WATER ACTIVITY: REACTION RATES, PHYSICAL PROPERTIES, AND SHELF LIFE

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SHELF LIFE AND STABILITY

• Consumers expect quality, freshness, nutritive value, and accurate label information.

• Shelf life indicates the extent of allowable product change due to
  – Time
  – Environment

• Understanding stability and factors that affect stability, such as moisture, can lead to improving shelf life and shelf life predictions.
TYPES OF STABILITY

• Microbial
• Sensory
• Chemical
• Physical
FOOD PRODUCT TYPES

• Dry (powders, cereals)
• Intermediate Moisture (bars)
• Solutions (beverages)
THE STABILITY QUESTION

• A food has a sensitive “attribute”
  - Loss of sensitive ingredient
  - Formation of an undesirable product
  - Undesirable change in texture
• How does this “attribute” change due to:
  - Processing
  - Distribution
  - Storage
    • Commercial
    • Consumer
• Answers come from modeling kinetic data
REACTION KINETIC OVERVIEW

Active Compound → Degradation
Product(s)
REACTION TYPES

- Hydrolysis
- Oxidation
- Rearrangement reactions
- Amine-Carbonyl (Maillard reaction)
- Enzymatic
KINETIC DATA

• zero order model: \[ [A] = [A]_o - kt \]

• first order model: \[ \ln([A]/[A]_o) = -kt \]

• Terms
  – \( k \) = rate constant
  – \( t \) = time
  – \([A], [A]_o\) = concentration
ZERO ORDER PLOT

-slope = k = conc/day
FIRST ORDER PLOT

-slope = k = 1/day

FACTORS INFLUENCING STABILITY

- Temperature
- Moisture
- pH
- Ingredients
- Oxygen
TEMPERATURE

• Reaction rates increase with increasing temperature
• Models
  – Arrhenius Equation
    \[ \ln(k) = \ln(A) - \frac{E_A}{RT} \]
    \[ \log(k) = \log(A) - \frac{E_A}{2.303RT} \]
  – \( Q_{10} \) Approach
    \[ Q_{10} = \frac{\theta_{s,T}}{\theta_{s,T+10}} \]
ARRHENIUS PLOT FOR VITAMIN C DEGRADATION AT \( a_W \) 0.32

\[ -\text{slope} = \frac{E_A}{2.303R} \]

SHELF LIFE PLOT FOR VITAMIN C DEGRADATION AT $a_w$ 0.32

-slope = $\log (Q_{10})/10$

SHELF LIFE PLOT FOR THIAMIN DEGRADATION AT $a_w$ 0.75

- slope = $\log (Q_{10})/10$

SHELF LIFE AND TEMPERATURE

- Define shelf life as the time for 10% thiamin loss.
- Shelf life at 25°C is 38 days.
- Shelf life increases by 3.3 for each 10°C decrease in temperature.
- Thus, the predicted shelf life at 20°C is ≈80 days.
- Small temperature changes can have large effects on product shelf life.
TEMPERATURE FLUCTUATIONS

![Graph showing temperature fluctuations with time interval x and temperature T_x.](image-url)
TEMPERATURE FLUCTUATIONS
Fraction of Shelf Life Consumed \((f_{\text{con}})\)

\[
f_{\text{con}} = \sum \frac{\text{time at temperature } x_i}{\text{total shelf life at temperature } x_i}
\]

<table>
<thead>
<tr>
<th>°C</th>
<th>Shelf Life</th>
<th>Time</th>
<th>f</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>150 d</td>
<td>33 d</td>
<td>0.22</td>
</tr>
<tr>
<td>30</td>
<td>75 d</td>
<td>7 d</td>
<td>0.093</td>
</tr>
<tr>
<td>40</td>
<td>38 d</td>
<td>2 d</td>
<td>0.053</td>
</tr>
</tbody>
</table>

\[
f_{\text{con}} = 0.366
\]
TIME TEMPERATURE INDICATORS

• Gives a visual indication of net exposure to time and temperature

MonitorMark is a registered trademark of 3M.
TIME TEMPERATURE INDICATORS

**Quality Indicator**
Use or freeze before center is darker than outer ring.

**Quality Indicator**
Use or freeze before center is darker than outer ring.
WATER & CHEMICAL STABILITY
MOISTURE DIFFUSION

CHEMICAL DETERIORATION

PHYSICAL DETERIORATION

MOISTURE DIFFUSION
WATER

OPEN

CHEMICAL DETERIORATION

PHYSICAL DETERIORATION
PERSPECTIVES ON WATER

- Moisture Content
- Water Activity (relative vapor pressure)
- Glass Transition (plasticizer effect)
- Water Mobility
WATER ACTIVITY

• Determines direction of moisture transfer
• Most reaction rates increase with increasing water activity
• Most rates correlate better with water activity than moisture content
• Moisture sorption isotherms are useful
GLASS-RUBBER TRANSITION

Amorphous Amorphous Glass Rubber Crystal

- Transition due to:
  - Temperature
  - Moisture
- Depicted by state diagram
- Relates to physical properties of system
  - Rigid glassy matrix converts into soft rubbery matrix
- Affects reactant mobility
QUESTION OF THE 1990’s

Does moisture affect reactions by water activity or by increasing reactant mobility with its plasticizing ability?
GENERAL EFFECT OF WATER ACTIVITY ON REACTION RATES

Water Activity vs. Reaction Rates

Graph showing the general effect of water activity on reaction rates, with a peak reaction rate at a specific water activity level.

Water Activity on the x-axis ranging from 0.0 to 1.0
Reaction Rates on the y-axis ranging from 0.0 to 1.4

The graph indicates a peak reaction rate at a water activity of approximately 0.8, suggesting an optimal water activity for the reaction process.
MOISTURE SORPTION ISOTHERM FOR MALTODEXTRIN (DE 25) AT 25°C

MODELING MOISTURE SORPTION ISOTHERM DATA

• GAB equation

\[ m = \frac{m_o k C a_w}{(1 - k a_w)(1 - k a_w + k C a_w)} \]

• Terms
  – \( m_o \) = monolayer
  – \( k \) = multilayer factor
  – \( C \) = heat constant
GENERAL EFFECT OF WATER ACTIVITY ON REACTION RATES

Water Activity vs. Reaction Rate
GLUCOSE MOVEMENT IN DRIED CARROTS
MONOLAYER = 7.2% (db)

<table>
<thead>
<tr>
<th>Moisture % (db)</th>
<th>Movement Detected</th>
</tr>
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<tbody>
<tr>
<td>5.9</td>
<td>No</td>
</tr>
<tr>
<td>8.1</td>
<td>Yes</td>
</tr>
<tr>
<td>10.2</td>
<td>Yes</td>
</tr>
<tr>
<td>13.9</td>
<td>Yes</td>
</tr>
<tr>
<td>18.1</td>
<td>Yes</td>
</tr>
<tr>
<td>21.7</td>
<td>Yes</td>
</tr>
<tr>
<td>26.3</td>
<td>Yes</td>
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</tr>
<tr>
<td>21.7</td>
<td>Yes</td>
</tr>
<tr>
<td>26.3</td>
<td>Yes</td>
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$m_o = 7.2$

ASPARTAME DEGRADATION

- Rearrangement reaction at pH > 6
- Hydrolysis reaction at pH < 4
- Both reaction types between pH 4 and 6
- Catalyzed by buffer salts
- Follows pseudo-first order kinetics
ASPARTAME DEGRADATION AS A FUNCTION OF WATER ACTIVITY AT pH 3 AND 30°C

ASPARTAME DEGRADATION

- Water activity 0.3 to 0.8
  - Solutes dissolving
  - Mobility increasing
  - Reactivity increasing
ASPARTAME DEGRADATION

- Water activity 0.8 to 1.0
  - Solutes becoming diluted
  - Reactivity decreasing
EFFECT OF T_g ON ASPARTAME DEGRADATION IN POLYVINYLPYRROLIDONE (PVP) AT 25°C AND pH 7

QA PLOT FOR ASPARTAME DEGRADATION
IN PVP AT 25°C AND pH 7

\[ \ln(Q_A) = \frac{-\text{slope}}{0.1} \]

\[ Q_A = 1.4 \]

\( Q_A \) CONCEPT

\[
Q_A = \frac{\text{half-life at } a_w}{\text{half-life at } a_w + 0.1}
\]

- \( Q_A = 1.4 \) means half-life decreases by 40% for each 0.1 \( a_w \) increase
- If \( a_w \) decreases by 0.1, half-life increases by 1.4
  - 33 days at \( a_w 0.33 \) (experimental)
  - 46 days at \( a_w 0.23 \) (predicted)
  - 65 days at \( a_w 0.13 \) (predicted)
RELATION BETWEEN ACTIVATION ENERGY OF ASPARTAME DEGRADATION AND WATER ACTIVITY

WATER ACTIVITY EFFECTS ON $Q_{10}$ VALUES OF ASPARTAME DEGRADATION AT pH 5

<table>
<thead>
<tr>
<th>$a_W$</th>
<th>$Q_{10}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.33</td>
<td>4.3</td>
</tr>
<tr>
<td>0.55</td>
<td>4.2</td>
</tr>
<tr>
<td>0.65</td>
<td>3.7</td>
</tr>
<tr>
<td>0.99</td>
<td>2.6</td>
</tr>
</tbody>
</table>
WATER ACTIVITY AND TEMPERATURE

- Activation energies often decrease as water activity increases.
- Sensitivity of a reaction to temperature changes as $a_W$ changes.
- A temperature increase has a larger effect (higher $Q_{10}$) on a reaction in low moisture food than in a high moisture food.
- However, the “dryness” adds stability, compensating for the food being more temperature sensitive.
MAILLARD REACTION
(NONENZYMATIC BROWNING)

- Bimolecular reaction involving:
  - unprotonated amines (amino acid)
  - carbonyl compounds (reducing sugars)
- Reactant loss follows second order kinetics
- Brown pigment formation modeled via pseudo-zero order kinetics
BROWN PIGMENT FORMATION IN GLUCOSE-GLYCINE MODEL SYSTEM AT 37°C

BROWN PIGMENT FORMATION IN GLUCOSE-GLYCINE MODEL SYSTEM AT 37°C

Water Activity

Dissolution, Higher Mobility

BROWN PIGMENT FORMATION IN GLUCOSE-GLYCINE MODEL SYSTEM AT 37°C

EXPERIMENTAL DESIGN TO ELIMINATE CONCENTRATION EFFECT

- Prepare each system with pre-determined reactant concentration so that after moisture sorption, all have the same reactant concentration in the aqueous phase (Bell et al. 1998. J. Food Sci. 63:625).

- For example
  - 10% moisture = 10 mg added reactants/g
  - 20% moisture = 20 mg added reactants/g
GLYCINE LOSS IN PVP-K15 AT 25°C AS A FUNCTION OF WATER ACTIVITY

GLYCINE LOSS IN PVP-K15 AT 25°C AS A FUNCTION OF GLASS TRANSITION

GLYCINE LOSS VIA MAILLARD REACTION

- Concentration effects eliminated
- Water activity 0.1 to 0.4
  - Mobility increasing
  - Reactivity increasing
- Water activity 0.4 to 0.7
  - Pass through glass transition
  - Structural collapse
  - Reactivity decreasing
GLUCOSE LOSS IN PVP AT $a_W$ 0.33 AND 25°C AS AFFECTED BY POROSITY AND COLLAPSE


Porous ($\Phi > 0.7$)  
Collapsed ($\Phi < 0.2$)
EFFECT OF GLASS TRANSITION ON BROWNING IN PVP AT pH 7, aw 0.54, and 25°C

BROWNING RATES IN PVP AT 25°C AS AFFECTED BY THE GLASS TRANSITION

WATER AND THE MAILLARD REACTION

- Moisture directly impacts this reaction primarily by dissolving and/or diluting the reactants.
- Moisture indirectly impacts this reaction by its effect on the glass transition.
- Various researchers have shown the glass transition affects the Maillard reaction:
VITAMIN STABILITY

- Ascorbic acid (vitamin C)
- Riboflavin
- Thiamin
VITAMIN C DEGRADATION AT 35°C AS INFLUENCED BY MOISTURE


QA PLOT FOR VITAMIN C DEGRADATION AT 23°C

QA = 1.7

VITAMIN C DEGRADATION IN DRIED TOMATO JUICE AT 20°C

QA PLOT FOR VITAMIN C DEGRADATION AT 20°C IN DRIED TOMATO JUICE

Below $m_0$; not included in $Q_A$ determination

$Q_A = 1.6$

RIBOFLAVIN DEGRADATION AT 37°C IN MODEL SYSTEMS AS AFFECTED BY WATER ACTIVITY

QA PLOT FOR
RIBOFLAVIN
DEGRADATION AT 37°C

Below \( m_0 \); not included in \( Q_A \) determination

\[ Q_A = 1.3 \]


Water Activity
QA PLOT FOR THIAMIN DEGRADATION IN PASTA AT 35°C

EFFECT OF MOISTURE ON THE ACTIVATION ENERGY OF THIAMIN DEGRADATION

<table>
<thead>
<tr>
<th>$a_W$</th>
<th>$E_A$ (kcal/mole)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.44</td>
<td>30.8</td>
</tr>
<tr>
<td>0.54</td>
<td>29.8</td>
</tr>
<tr>
<td>0.65</td>
<td>26.6</td>
</tr>
</tbody>
</table>

THIAMIN DEGRADATION IN PVP AT 20ºC AS AFFECTED BY WATER ACTIVITY

THIAMIN DEGRADATION IN PVP AT 20ºC AS AFFECTED BY $T_g$


Glassy

PVP-LMW

PVP-K30

Rubbery

$T_T$
ENZYMES AND WATER

• Enzyme activity
  – Water can:
    • Dissolve substrate
    • Increase substrate mobility
    • Be a reactant

• Enzyme stability
  – Moisture can influence “denaturation”
    • Hydrolysis
    • Deamidation
    • Oxidation
EXTENT OF LECITHIN HYDROLYSIS BY PHOSPHOLIPASE AFTER 12 DAYS

SUCROSE HYDROLYSIS BY INVERTASE AS A FUNCTION OF WATER ACTIVITY

- T=Tg

Water Activity vs. Hydrolysis Rate
QA PLOT FOR INVERTASE STABILITY IN PVP AT 30°C

INVERTASE STABILITY IN PVP AT 30ºC AS AFFECTED BY THE GLASS TRANSITION

RESIDUAL TYROSINASE ACTIVITY IN PVP AFTER 3 DAYS EQUILIBRATION AT 20ºC

RESIDUAL TYROSINASE ACTIVITY IN PVP AFTER 3 DAYS EQUILIBRATION AT 20°C

RATE CONSTANTS FOR TYROSINASE ACTIVITY LOSS AT 20°C AS AFFECTED BY $a_W$

RATE CONSTANTS FOR TYROSINASE ACTIVITY LOSS AT 20ºC AS AFFECTED BY $T_g$


Glassy

Rubbery

$T_g$

PVP-LMW

PVP-K30

T - $T_g$
LIPID OXIDATION

- Initiated by metal ions
- Measured by
  - Oxygen consumption
  - Peroxide values
  - Hexanal formation
- Complex kinetic modeling
OXYGEN UPTAKE IN CELLULOSE/LINOLEATE MODEL SYSTEMS AT 37°C

Labuza et al. 1971. JAOCS. 48:86.
RATE CONSTANT FOR OXYGEN UPTAKE BY LINOLEATE IN CELLULOSE MODEL SYSTEMS AT 37°C AS AFFECTED BY WATER ACTIVITY

Labuza et al. 1971. JAOCS. 48:86.
LIPID OXIDATION IN POTATO CHIPS AT 37°C


Water Activity

0 0.2 0.4 0.6 0.8
WATER AND LIPID OXIDATION

- Increase $a_w$ from 0 to 0.3
  - Less available metal ions due to hydration spheres
  - Reduced oxygen diffusion
  - Free radical quenching
- Rate decreases
WATER AND LIPID OXIDATION

- Increase $a_w$ from 0.3 to 0.8
  - Increased dissolution of catalysts
  - Increased mobility of oxygen and metal ions
- Rate increases
LIPID OXIDATION AND GLASS TRANSITION

• Glassy encapsulants decrease oxidation by reducing oxygen diffusion
• Conversion to a rubbery matrix can increase oxygen diffusion and thus oxidation
• Structural collapse can:
  – Reduce oxidation of entrapped lipid by eliminating pores
  – Enhance oxidation if lipid becomes exuded
• For additional information about water and lipid oxidation:
pH EFFECTS

• Reactions affected by pH
  – Aspartame degradation
  – Maillard reaction
    • non-enzymatic browning
    • amino acid destruction
  – Vitamin degradation

• The importance of pH is not limited to solutions
  – Reducing water activity/moisture content can result in a pH change
  – pH changes can affect food chemical stability
pH ESTIMATION OF REDUCED-MOISTURE SOLIDS USING A CHEMICAL MARKER

  – At $a_w$ 0.99, 0.1 M phosphate buffer in agar/MCC has a pH of 6.5
  – After lyophilization and equilibration to $a_w$ 0.34, system behaves as pH 5
    – Generally attributed to increased concentration of buffer salts and their selective precipitation

• Results supported by other methods of estimating reduced-moisture pH
ASPARTAME DEGRADATION IN 0.1 m PHOSPHATE BUFFER AT 25°C AS AFFECTED BY pH

ASPARTAME DEGRADATION IN 0.1 m PHOSPHATE BUFFER AT 25°C AS AFFECTED BY pH


- Control
- Added 2 m sucrose

Actual pH

0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
4.5 4.7 4.9 5.1 5.3 5.5 5.7 5.9

0
STABILITY TESTING

• System as close to commercial product as possible
  – formulation
  – processing
  – packaging
• Method of analysis
• Number of data points/extent of reaction
  – 8 points minimum
  – 50% change in reactant concentration
• Three temperatures
• Three water activities
• Extreme conditions may be used to accelerate testing
**SHELF LIFE TESTING EXAMPLE**

Given the following aspartame degradation data, estimate the shelf life at 20ºC and $a_W$ 0.15

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Rate Constant (d⁻¹)</th>
<th>$t_{10%}$ loss (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a_W$ 0.34, 30ºC</td>
<td>0.00548</td>
<td>19.2</td>
</tr>
<tr>
<td>$a_W$ 0.35, 37ºC</td>
<td>0.01538</td>
<td>6.9</td>
</tr>
<tr>
<td>$a_W$ 0.42, 45ºC</td>
<td>0.04828</td>
<td>2.2</td>
</tr>
<tr>
<td>$a_W$ 0.34, 30ºC</td>
<td>0.00548</td>
<td>19.2</td>
</tr>
<tr>
<td>$a_W$ 0.57, 30ºC</td>
<td>0.01574</td>
<td>6.7</td>
</tr>
<tr>
<td>$a_W$ 0.66, 30ºC</td>
<td>0.02224</td>
<td>4.7</td>
</tr>
</tbody>
</table>

SHELF LIFE PLOT FOR ASPARTAME DEGRADATION AT $a_w$ 0.34

Temperature (°C)

$Q_{10} = 4.25$
QA PLOT FOR ASPARTAME DEGRADATION AT 30°C

QA = 1.55

Water Activity
SHELF LIFE CALCULATION

• From kinetic data:
  - At $a_w$ 0.34 and 30°C, $t_{10\%} = 19.2$ days
  - $Q_{10} = 4.25$
  - $Q_A = 1.55$

• Want to know shelf life at $a_w$ 0.15 and 20°C

\[
\frac{T}{10} \times (Q_A)^{\Delta a/0.1} \times (t_{10\%, a_w 0.34, 30°C}) \times (Q_{10})^{\Delta T}
\]

- $\Delta T = \text{change in temperature from 30°C}$
- $\Delta a = \text{change in water activity from 0.34}$
- $(19.2) \times (4.25)^{10/10} \times (1.55)^{0.19/0.1} = 188$ days
PROBLEMS OF ACCELERATED SHELF LIFE TESTING AT EXTREME TEMPERATURES

• Water activity changes with temperature
• pH changes with temperature
• Solubility of reactants change
• Phase changes
  – Glass transition
  – Crystallization
• Competing chemical reactions
SIMULTANEOUS DEGRADATIVE REACTIONS WITHIN A FOOD

- Reaction 1
- Reaction 2

Crossover at 25°C

1000/Temperature (K⁻¹)
WATER & PHYSICAL STABILITY
PHYSICAL STABILITY

• Solutions
  – separation
  – crystallization
• Low and intermediate moisture systems
  – hardening or softening*
  – caking and sticking of powders*
  – crystallization*

*Influenced by conversion of a glassy matrix into a rubbery matrix
SENSORY CRISPNESS INTENSITY OF SALTINE CRACKERS AS A FUNCTION OF $a_W$


Water Activity

Very crisp
Moderately Crisp
Minimum acceptability
Slightly crisp

$a_{W,c}$
TEXTURAL ISSUES

• Staling (softening) of cereal products
  – Crispness, crunchiness lost if $a_W > 0.4$
  – Aim to keep $a_W < 0.4$

• Hardening of fruit pieces
  – Softness, chewiness lost if $a_W < 0.5-0.6$
  – Aim to keep $a_W > 0.5-0.6$

• Contradictory goals for a fruit-containing cereal product
CAKING AND STICKING OF POWDERS

• Powders in the glassy state become rubbery from:
  – Moisture sorption
  – Temperature abuse
• Rubbery powders flow together under the force of gravity
• Over long periods of time, the net result is formation of a caked mass
• Supporting literature
MOISTURE SORPTION ISOTHERM OF FREEZE-DRIED LACTOSE AT 34°C

EFFECT OF EXPOSURE TIME AT $a_w$ 0.3 AND 24°C ON MOISTURE CONTENT AND CRYSTALLINITY OF AMORPHOUS SUCROSE

EFFECTS OF CRYSTALLIZATION

• Amorphous ingredients may crystallize from:
  – Moisture gain
  – Temperature abuse
  – Storage (time)
• Crystalline materials hold less moisture so upon crystallization water is released.
• This water is redistributed in the food, causing:
  – Water activity to increase
  – Glass transition temperature of remaining amorphous regions to decrease
  – Further chemical and physical deterioration!
• Literature
EFFECTS OF CRYSTALLIZATION

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• Literature
USING MOISTURE SORPTION ISOTHERMS AND PHASE DIAGRAMS TO ESTIMATE CRITICAL WATER ACTIVITY VALUES
APPLICATION OF PHASE TRANSITION TO A MALTODEXTRIN POWDER

- Caking of powders occurs due to the conversion of glassy particles into rubbery particles which stick together.
APPLICATION OF PHASE TRANSITION TO A MALTODEXTRIN POWDER

• Caking of powders occurs due to the conversion of glassy particles into rubbery particles which stick together.

• From state diagram, moisture content for $T_g$ to be at room temperature (20-25°C) is 8% (wb).
GLASS TRANSITION STATE DIAGRAM FOR MALTODEXTRIN (DE 25)

APPLICATION OF PHASE TRANSITION TO A MALTODEXTRIN POWDER

- Caking of powders occurs due to the conversion of glassy particles into rubbery particles which stick together.
- From state diagram, moisture content for $T_g$ to be at room temperature (20-25°C) is 8% (wb).
- From moisture sorption isotherm, maltodextrin holds 8% water at $a_w$ 0.5.
MOISTURE SORPTION ISOTHERM FOR MALTODEXTRIN (DE 25) AT 25°C

APPLICATION OF PHASE TRANSITION TO A MALTODEXTRIN POWDER

- Caking of powders occurs due to the conversion of glassy particles into rubbery particles which stick together.
- From state diagram, moisture content for $T_g$ to be at room temperature (20-25°C) is 8% (wb).
- From moisture sorption isotherm, maltodextrin holds 8% water at $a_W$ 0.5.
- Moisture gain from an environment when $a_W > 0.5$ will promote caking of the maltodextrin.
SUGGESTIONS FOR CONTROLLING MOISTURE TRANSFER (GAIN OR LOSS)

• Understand moisture sorption isotherms
• Formulation approaches
  – Humectants
  – Anticaking agents (e.g. calcium silicate)
• Packaging approaches
  – Select to minimize water permeation
  – Resealable packaging
• Handling instructions
OVERVIEW: WATER AND STABILITY

• Chemical Stability
  – No universal physicochemical parameter describes the effects of water
  – Water activity and plasticization by water affects chemical stability differently depending upon:
    • Reaction type
    • Matrix

• Physical Stability
  – Water affects physical stability primarily by plasticizing glassy systems into rubbery systems
本文通过翔实的实验数据、图表、直观的电镜照片对食品化学上的反应速率、物理上的表观性状以及食品的货架保存时间和水活度的相关性做出了详细的论证，由本文数据可见：水活度的高低对食品的化学稳定性、物理稳定性和保存时间直接关联。

事实上水分活度\(aw\)能直接影响食品的“保质期、色泽、香味、风味和质感”。是食品安全，食品研究，设计，开发，品质控制非常重要的指标！

化学及生物化学反应（Chemical / Biochemical Reactivity）
水分活度除了能影响食品中的微生物繁殖，把食品变坏；还会影响化学及酶素的反应速度。对食品保质期、色泽、香味和组织结构均有影响。

- Non-enzymatic browning 食品褐变（非酶褐变）
- Lipid oxidation 脂肪氧化
- Degradation of vitamins 维生素破坏
- Enzymatic reactions 酶素的活力
- Protein denaturation 蛋白质变质
- Starch gelatinization / reno gradation 淀粉变质

物理特性（Physical Properties）
水分活度除了能预测化学及生物化学反应速度，水分活度也影响食品组织结构。高\(aw\)的食品结构通常比较湿润，多汁，鲜嫩及富有弹性。若把这些食品的\(aw\)降低，会产生不理想食品结构变化，例如坚硬，干燥无味。低\(aw\)的食品结构通常比较松脆，但当\(aw\)提高后，这些食品就变得潮湿乏味；水分活度\(aw\)还改变粉状及颗粒的流动性，产生结块现象等。

食品水分活度\(aw\)，温度、酸值（pH）等均影响微生物的生长；但水分活度对食品包装后的保质期有着至关重要的影响。水分活度（不是水分含量）是直接影响食品中细菌、霉菌及酵母菌等繁殖的重要指标。对食品安全非常重要。“传统测定食品中水分含量是食品的总水分含量，不能提供以上的重要数据”。

水活度对微生物生长影响的论证请参考本公司其他的技术文章！