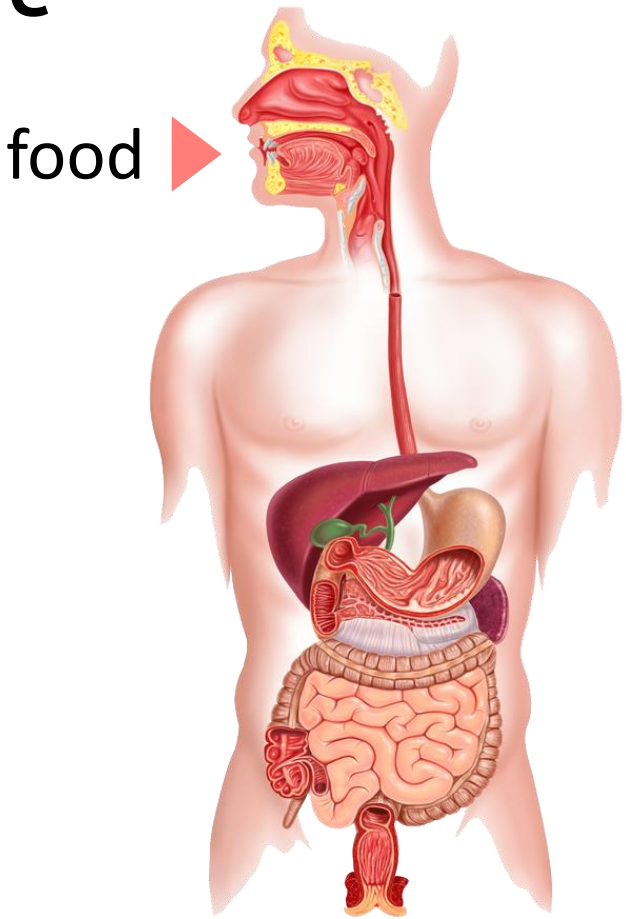


Figure
General reaction scheme of the Maillard reaction leading to the formation of dicarbonyl compounds and advanced glycation end products (AGEs) in foods during thermal processing.

Maillard Reaction in Human Body

T=37ºC



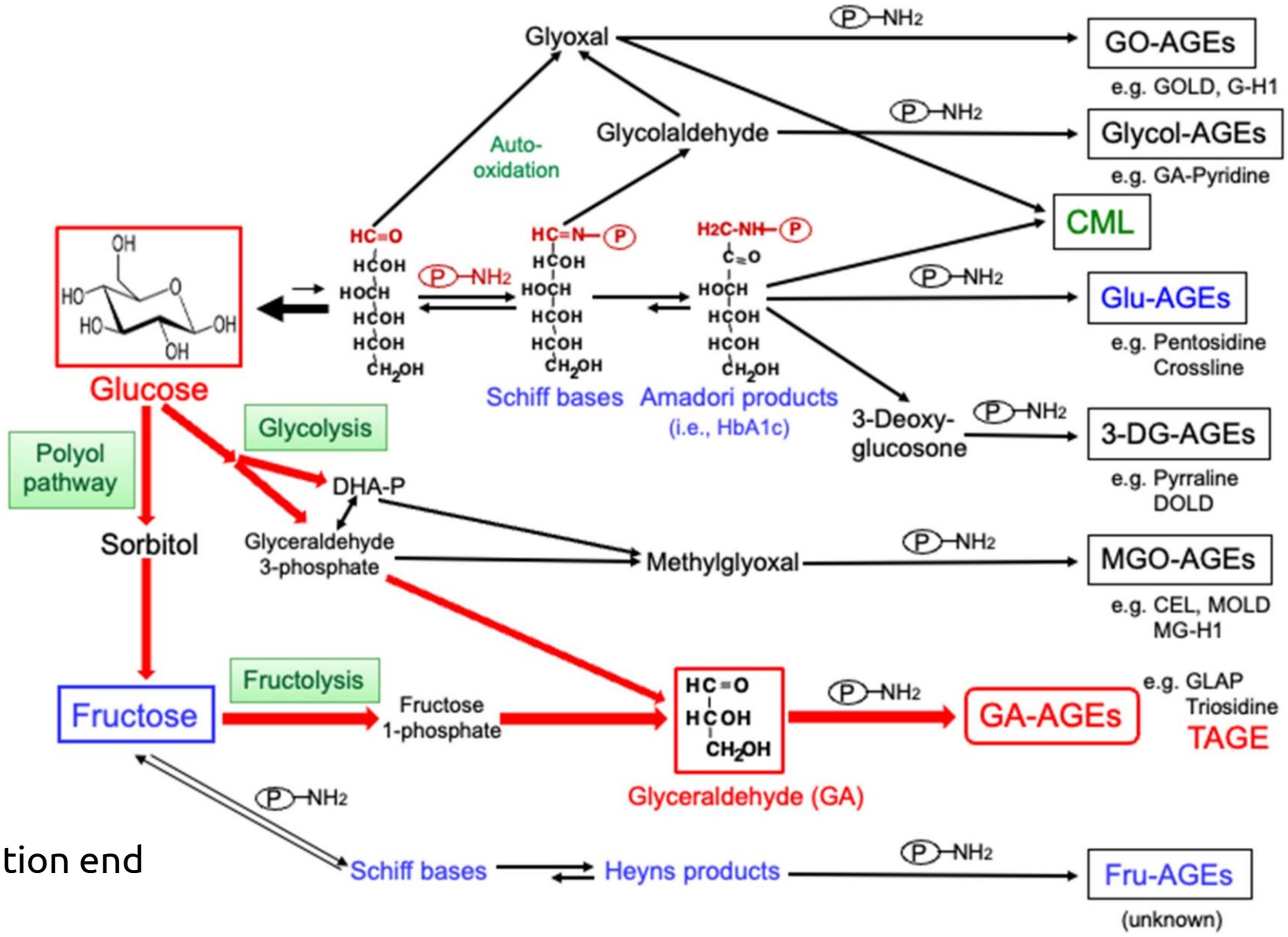
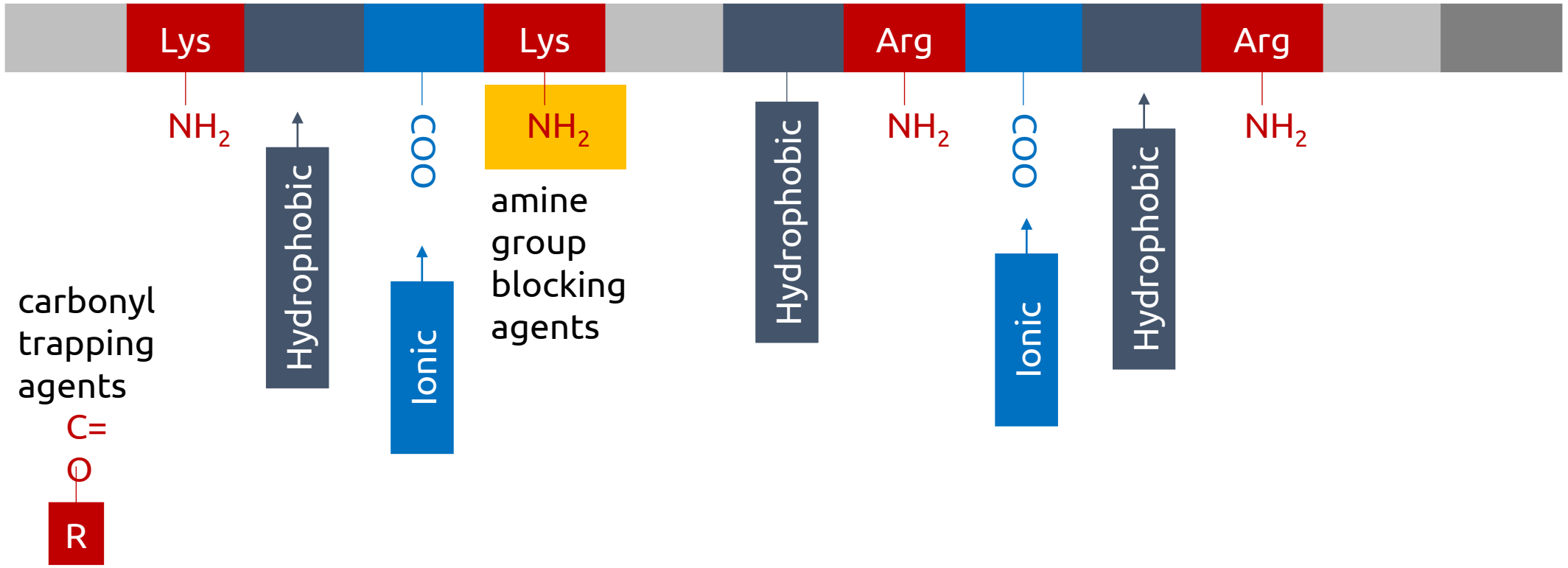


Figure
Formation mechanism of advanced glycation end products (AGEs) in the human body.

Anti-Glycation Scenarios



steric hindrance of free amino groups by hydrophobic (polyphenols) or ionic interactions (Ca^{2+})

Dicarbonyl Compounds

Maximum limits are not regulated in EU.

Dicarbonyl compounds form advanced glycation end (AGEs) products that play a role in diabetes, aging and Alzheimer's diseases.

Dicarbonyl Compounds

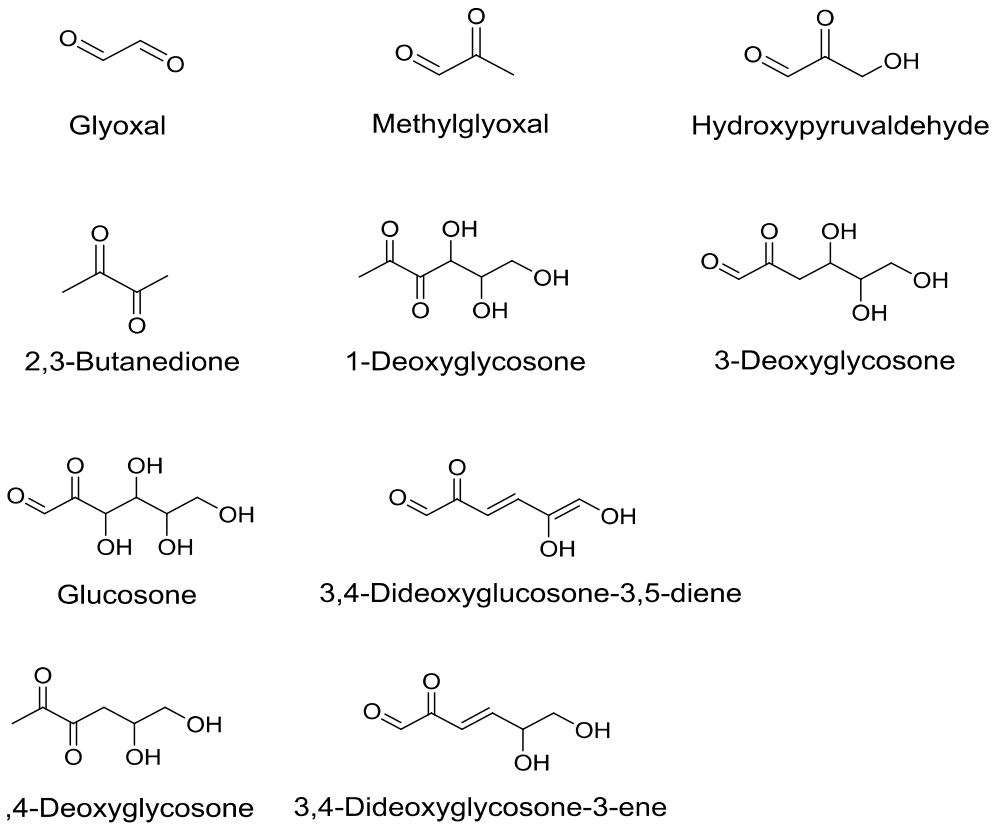


Figure
Examples of the structures of α-dicarbonyl compounds generated in foods because of Maillard reaction, sugar decomposition and lipid oxidation reactions

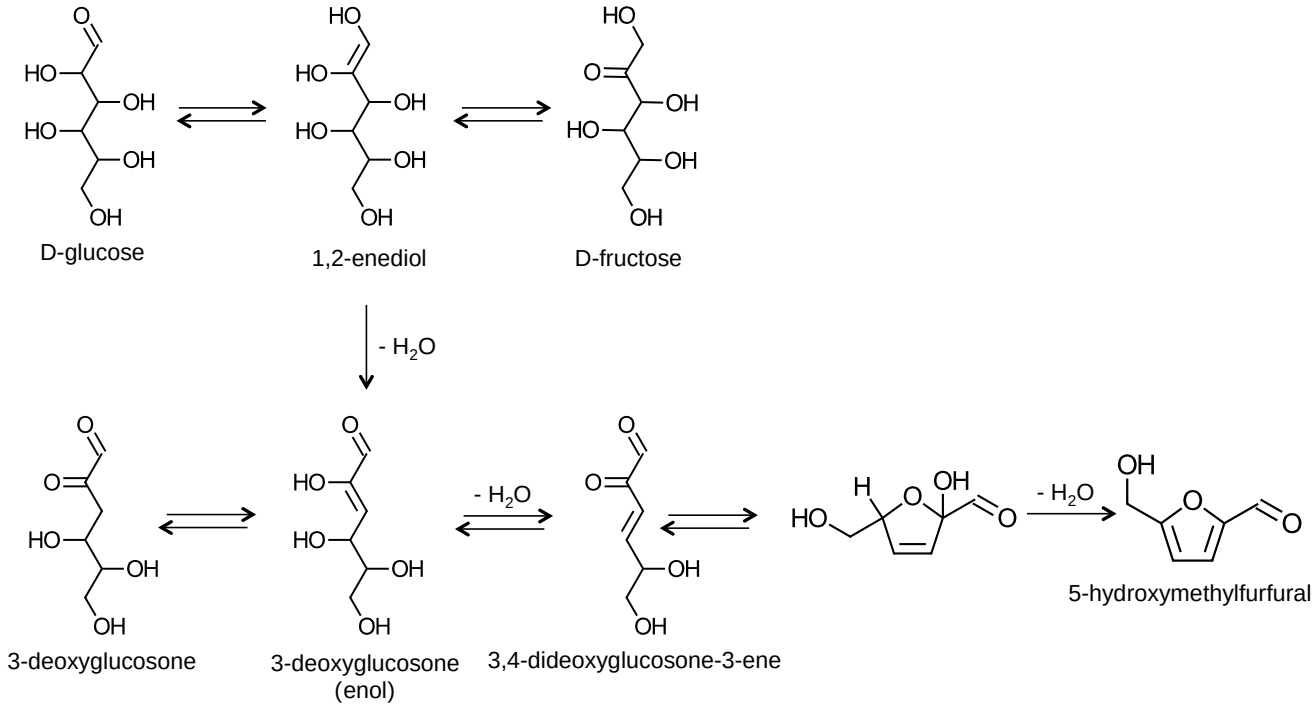


Figure
Formation mechanism of α-dicarbonyl compounds via dehydration of glucose

Hidroksimetilfurfural

Maximum limits are regulated in EU.

- 40 mg/ kg in general
- 80 mg/kg in tropical honey

Sugar Rich Products

HMF is formed in the Maillard reaction as well as during caramelization. HMF can form in sugar-containing food, particularly as a result of heating or cooking. It is also slowly generated during storage. Acid conditions favor generation of HMF. Its formation has been the topic of significant study as HMF was regarded as being potentially carcinogenic to humans.

HMF

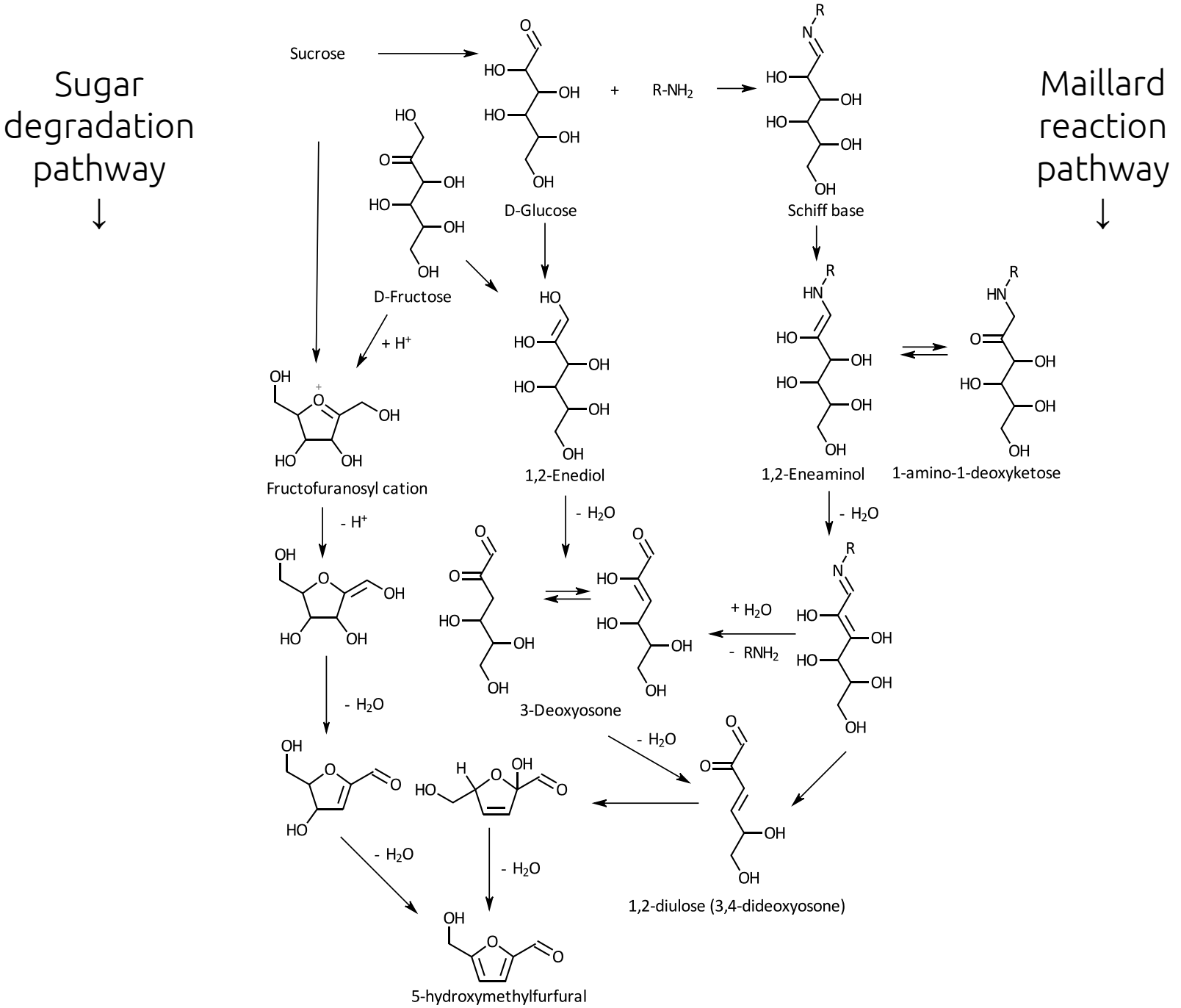


Figure
Formation mechanism of HMF

Heterocyclic Amines

Maximum limits are not regulated in EU.

Roasted Meats

Heterocyclic amines (HCAs) are a group of mutagenic compounds found in cooked meats, particularly well-done meats.

HCAs in the form of **amino carboline** or **amino imidazo-azaarene** groups are formed during frying, broiling, smoking, or barbecuing meat and fish at high temperatures due to the abundance of amino acids or creatine in these foods.

Heterocyclic Amines

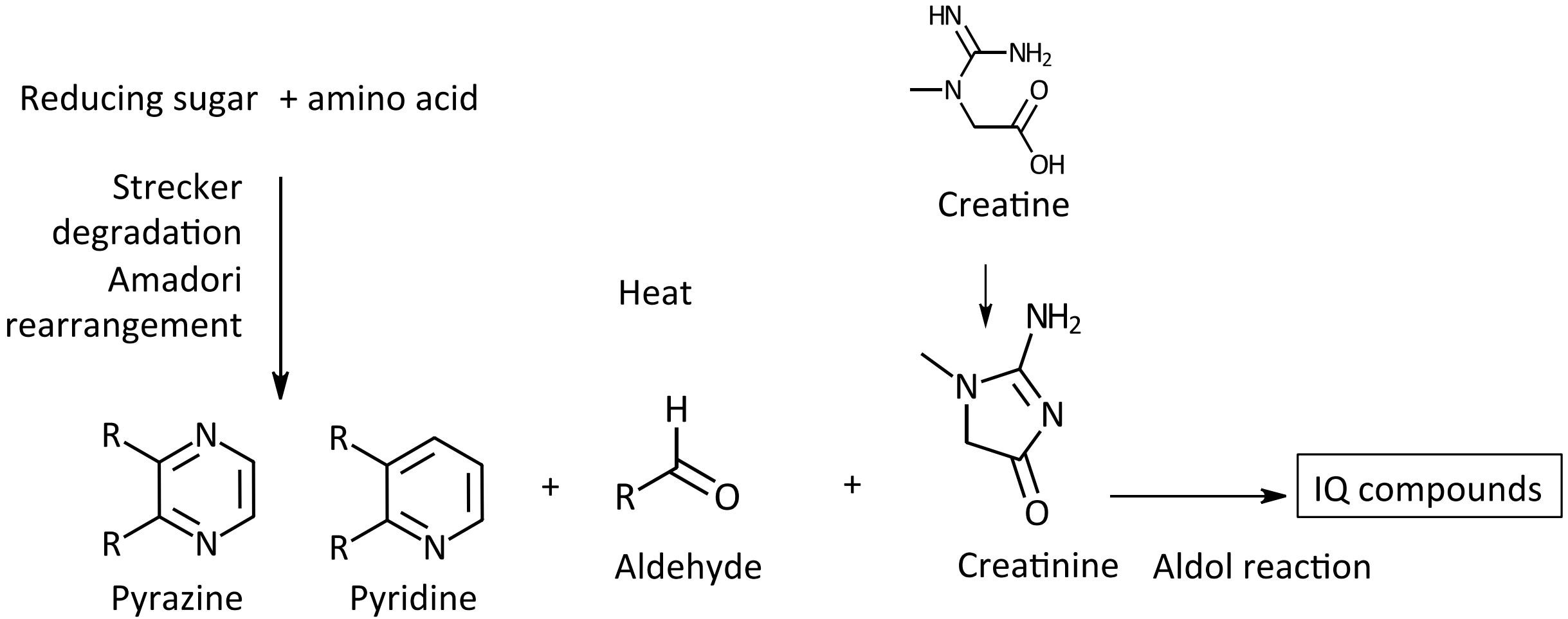


Figure
Formation mechanism of heterocyclic amines in foods via the Maillard reaction

Take home message

Eating is not free of risk


Food
Quality
& Safety