Improvement of Shelf Life for Space Food through a Hurdle Approach

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Background

- The current space food system is comprised mostly of processed and prepackaged foods, all stored at room temperature.
  - Regular resupply (3 - 4 times per year)
  - Supplemented occasionally by fresh foods

- Current shelf-life is approximately 1-3 years with current stabilization techniques

Background (continued)

- Early long-duration exploratory missions will likely utilize the current prepackaged food system but require extended shelf-life (3-5 years), without replenishment.

- Currently available stabilization strategies do not preserve the acceptability or nutritive value of space foods for a five-year period.
  - Thermostabilized/Irradiated (<3 years)
  - Freeze dried (≤2 years)
  - Bite size –fruit (≤1 year)
  - Bite-size –other (≤2 years)
  - Extended shelf-life breads (≤2 years)

Hurdle Approach

- Hurdle approach is the combination of several preservative factors to improve the microbial stability, safety, quality and nutritive value of foods.

- Common hurdles in food include:
  - High temperature processing
  - Low temperature storage
  - High barrier packaging
  - Manipulation of pH and water activity
  - Preservatives
  - Controlled atmosphere packaging

Objectives

- Determine the ability of specific hurdle combinations to prevent loss of food quality and nutrition in representative space foods.
- Determine the impact of storage temperature (-80°C, -20°C, 4°C, 21°C) on quality, sensory, and/or nutrition of select space foods and condiments over 5 years.
- Determine the impact of different processes (retort, irradiation, MATS, vacuum packaging) in combination with storage temperature (-80°C, -20°C, 4°C, 21°C) on quality, sensory and nutrition of select space foods and the film barrier and seal integrity of current and proposed space food packaging materials.

Representative Foods

- 24 foods (whole and component) and 9 condiments will be examined in this study.
- Results from these foods will be used to extrapolate shelf-life for similar space foods.

Single Component Foods	Multi-Component Foods	Condiments
Green Beans (FD)	Vanilla Breakfast Drink (B)	Ketchup
Broccoli (FD)	Sweet & Savory Kale (FD)	Mayonnaise
Shrimp (FD)	Wheat Flat Bread (NF)	Mustard
Chicken Breast (T)	Apricot Cobbler (T)	Barbecue Sauce (Reconstituted)
Quinoa (T)	Tomato Basil Soup (T)	Strawberry Spread
Noodles (FD)		Chili Pepper Paste
Spinach (FD)		Soy Sauce
Potatoes (FD)		Olive Oil
Dried Apricots (NF)		Cheese Sauce
Macadamia Nuts (NF)		

	Formulation	Preparation	Packaging	Processing
Italian Vegetables (FD)	X			
Strawberries (FD)			X	
Rice and Chicken (FD)	X			
Turkey Tetrazzini (FD)		X		
Peaches (T)				X
Carrot Coins (T)				X
Indian Fish Curry (T)				X
Grilled Chicken (T)				X
Beef Steak (T)				X

Hurdles Examined

Formulation	Preparation	Packaging	Processing	Temperature Storage
Minimally processed ingredients Sodium content	Cook process prior to processing	Vacuum level Desiccant Material	Retort MATS Irradiation Freeze-drying	-80°C storage -20°C storage 4°C storage 21°C storage

Methods for shelf-life determination

- ***Sensory evaluation –*** JSC untrained panel (n ≥ 25)
  - Each sample will be rated on appearance, color, aroma, flavor, texture, and overall acceptability on a 9-point hedonic scale.
- ***Nutritional analysis*** – performed by a reference laboratory, using official methods of analysis of the AOAC International.
  - Vitamin analyses selection is based on previous nutritional analyses of the selected foods.
- ***Color and texture –*** Measured analytically using colorimeter and texture analyzer, respectively.
- ***Rehydration ratio*** – Calculated measure to determine degree of water retention after rehydration.

End of Shelf-life Determination

- End of shelf-life is determined as follows:
  - *Sensory* – Any items that decline below 6.0 on the 9.0-hedonic scale for overall acceptability OR any single attribute that declines below 4.0 on the 9.0 hedonic scale.
  - *Microbial Safety* – Initial microbiological requirements fail to be met for consumption or package failures compromise product safety.
  - *Nutrition* – Nutrient data will not be used as end of test decision but will inform shelf-life determination and the value of certain hurdles.

Project Status

SFSL PRODUCED FOODS					
	Timepoint - 1 (Shelf-life Start)	Timepoint - 2	Timepoint - 3	Timepoint - 4	Timepoint - 5
Wheat Flat Bread	■	■	■		
Dried Apricots	■	■	■		
Tomato Basil Soup	■	■	■		
Macadamia Nuts	■	■	■		
Vanilla Breakfast Drink	■	■	■		
Rice and Chicken	■	■	■		
Italian Vegetables	■	■	■		
Turkey Tetrazzini	■	■	■		
Strawberries	■	■	■		
Sweet and Savory Kale	■	■	■		
Apricot Cobbler	■	■	■		
Component - Chicken	■				
Component - Green Beans	■				
Component - Shrimp	■				
Component - Broccoli	■				
Component - Quinoa	■				
Component - Potatoes	■				
Component - Noodles	■				
Component - Spinach	■				

AMERIQUAL WET PACK FOODS					
	Timepoint - 1 (Shelf-life Start)	Timepoint - 2	Timepoint - 3	Timepoint - 4	Timepoint - 5
Peaches	■	■	■		
Carrot Coins	■				
Indian Fish Curry	■	■	■		
Beef Steak	■				
Grilled Chicken	■				
Note: All AmeriQual wet pack foods were also produced at the SFSL for comparison purposes.					

COMMERCIAL CONDIMENTS					
Strawberry Spread	■	■	■		
Mayonnaise	■	■	■		
Ketchup	■	■	■		
Olive Oil	■	■			
Chili Pepper Paste	■	■			
Mustard	■	■			
BBQ Sauce	■	■			
Soy Sauce	■	■			
Cheese Sauce	■				

COVID-19 has delayed evaluation of several items at the third timepoint (36 months).

Items discussed today have all reached the third timepoint (36-45 months).

Results – Sensory

Foods				
	Product Age (months)	21°C	4°C	-20°C
Wheat Flat Bread	46			
Dried Apricots	46	N/A		
Tomato Basil Soup	44			
Macadamia Nuts	43			
Vanilla Breakfast Drink	41			
Rice and Chicken (Standard ISS formula	45			
Rice and Chicken (High salt)	45			
Rice and Chicken (scavenger added)	45			
Italian Vegetables (Frozen Veg)	43			
Italian Vegetables (Fresh Veg)	43			
Turkey Tetrazzini (Prebake meat)	41			
Turkey Tetrazzini (Cook meat in sauce)	41	(T)		
Strawberries (High Vac)	43			
Strawberries (Low Vac)	43	(O)	(T)	(T)
Sweet and Savory Kale	40			(A)
Apricot Cobbler	44	(A/C)		
Tomato Basil Soup	44			
Peaches (Thermo)	40	(A/C/T)		
Peaches (MATS)	40	(O)		
Indian Fish Curry (Thermo)	36			
Indian Fish Curry (MATS)	36			

Commercial Condiments				
	Product Age (months)	21°C	4°C	-20°C
Strawberry Spread	38			
Mayonnaise	38			N/A
Ketchup	37			

Passing - Overall acceptability above 6.0; all attributes above 6.0
Passing with concerns - Overall acceptability above 6.0; at least one attribute below 6.0
Failing - Overall acceptability below 6.0; at least one attribute below 4.0; or microbial failure
N/A - Product excluded from sensory evaluation, due to extreme quality degradation
O- Overall acceptability
T- Texture
A- Aroma
C- Color

Results – Nutrition

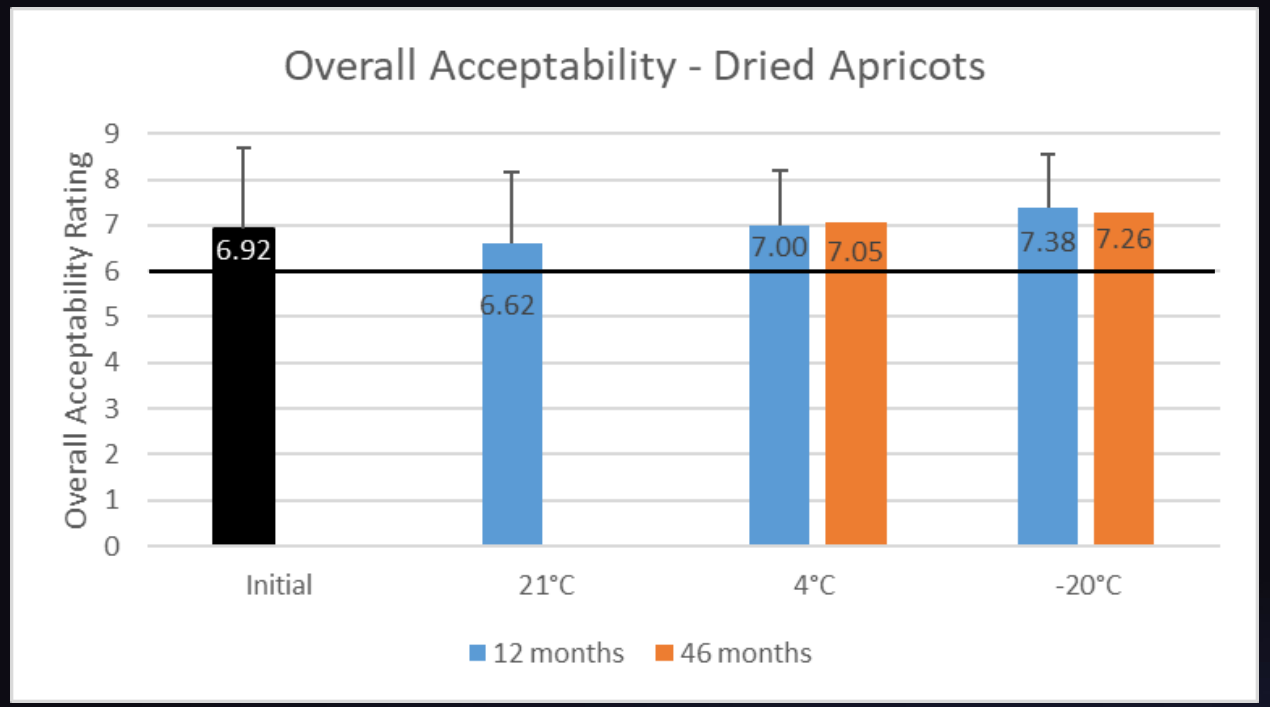
	Nutrients Tested	Nutrient status 12 months	Nutrient status ≥36 months
Wheat Flat Bread	B1,B2,B3, B9		
Dried Apricots	A, BC		
Tomato Basil Soup	A, E, BC, Ly		
Macadamia Nuts	B1		
Vanilla Breakfast Drink	B1, B6, B12, C, B9		
Rice and Chicken (Standard ISS formula	B1		
Rice and Chicken (High salt)	B1		
Rice and Chicken (scavenger added)	B1		
Italian Vegetables (Frozen Veg)	BC, A, C, K, B9		
Italian Vegetables (Fresh Veg)	BC, A, C, K, B9		
Turkey Tetrazzini (Prebake meat)	E, B3, B6		
Turkey Tetrazzini (Cook meat in sauce)	E, B3, B6		
Strawberries (High Vac)	C, B9, Ant		
Strawberries (Low Vac)	C, B9, Ant		
Sweet and Savory Kale	K, Leu		
Apricot Cobbler	A, BC, C, B1, B9		
Peaches (Thermo)	C		
Peaches (MATS)	C		
Indian Fish Curry (Thermo)	E		
Indian Fish Curry (MATS)	E		

All nutrients maintained at least 85% of initial value
1 or more nutrients degraded below 85% of initial value
Ant- Anthocyanin
A- Vitamin A
B1 - Thiamin
B2 - Riboflavin
B3 - Niacin
B6 -pyridoxine
B9 - Folic Acid
B12 -Vitamin B12
BC - Beta carotene
C - Vitamin C
E - Vitamin E
K- Vitamin K
Leu - Leutine
Ly - Lycopene

Nutritional stability is not used for shelf-life determination but will be used to determine the value of certain hurdles.

Results

Results – Dried Apricots



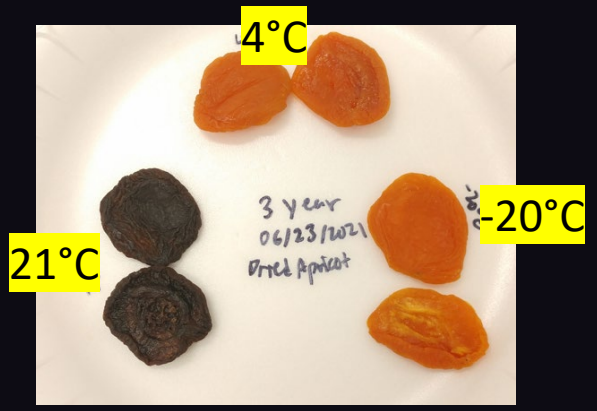


Image: Dried apricots after 46 months of storage.

Image: Crystallization was apparent in some 4°C samples

- All items maintained satisfactory ratings through 46 months of storage.
  - 21°C samples were excluded from sensory evaluation
  - Crystallization was apparent in 4°C samples
- Beta-carotene fell below 85% at all temperatures; extremely unstable at 21°C

Percentage of Nutrient Degradation

	B-Carotene
21°C	57%
4°C	23%
-20°C	18%

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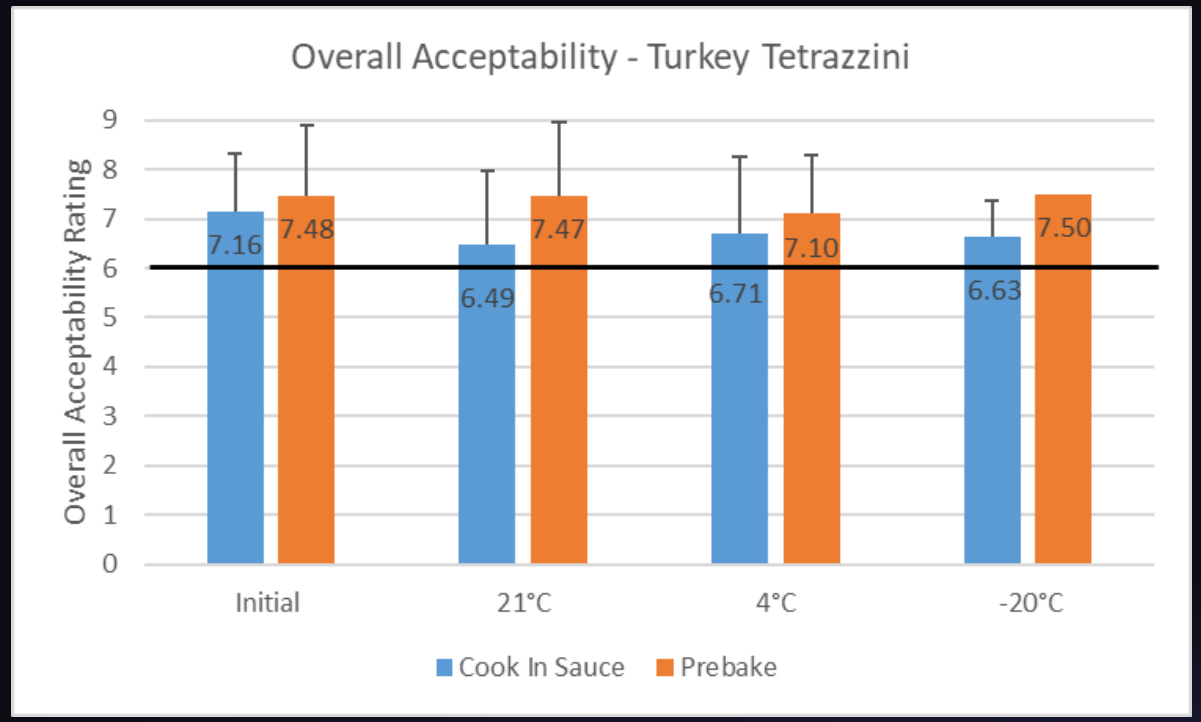
Turkey Tetrazzini



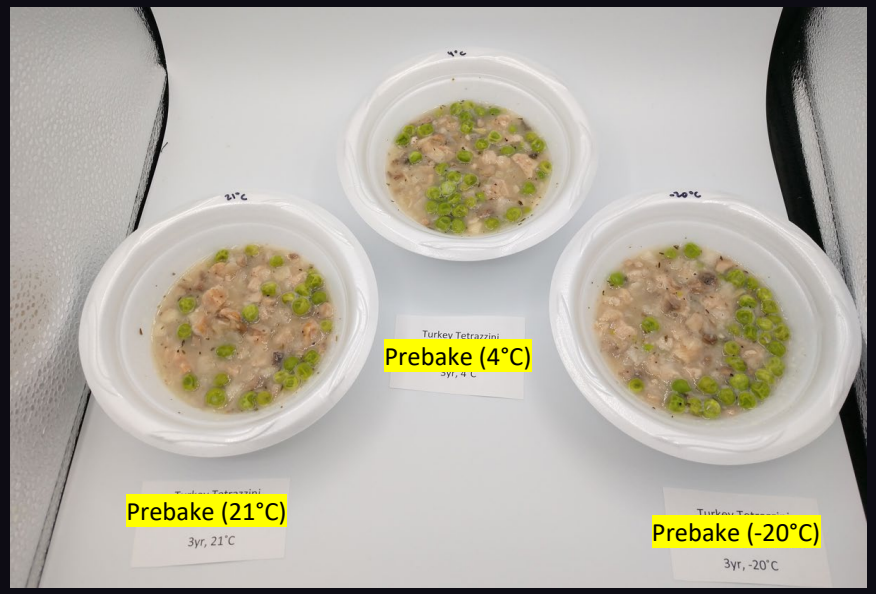


Image: Turkey tetrazzini (prebake) after 41 months of storage

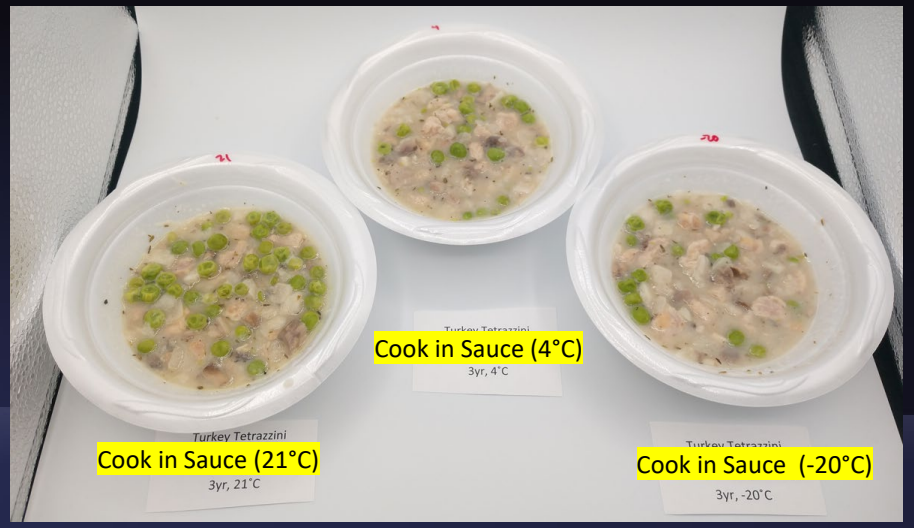
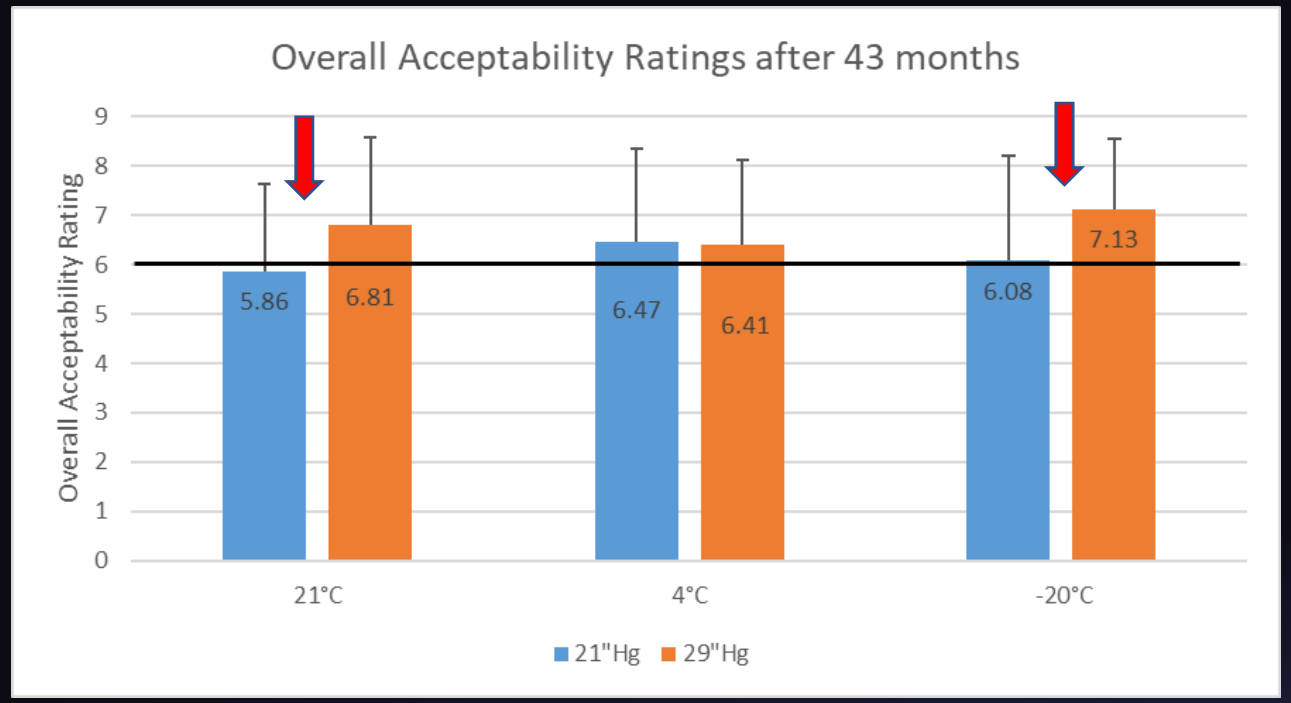


Image: Turkey tetrazzini (cook-in-sauce) after 41 months of storage

- Prebaked samples received notably higher acceptability ratings than samples that were cooked in sauce.
  - CIS turkey described as tough or “rubbery”
- Niacin and vitamin B6 remained stable at all temperatures.

Strawberries



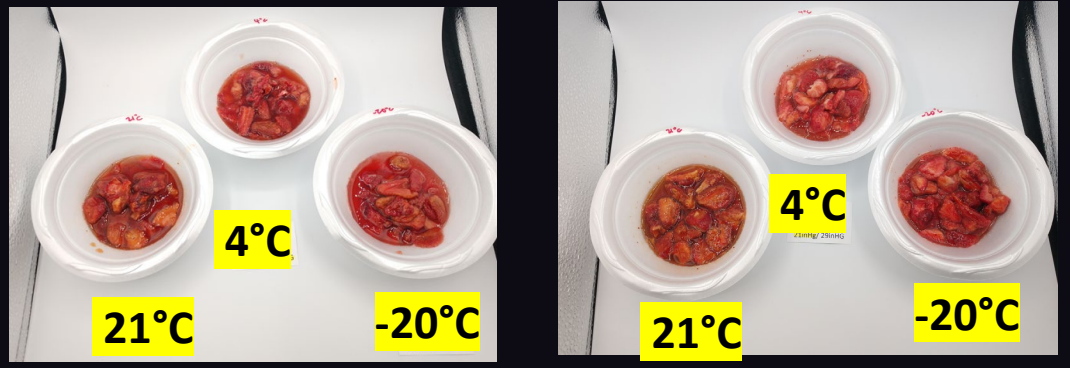


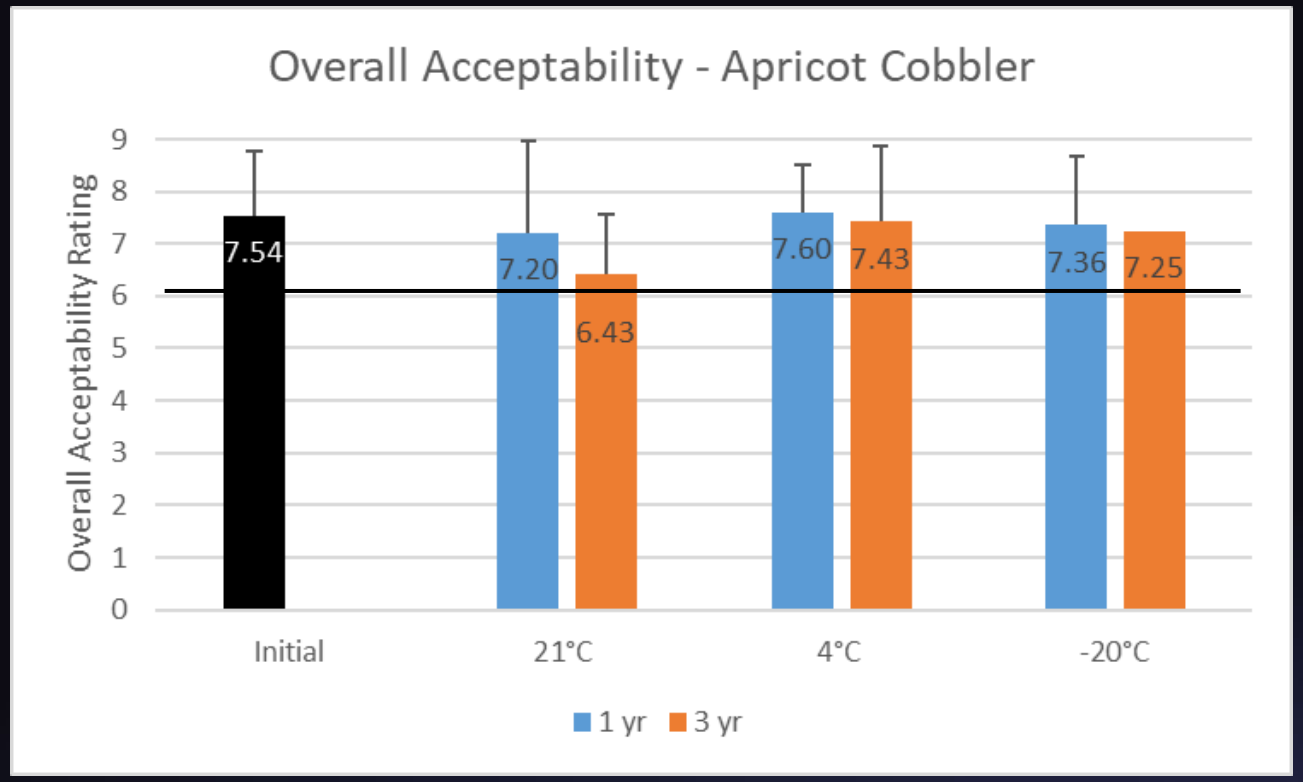
Image: Strawberries after 43 months of storage (29”Hg left; 21” Hg right)

Percentage of Nutrient Degradation

	Vitamin C		Folic Acid		Anthocyanins	
	21"-Hg	29"-Hg	21"-Hg	29"-Hg	21"-Hg	29"-Hg
21°C	64%	42%	49%	44%	71%	46%
4°C	42%	23%	45%	38%	48%	77%
-20°C	46%	39%	40%	17%	53%	77%

- High-vacuum samples stored at 21°C and -20°C scored ~ 1 point higher than low-vacuum samples.
  - Product texture is a problem for low-vac samples– “tacky, chewy, spongy”
  - *Note: High-vac samples required 12+ hours to rehydrate, requires refrigerated storage for safety*
- All nutrients fell below 85% of the original concentration after 43 months.
  - Anthocyanins extremely unstable.

Apricot Cobbler



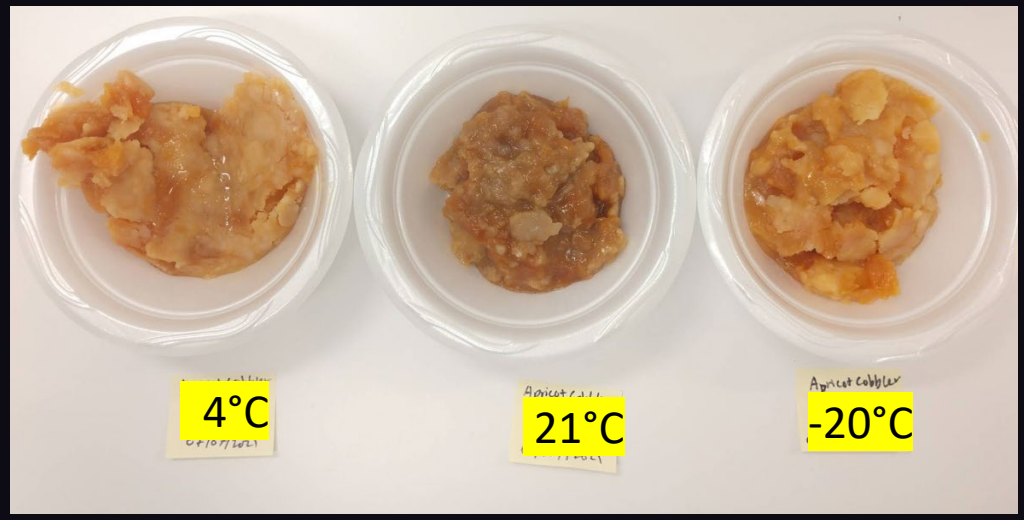


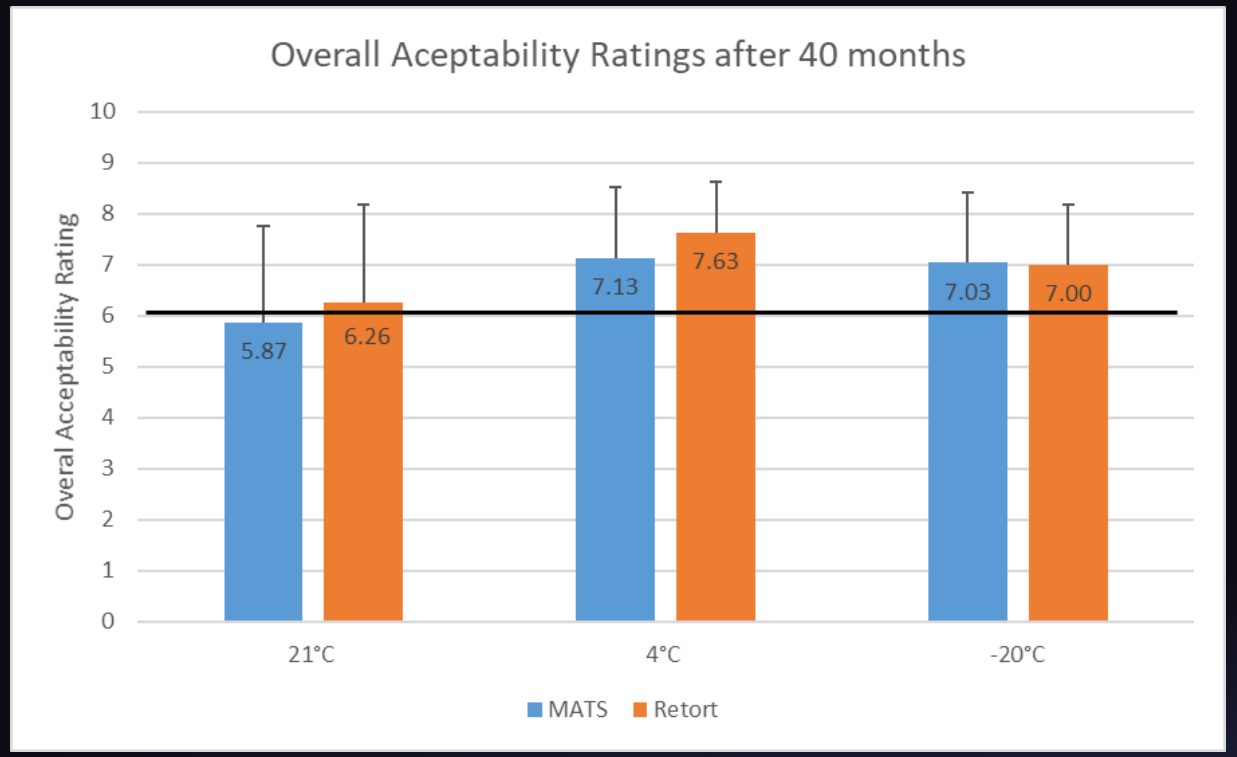
Image: Apricot Cobbler after 44 months of storage.

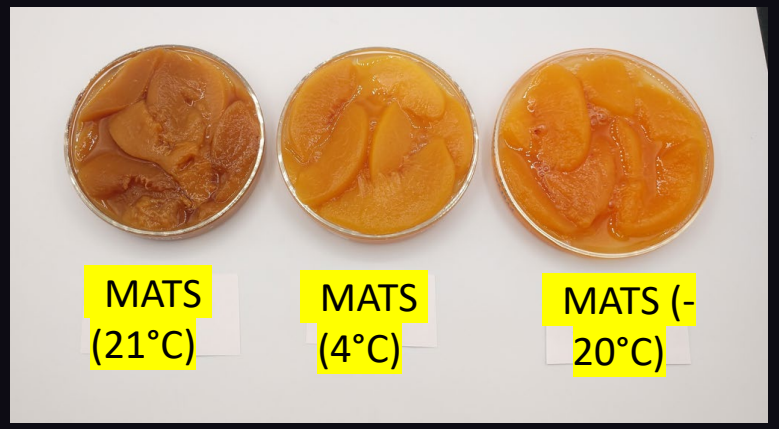
Percentage of Nutrient Degradation

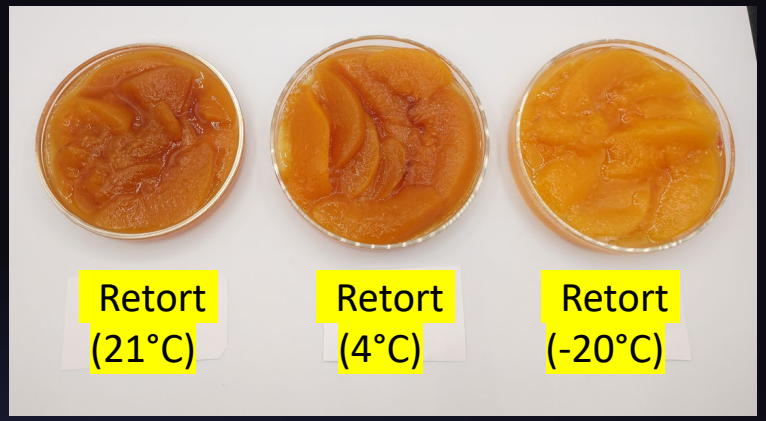
	B-Carotene	Vitamin C	Thiamin	Folic Acid
21°C	34%	82%	0%	100%
4°C	36%	16%	11%	100%
-20°C	36%	5%	0%	100%

- All items passed sensory evaluation, but ambient samples received notably lower scores than low-temperature samples.
- Vitamin C is extremely unstable at 21°C. Vitamin C is relatively stable at -20°C.
- All samples maintained 85% of the original thiamin concentration.
- Folic Acid degraded to undetectable levels after 44 months of storage.

Peaches





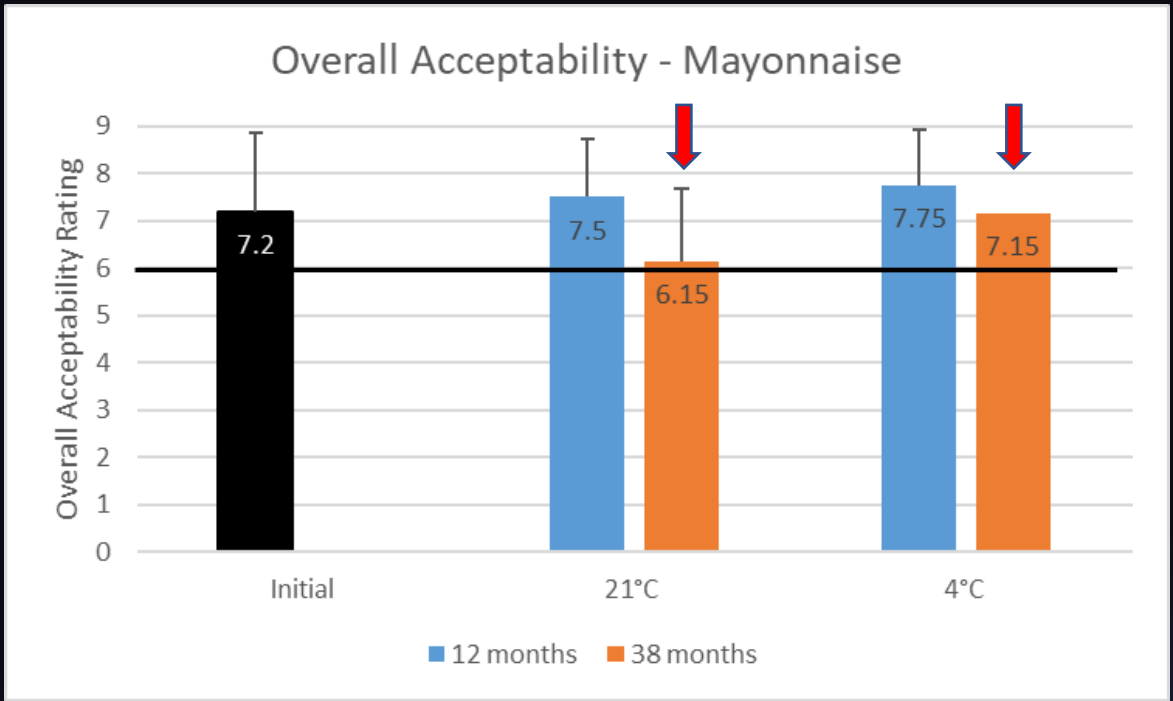


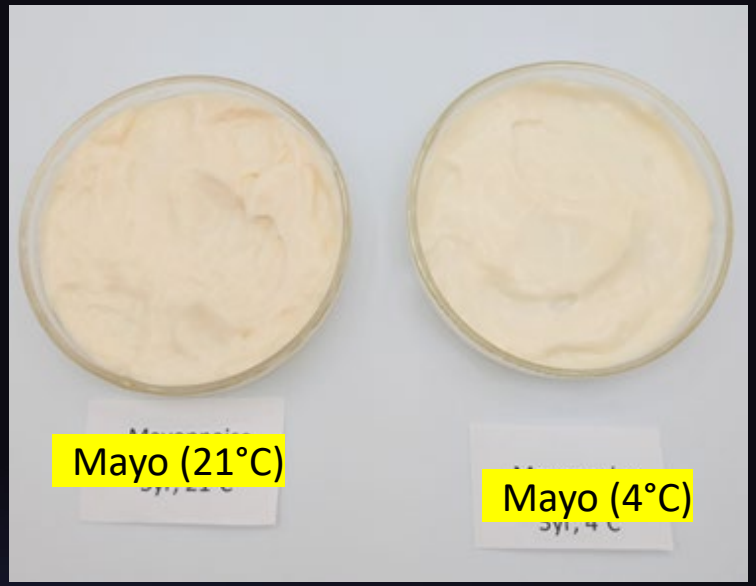
- Items stored at 21°C had notably lower acceptability ratings than samples stored at 4°C and -20°C.
- MATS peaches were unacceptable.
  - Darkening in ambient samples
  - Freezing had deleterious effects on product texture
- Vitamin C is unstable at 21°C, regardless of processing method.

Percentage of Nutrient Degradation

	Vitamin C	
	MATS	**Retort**
21°C	52%	61%
4°C	0%	5%
-20°C	0%	13%

Condiments – Mayonnaise





- Both items maintained satisfactory ratings through 38 months. However, 4°C samples were rated one point higher than 21°C samples.
  - Ambient samples developed off-flavor and odor, described as “rancid” or “acidic” by some panelists

Note - Frozen samples (-20°C) previously excluded from sensory testing due to quality loss.

Discussion

- Most products maintain acceptability despite ≥ 1-year delays in shelf-life evaluation.

- Some foods will benefit from low temperature storage to improve quality and nutritional value.
  - Fruits require refrigeration or freezer temperatures
  - Fruits require blast freezing; no temperature deviations while frozen

- Processing method may improve product quality but does not have an apparent impact on nutritional stability*
  - Pending multivariate statistical analysis

Next Steps

- Shelf-life evaluation continues
  - Many items delayed ≥1 year for second and third timepoint.
  - Schedule deviation may impact ability to accurately determine end-of-shelf-life

- Packaging evaluation of MATS and retort items continues

Questions?