Making Milk with Forage:

Preserving the Quality of Silage Through Improved Aerobic Stability

Limin Kung, Jr.

Dairy Nutrition & Silage Fermentation Lab

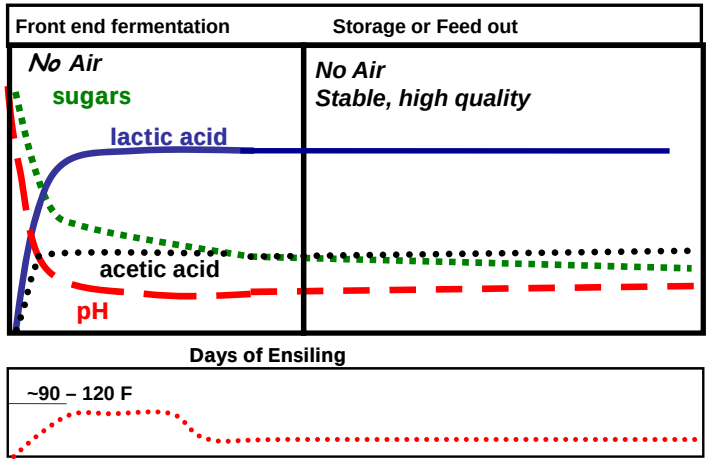
Dairy Research, Teaching, and Extension

UNIVERSITY OF DELAWARE

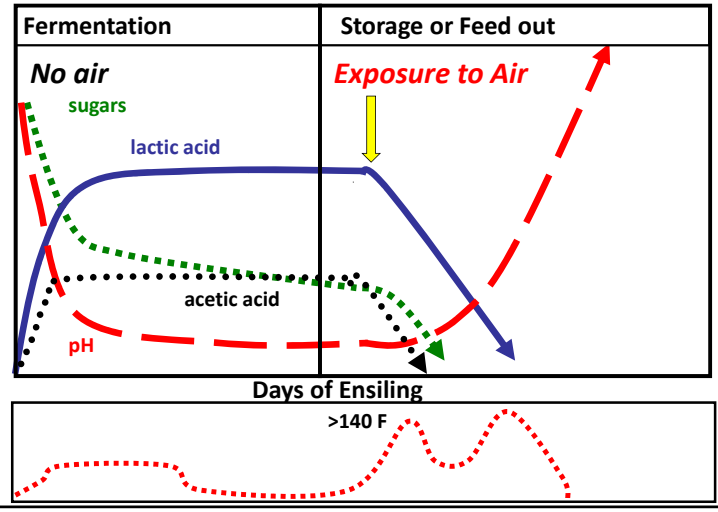
Factors Affecting the Quality Silage

- Maturity at harvest
- Type of fermentation
- Aerobic stability during storage and feed out

Ideal Fermentation and Good Storage Conditions



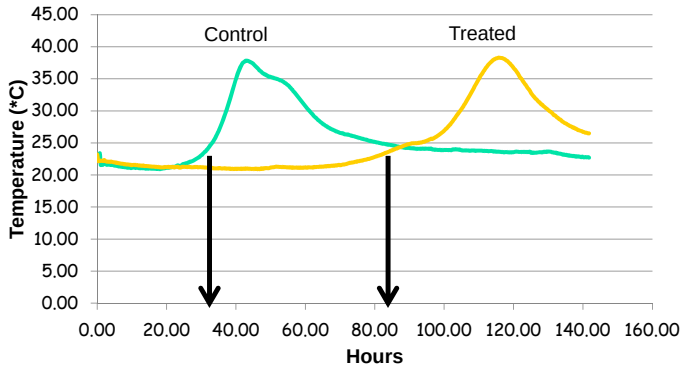
Example of an Ideal Fermentation – but Poor Aerobic Stability



What is Aerobic Stability?

- Definition of aerobic stability: *The amount of time a silage remains stable (and does not spoil) after it is exposed to air under defined conditions.*
- *The longer a silage stays stable after exposure to air, the better*

Example of Measuring Aerobic Stability in Corn Silage



What Causes Aerobic Spoilage? Air and Bad Yeasts!

- ➡ Silage is exposed to air
  - ➡ Yeasts 'wake up' and degrade lactic acid
    - ➡ Numbers of yeasts increase
      - ➡ Highly degradable nutrients are destroyed
        - ➡ Heat is produced
          - ➡ pH increases
            - ➡ Molds/bacteria 'wake up' causing further spoilage
              - ➡ More heating
                - ➡ Massive spoilage

But I pack my silo well…I don't need worry … right?

- **Air penetrates into the face of a well packed silo as much as 3 ft!**
- This means…
  - If you remove 6 inches a day…silage you see has been exposed to air for 6 days
  - If you remove 12 inches a day…silage you see has been exposed to air for 3 days

Molds are NOT responsible initiating aerobic spoilage!!!!

Kung, 2004

All Types of Yeasts in Silages are Undesirable

Fermenters –
- Glucose -> ethanol + CO_2
- *Saccharomyces sp.*
- Large DM losses

Lactate Utilizers –

Lactic acid -> CO_2 + H_2O
- *Candida sp.*
- *Hansenula sp.*
- *Pichia sp.*
- Aerobically spoils silages – low intakes, low nutritive value

Lactate Utilizing Yeasts Primarily Initiate Aerobic Spoilage

- Most common initiating spoilage microbe: Lactating utilizing yeasts –

  Lactic acid -> carbon dioxide and water

- Spoilage microbe sometimes found in corn silages: Acetobacteria –

  Lactic acid -> acetic acid -> carbon dioxide and water

Why Should We Care About the Aerobic Stability of Silages?

- Silage can undergo a perfect fermentation but…if followed by exposure to air, can result in poor quality feed

- Aerobic spoilage may account for more than 50% of total DM losses in a silo

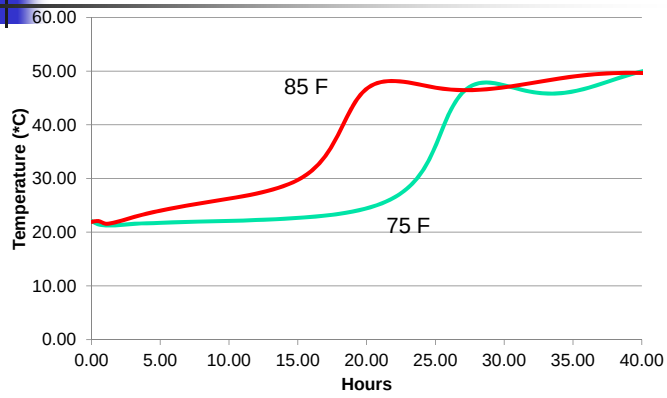
Why Should We Care About the Aerobic Stability of Silages?

- Spoilage can occur during storage and feedout
- Spoiled silage can result in
  - Production of undesirable end products
  - Depress nutrient intake and production
  - Reduce farm income

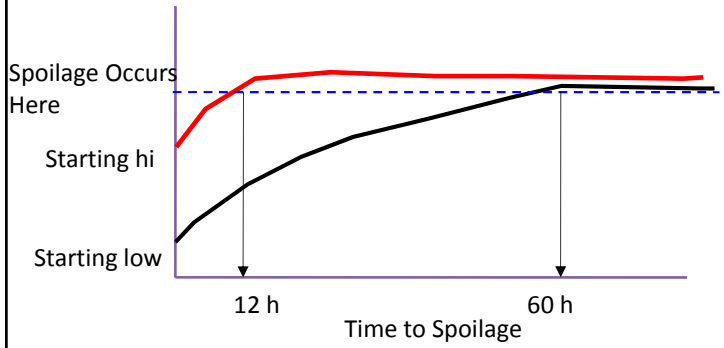
What are the Main Factors Affecting Aerobic Stability

- Air - Porosity (density) of the silage
- Numbers of lactate utilizing yeasts
- Ambient temperature

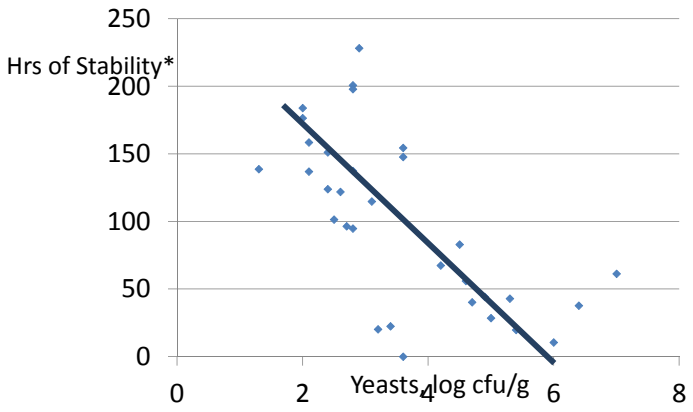
Ambient Temperature Affects Rate of Spoilage of a TMR



How do initial populations of yeasts affect time to spoilage?

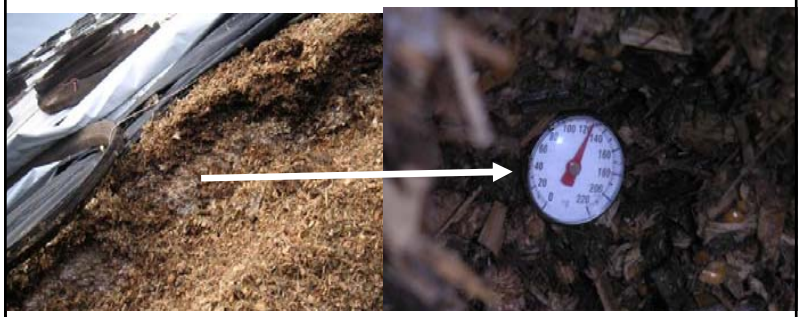


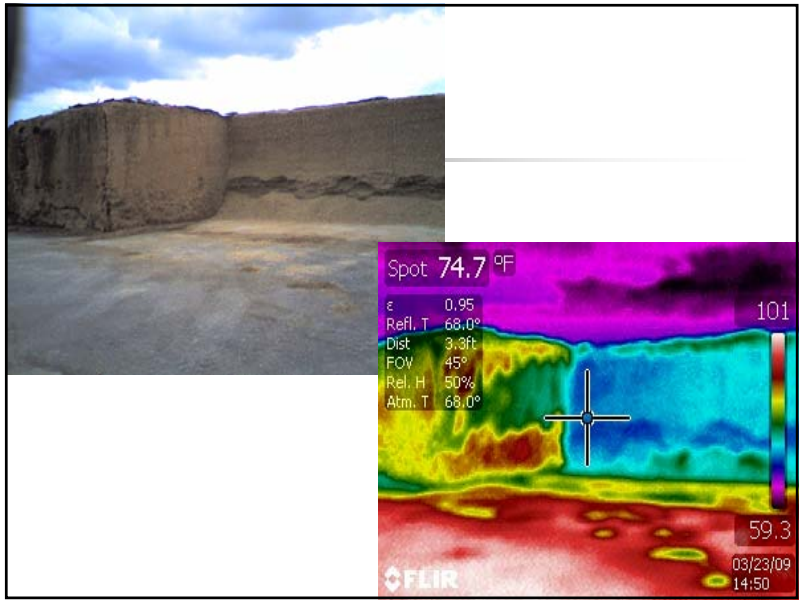
Relationship Between Numbers of Yeasts in Corn Silage and Aerobic Stability



•Number of hours before the silage mass increases 2C above baseline after exposure to air

Aerobically Spoiling Silage Often Reaches Temps above 130-140 F….





Aerobically Spoiling Silage

Aerobically Spoiled Silage Stored for Months

Feeding Aerobically Spoiled Silages Depresses Intakes and Reduces Digestion in Steers

	-Spoiled Silage, % of DM-			
Item	0	5.4	10.7	16
DMI, kg/d	17.6	16.3	15.4	14.7
NDF dig., %	63.2	56.0	52.5	52.3

Whitlock and Bolsen, 2001 KSU

Effect of Feeding a Spoiling TMR to Heifers

- Control vs Spoiling TMR fed to heifers
- Fed during the winter
- Spoiling TMR ranged from 35 to 54°C at feeding

2013 Windle and Kung

Nutrient Analysis of TMR

Item	Fresh TMR	Spoiling TMR	*P*-Value
DM, %	48.89	49.37	0.59
CP, %	10.57	11.19	0.27
Soluble protein, % CP	42.49	38.80	0.11
ADF, %	24.87	24.03	0.23
NDF, %	41.27	40.66	0.54
In vitro 30 h NDF-D, % NDF	63.65	61.46	0.49
Starch, %	26.58	28.22	0.26
Starch-D, % Starch	80.01	78.69	0.20

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Fermentation Analysis and Numbers of Yeasts in TMRs Fed to Heifers

Item	Fresh TMR	Spoiling TMR	*P*-Value
pH	4.16	5.17	<0.01
WSC, %	2.46	1.85	<0.01
Lactic acid, %	4.17	2.59	<0.01
Acetic acid, %	0.97	0.64	<0.01
Ethanol, %	5.82	6.07	<0.01
Yeasts, $\log_{10}$ cfu/g	5.03	7.82	<0.01

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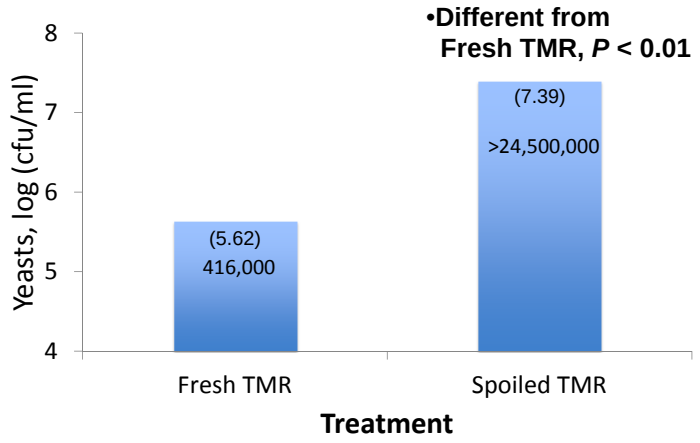
107,151 yeasts/g **66,069,345 yeasts/g**

Numbers of Yeasts in Rumen Fluid



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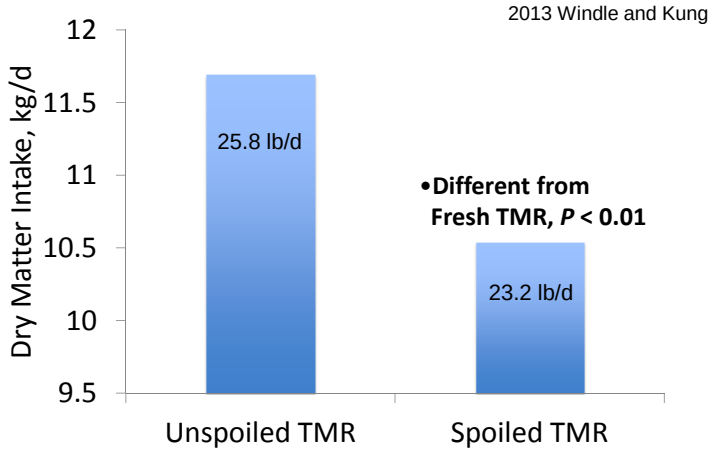
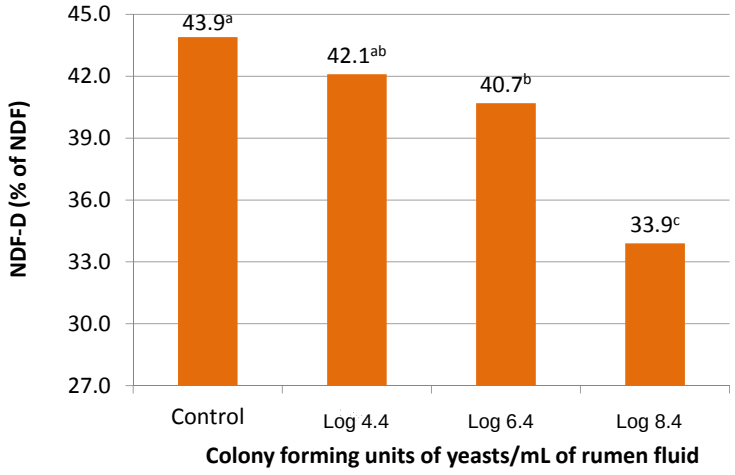
Dry Matter Intake of Heifers Fed Fresh vs. Aerobically Spoiling TMR



In Vitro 12-hr Digestibility of NDF (% of NDF) from a TMR Incubated with a Spoilage Yeast



Santos et al., 2011

What Do We Really Know About These Wild Yeasts in Silages?

- When yeasts are high –> low intakes, low fat tests, etc.
- High numbers of yeasts are a "marker"
- Actual reasons for observed animal effects unknown
- Could be:
  - Taste?
  - Smell?
  - Toxins?
  - Competition with rumen bugs?
  - Immunological effect?

How Do We Minimize Air and Spoilage Yeasts in Silages?

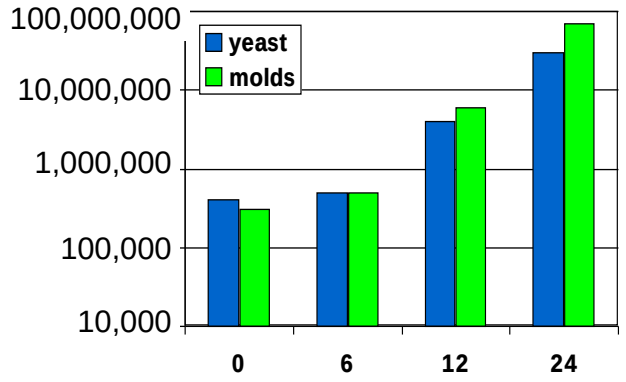
- Pack quickly
- Pack tightly
- Seal quickly
- Plastic and weights

Minimizing Air is Silos –

- Porosity, (not DM density) controls air in the silo
- Porosity should be < 40%
- To achieve this bulk density should be not < than 44 lb as fed/ cu ft.

- For 30% DM forage = 13.2 lb DM/cu ft
- For 40% DM forage = 17.6 lb DM/cu ft

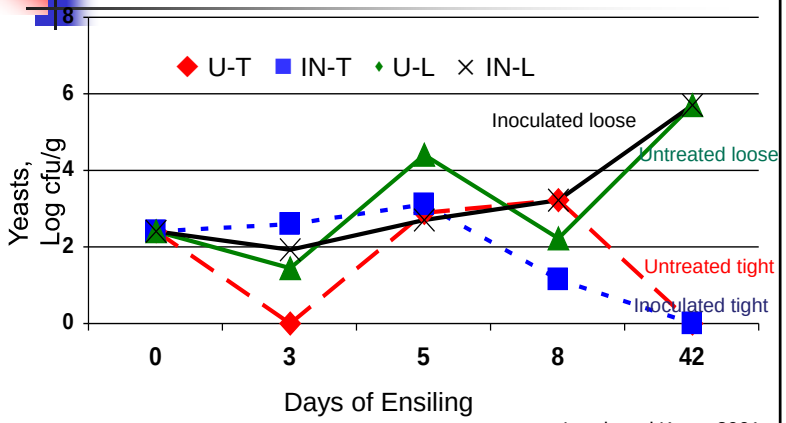
Delayed Filling Increases Yeasts and Molds on Corn Forage



Hirsch and Kung, 1999

Effect of Packing Density on Yeasts in Lucerne Silage (with homolactic inoculant)

Loose pack = 9.4 lb DM cubic ft
Tight pack = 14.3 lb DM cubic ft



Lynch and Kung, 2001

Oxygen Barrier Plastic Can Reduce Aerobic Losses During Storage

	Single Layer PE	Double Layer PE	OB Film
DM loss,%	14.4	12.5	7.4
Surface mold growth, in	6	3.7	0.0

Single layer = 4.92 mil plastic
Double layer = 4.92 mil plastic (9.84 mil)
OB film = Single layer 1.77 mil oxygen barrier plastic

Wilkinson and Rimini (2002)

Manage the Feeding Face to Minimize Aerobic Spoilahe

-Remove sufficient silage each day to prevent spoilage ~ 12 in/d
-More in hot weather and for drier and poorly packed silages
-Keep face clean, minimize face damage
-Knock down only enough silage to feed

Keep Air From Penetrating into the Silage Mass

Additives to Control Yeasts in Silages

- A low pH and lactic acid alone will not control yeasts in silages….

Mechanisms of Improving the Aerobic Stability of Silages with Additives

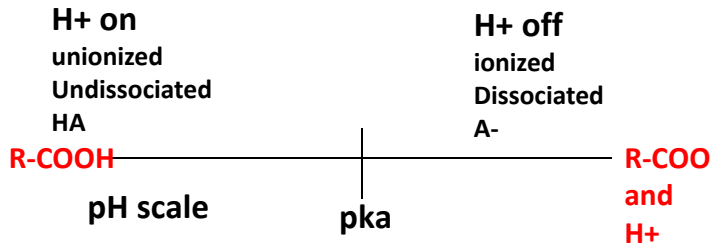
- Direct addition of production of (by added microbes) of organic acids with antifungal activity
- Production of other antifungal compounds (by added microbes)
  - e.g., cyclic dipeptides

Improving Aerobic Stability – Antifungal Mode of Action of Organic Acids

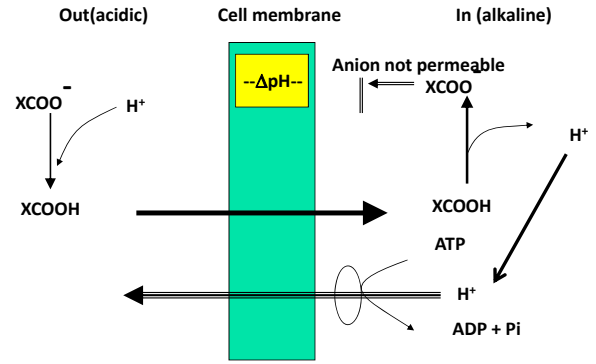
- Buffered propionic acid, potassium sorbate, sodium benzoate, etc.: 0.05 - 0.20 %
- Some synergistic effects of combinations
- More effective at low pH because of the undissociated form is more toxic
  - Lowering of internal cell pH
  - Possible direct effects on fermentation pathways
  - Decrease supply of ATP
  - Alter transport across cell membranes

pH Affects the Activity of Antifungal Acids

pka = pH of acid at half dissociation [A-]=[HA]



Effect of pH Gradient on Accumulation of Dissociated Organic Acid Anions (XCOO-)



When Are Weak Organic Acids Most and Least Effective?

When the pH is one unit less than the pKa, then about 90% is in the effective form.

When the pH is 1 unit greater than the pKa, only about 10% is in the effective form.

Relationship Between pH and Form of Acids

		% undissociated acid at pH			
Preservative	**pKa**	**2.5**	**3.5**	**4.5**	**5.0**
Acetic acid	**4.74**	**99**	**95**	**63**	**33**
Lactic acid	**2.74**	**64**	**15**	**1.7**	**0.5**
Benzoic acid	**4.19**	**98**	**83**	**33**	**13**
Prop acid	**4.87**	**100**	**96**	**70**	**43**
Sorbic acid	**4.76**	**99**	**95**	**65**	**37**

Issues with Adding Chemical Additives to Improve Aerobic Stability of Silages

- Relatively high costs
- Requires significantly more water for application (usually 1 to 2 liters/ton or more of wet forage) than microbial inoculants (as low as 40 ml/ton with low volume applicators

Improving the Aerobic Stability of Silages with Additives

- Microbial inoculants
  - Homolactic acid inoculants (alone) can often make aerobic stability worse

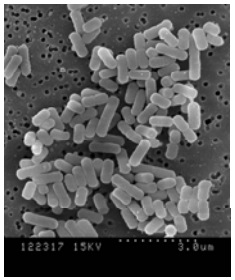
Aerobic Stability of Orchardgrass Silage

Treatment	Yr 1	Yr 2
Untreated	178[b]	198[b]
H-inoculant A	46[c]	176[b]
H-inoculant B	44[c]	203[b]
H-inoculant C	42[c]	not tested

  - Because organic acid production is shifted primarily to lactic acid

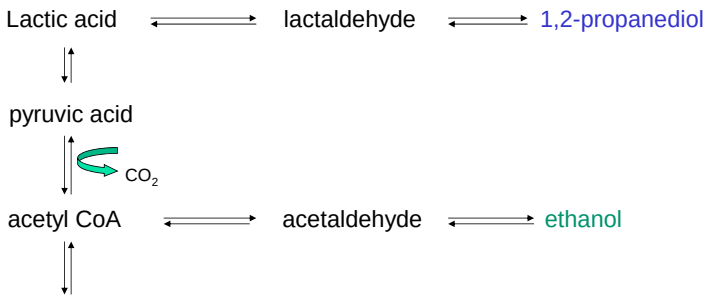
Improving Aerobic Stability with *Lactobacillus buchneri*

- Naturally occurring bacterium that converts small amounts of lactic acid to acetic acid
- Acetic acid is highly antifungal – decreases numbers of yeasts
- Identified by Muck and Spoelstra



Pathway of Lactic Acid Degradation by *L. buchneri*

(Oude Elferink et al., 2001)



production can be equivalent to 7 - 12 lb of acetic per ton of wet 35% DM silage

L. buchneri 40788 Field Study on Farms in the Midwest USA

- Corn silage samples
- Collected from dairy farms
- 15 farms using no inoculant
- 16 farms using an inoculant containing either *L. buchneri* (LB) 40788 alone or LB and *P. pentosaceus* (LBC)

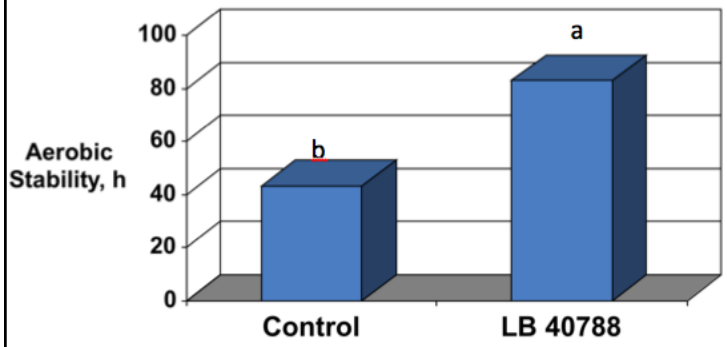
Spoilage Yeasts in Corn Silages Untreated or Treated with *L. buchneri 40788* From Dairy Farms in the US

Item	Untreated	LB-40788
Spoilage yeasts, # per g of silage	320,000[a]	43,000[b]

[a,b]$P < 0.05$

Mari et al., 2009

Aerobic Stability of Maize Silages Untreated or Treated with *L. buchneri 40788* From Dairy Farms in the US



[a,b]$P < 0.05$

Mari et al., 2009

Effects of *L. buchneri* + *P. pentosaceus* on the Aerobic Stability of Maize Silage – 5 Replicated Studies from Different Locations

Treatment	Aerobic Stability, h
Control	44
L. buchneri 40788	267
L. buchneri 40788 + *P. pentosaceus*	255

Schmidt et al., 2006

Some (+) & (-) of Organic Acids (OA) and *L. buchneri (LB)*

- (-) OA - must be undissociated to be active - less active when pH is high
- (+) OA - more stable product during storage and application
- (+) OA - No reliance on an organism having to compete in silage and produce antifungal compounds
- (-) LB - must be alive, survive fermentation and produce adequate amts of acetic acid…
- (+) LB – lower cost and volume applied than OA

Silages That Are Most Prone to Aerobic Spoilage that may Benefit from Silage Additives

- High moisture maize
- Maize and barley silage
- Silages with high DM (>40%DM)
- Silage fed during warm weather (summer, etc.)
- Silages fed out slowly
- Silage that will be moved between silos
- Silage fed from intermediate feeding piles

L. Kung, Univ. of Delaware

Summary

- In order to maintain forage quality, silages should ferment well and be aerobically stable
- Yeasts that metabolize lactic acid under aerobic conditions are the primary initiators of spoilage
- Basic silo management and various additives have the potential to minimize aerobic spoilage of silages

THANK YOU!!!!

Email: LKSILAGE@UDEL.EDU