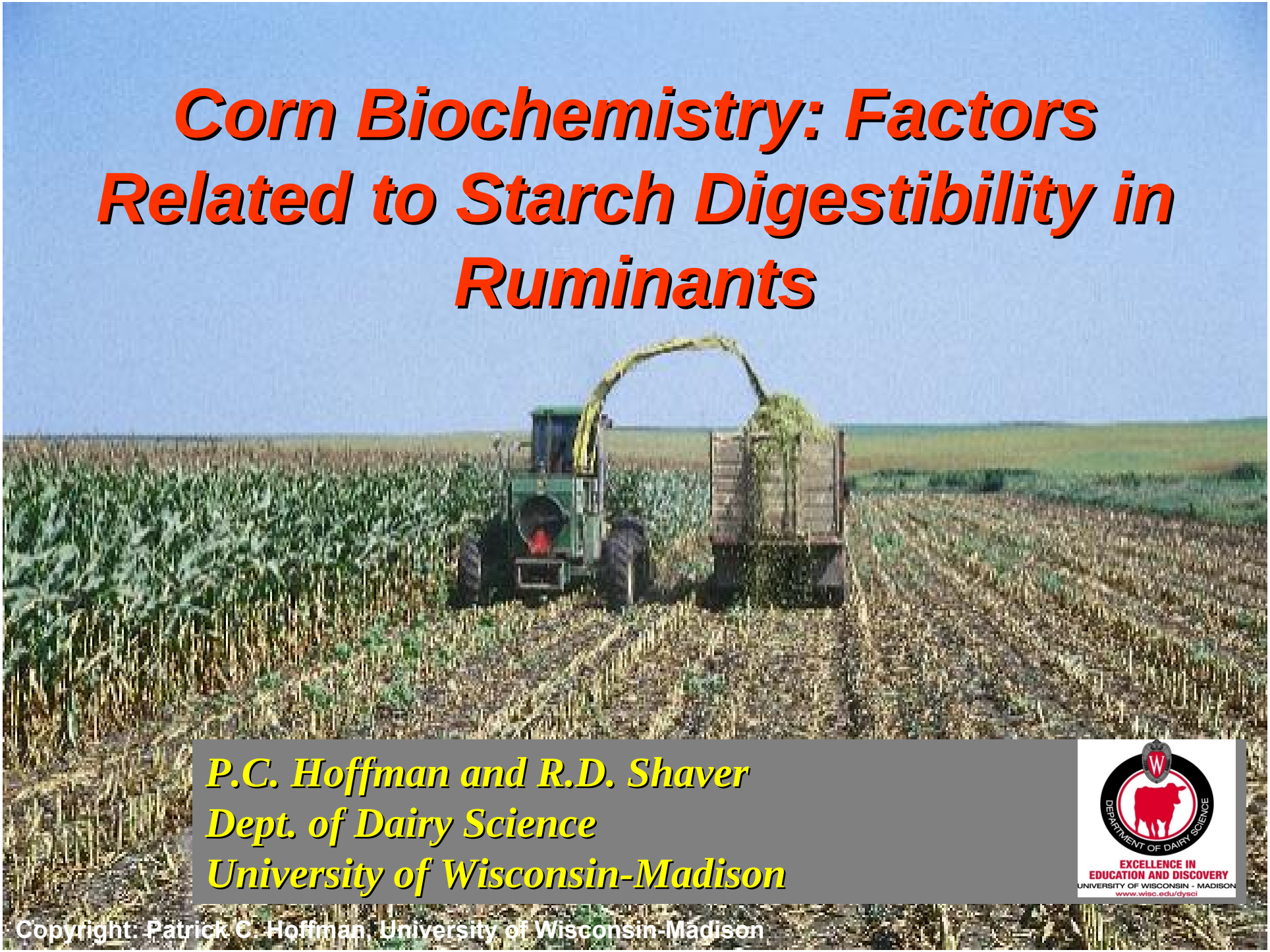
# Corn Biochemistry: Factors Related to Starch Digestibility in Ruminants



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*Dept. of Dairy Science*
*University of Wisconsin-Madison*

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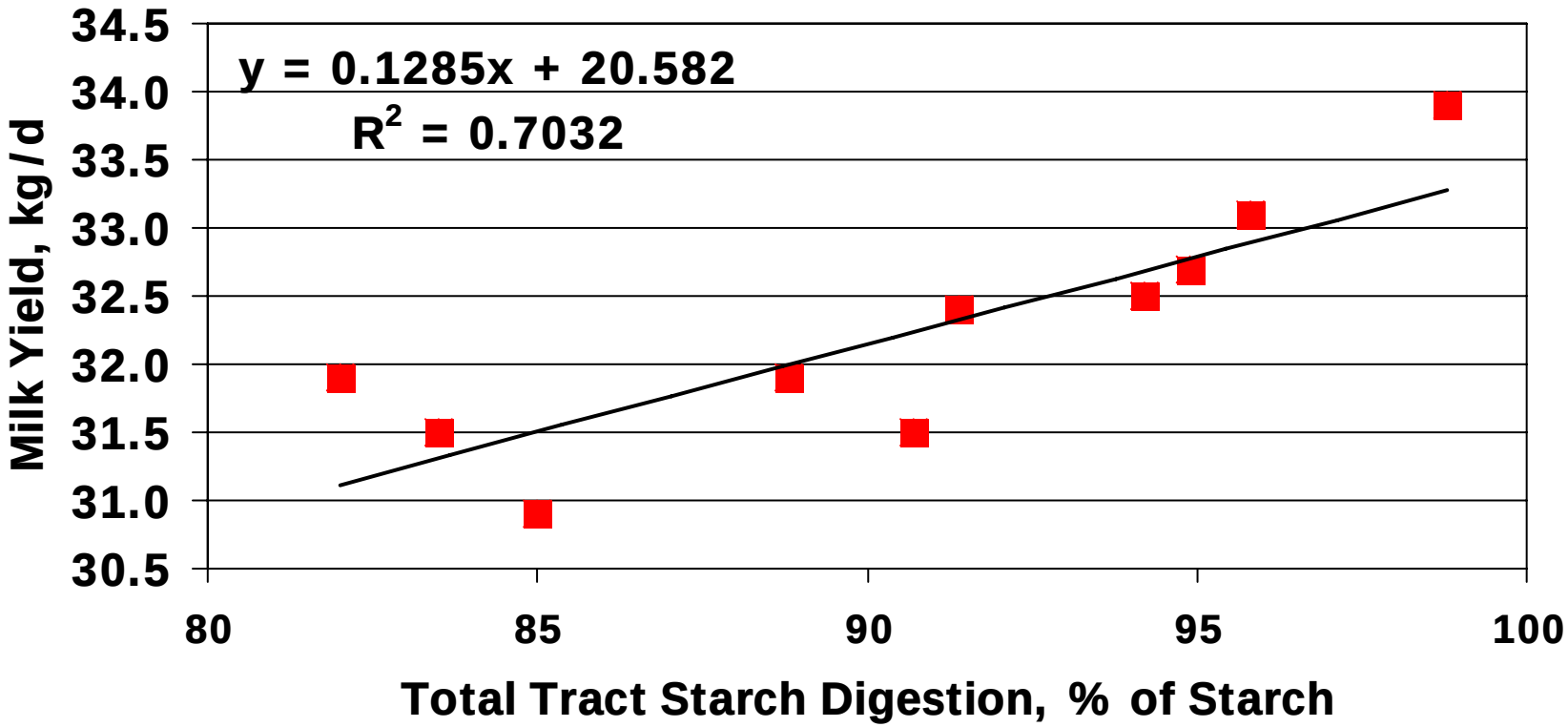
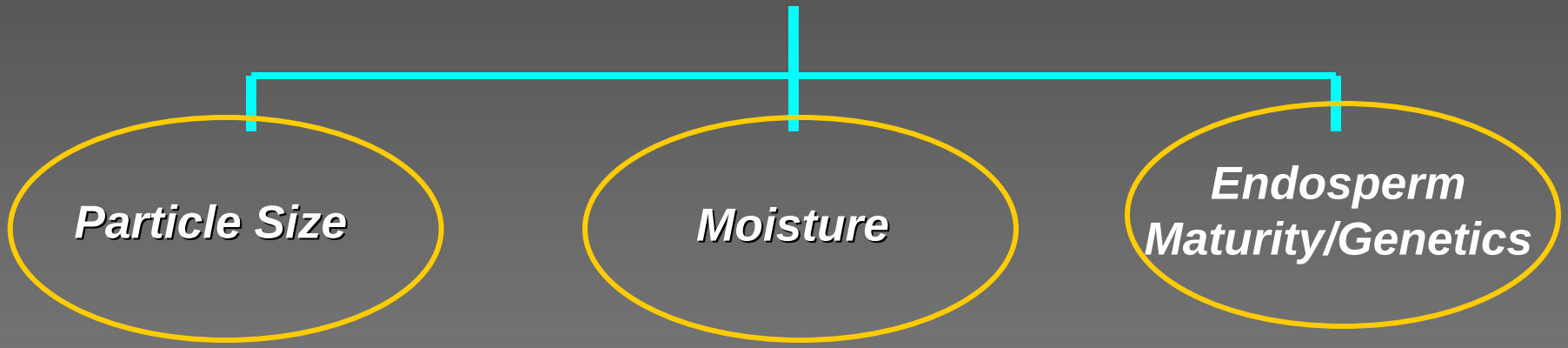
# Effect of Starch Digestibility on Milk Yield, **Firkins et al., 2001**



# Starch Digestibility

## Principal Components of Starch Digestion




**Easy to Measure in Grain Challenging to Measure in Corn Silage**

**Routinely Measured Marker of Maturity**

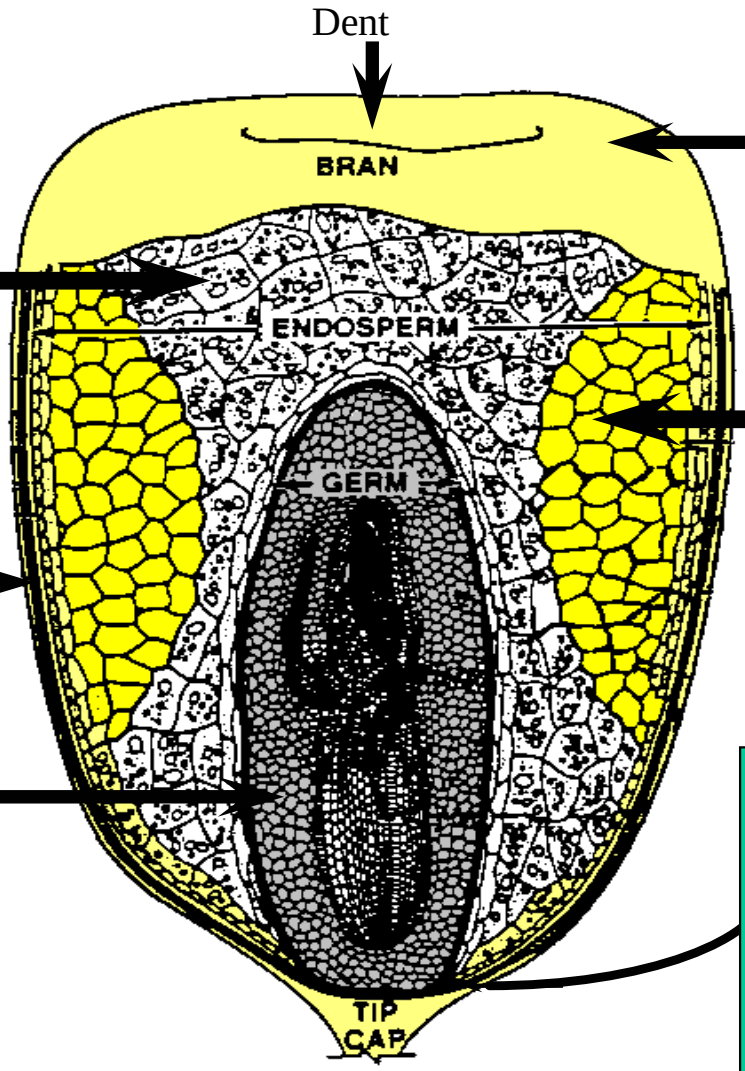
**?**

# •Trick Questions

- **Chemically-What makes forage indigestible?**
- ***NDF, ADF, Lignin, Cellulose***

- **Chemically-What makes corn starch indigestible?**

## *Basic Corn Morphology*



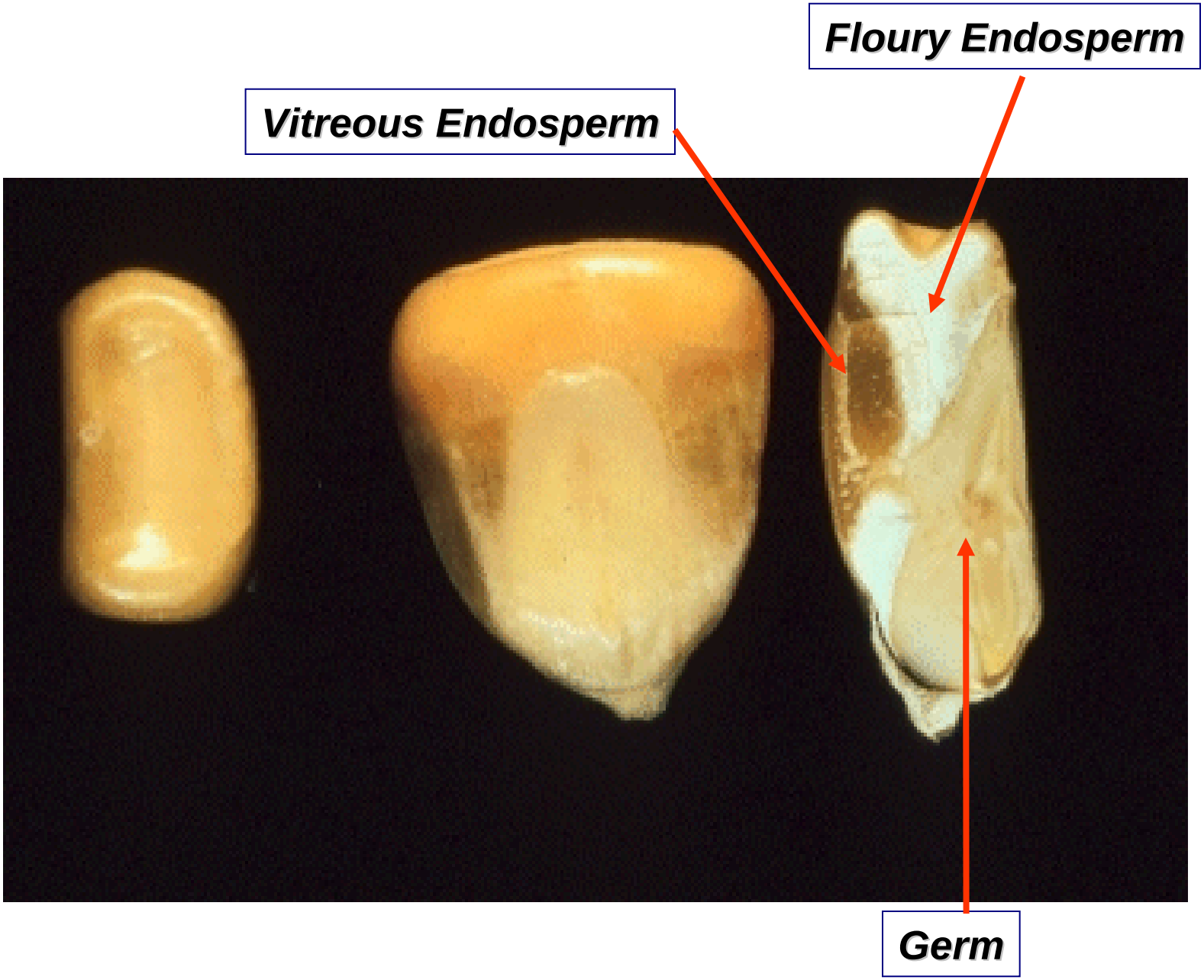

Floury endosperm. More "open" in structure. Dent corn has about equal proportions of vitreous to floury starch (compared to popcorn w/ mostly vitreous starch.

Pericarp(bran)

Germ scutellum and embryonic axis. Germ will be bigger in high oil corn at the expense of starch. Each 1% increase in oil, expect 1.3% decrease in starch.

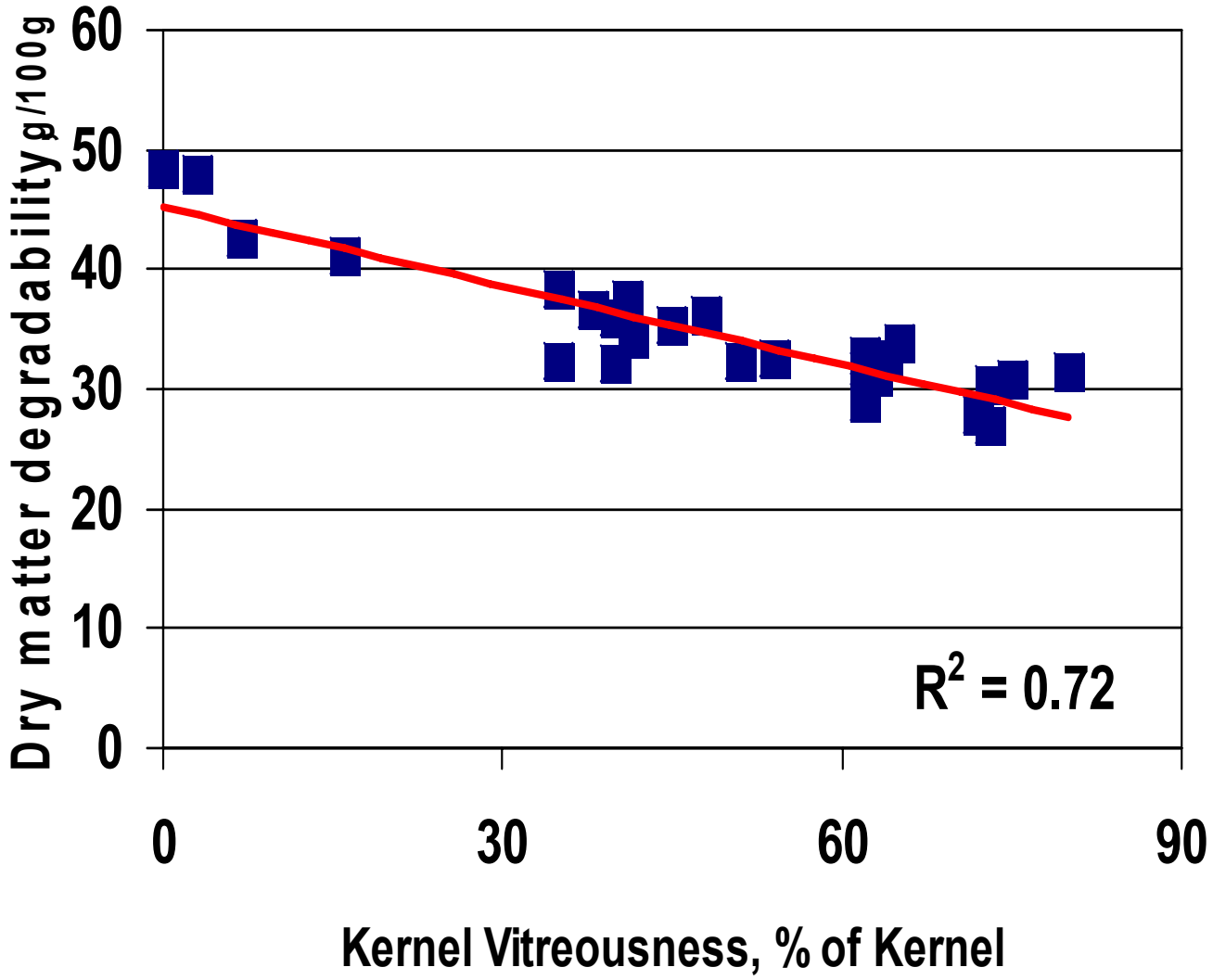
Vitreous endosperm. Also called horneous, corneous or hard endosperm. Produces grits in dry milling. Tightly compacted and translucent. More of this starch in mature, high test weight kernels.

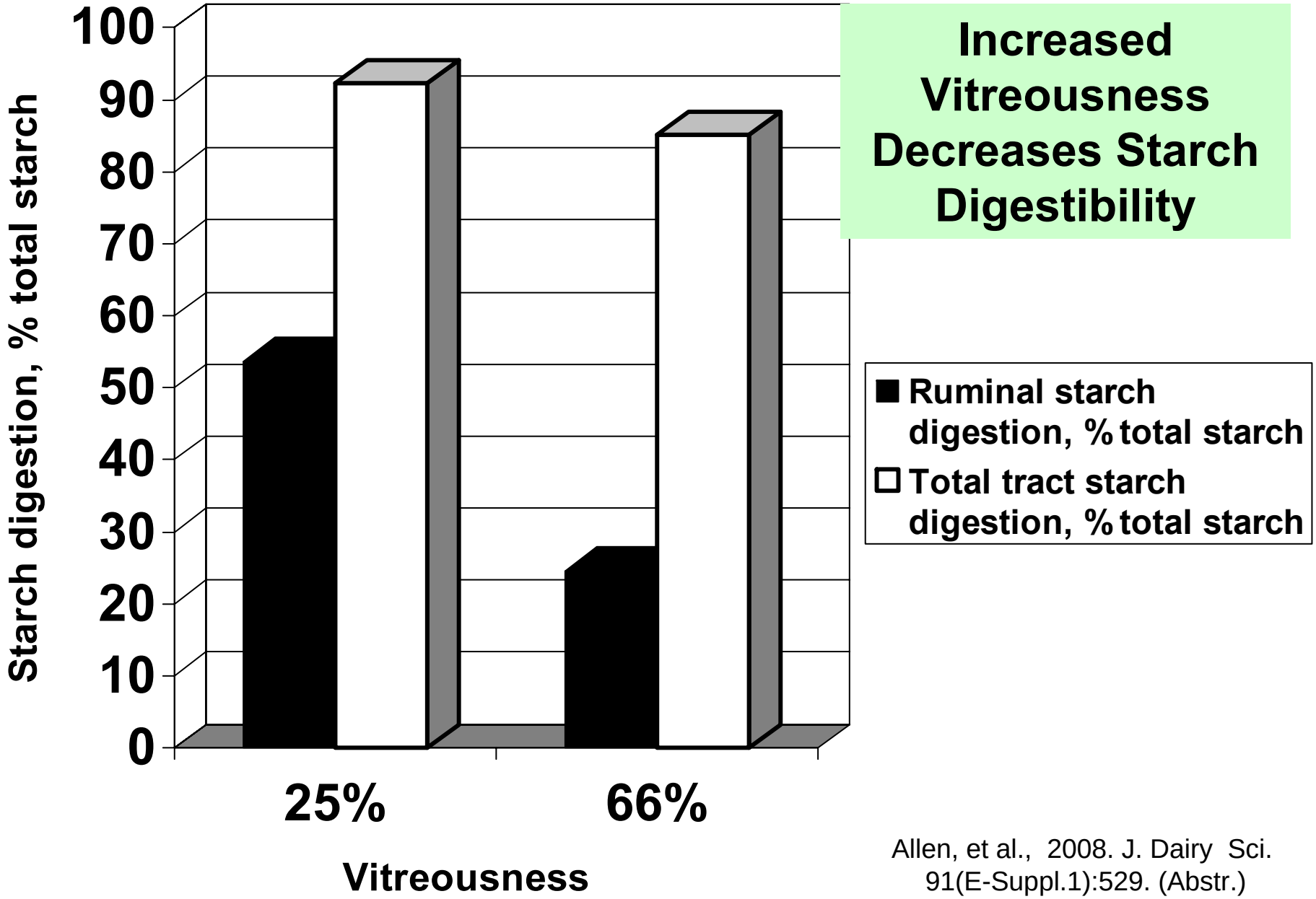
Hilum or abscission layer. Also called blacklayer. Caused by collapse and compression of several layers of cells at physiological maturity. Cool weather can cause premature BL.


Floury Endosperm
Vitreous Endosperm
Germ

# Increased Vitreousness Decreases Starch Degradability

Ngonyamo-Majee, et al., Anim. Feed Sci. Technol. 142:259-274.






Allen, et al., 2008. J. Dairy Sci. 91(E-Suppl.1):529. (Abstr.)

- Another Question

- **Chemically-What makes starch vitreous?**

# The Starch Protein Matrix

- The endosperm is a starch protein matrix
  - 4 types of Protein in Corn Endosperm
  - Albumins, Globulins, Glutelins, **Prolamins**
- Prolamins
  - Named (Zein) in Corn
  - 50-60 % of the Protein in Corn
  - Major Amino Acid = Proline (Hydrophobic)
  - Prolamins are not Soluble in $H_2O$ or Rumen Fluid
  - Industrial Use (Edible-Biodegradable Plastic)

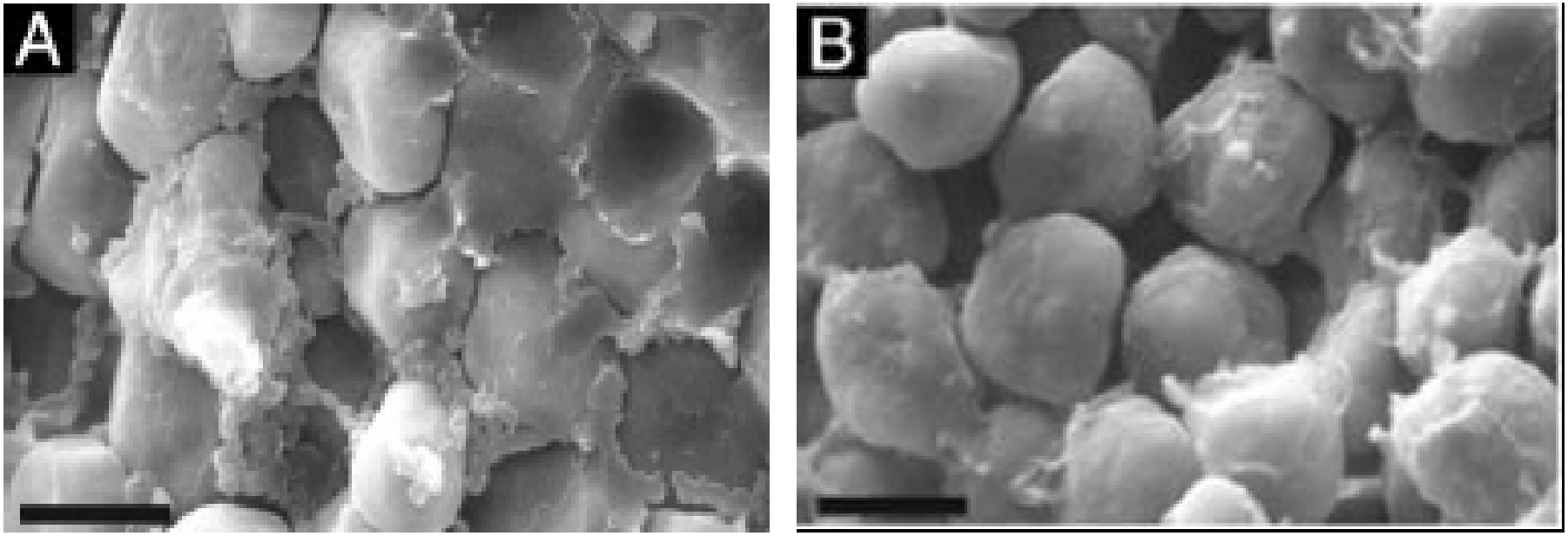
# Prolamins: Corn Endosperm Protein of Interest

- **Prolamin Zein ( 4 Types) – άβγδ**
- **Form on the Starch Granule Surface**
- **Prolamin Proteins Can Cross-link**
- **Encapsulate Starch into a Matrix**
- ***Advances with maturity – (like NDF in forages)***
- ***Genetic differences in corn***
  - ***Floury/Opaque Corns are Missing the Y-zein Gene***
  - ***Floury/Opaque Corns are Low in Prolamins***
  - ***Flint Corns are Very High in Prolamins***
  - ***Common Corn Hybrids are Moderately-High in Prolamins***

# The Starch-Protein Matrix

**Vitreous Endosperm**

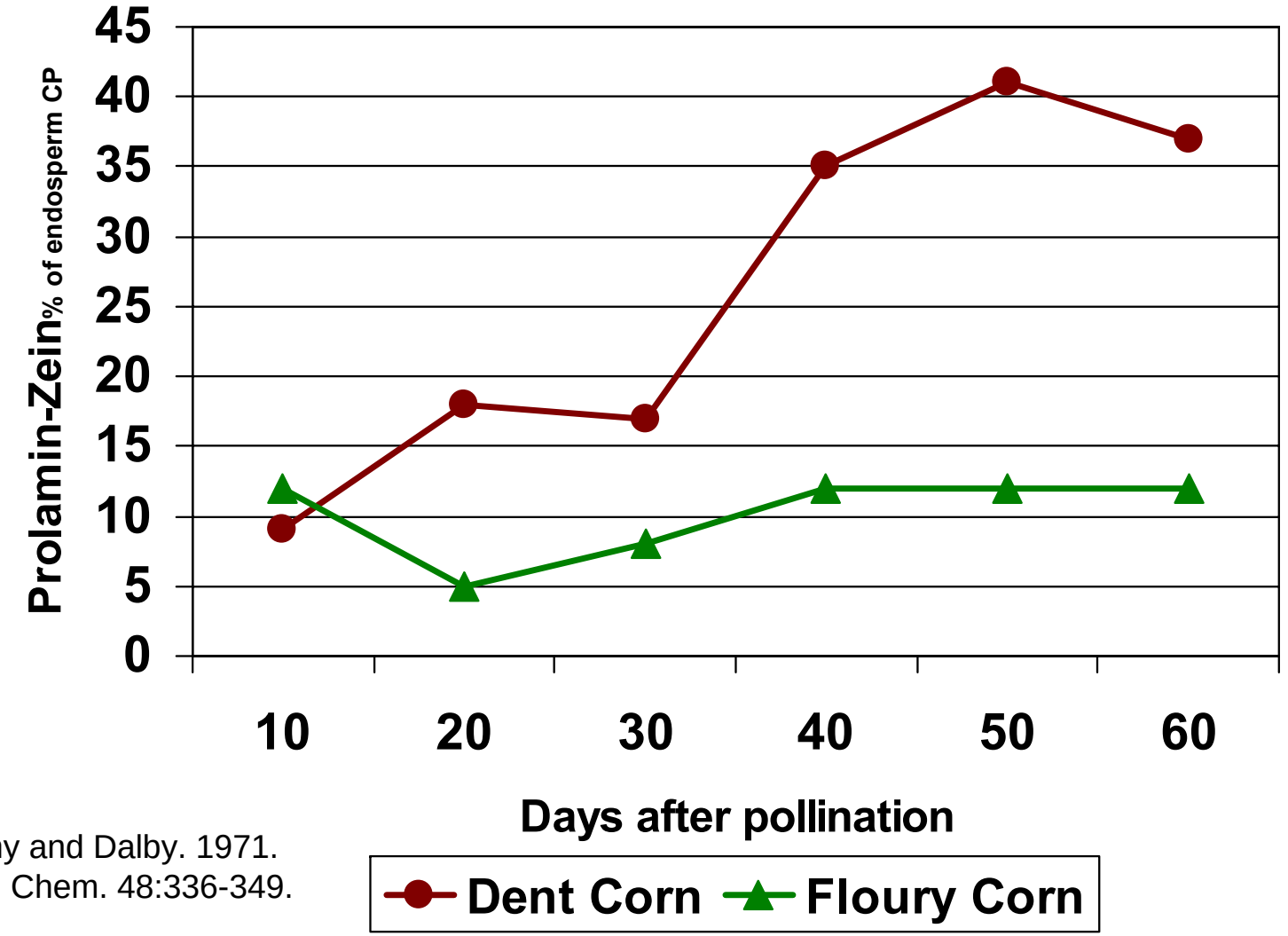
**Floury Endosperm**




**Scanning electron microscopy of starch granules in corn: A) starch granules heavily imbedded in prolamin-protein matrix, B) starch granules in opaque corn endosperm with less extensive encapsulation by prolamin-proteins (Gibbon et. al., 2003).**

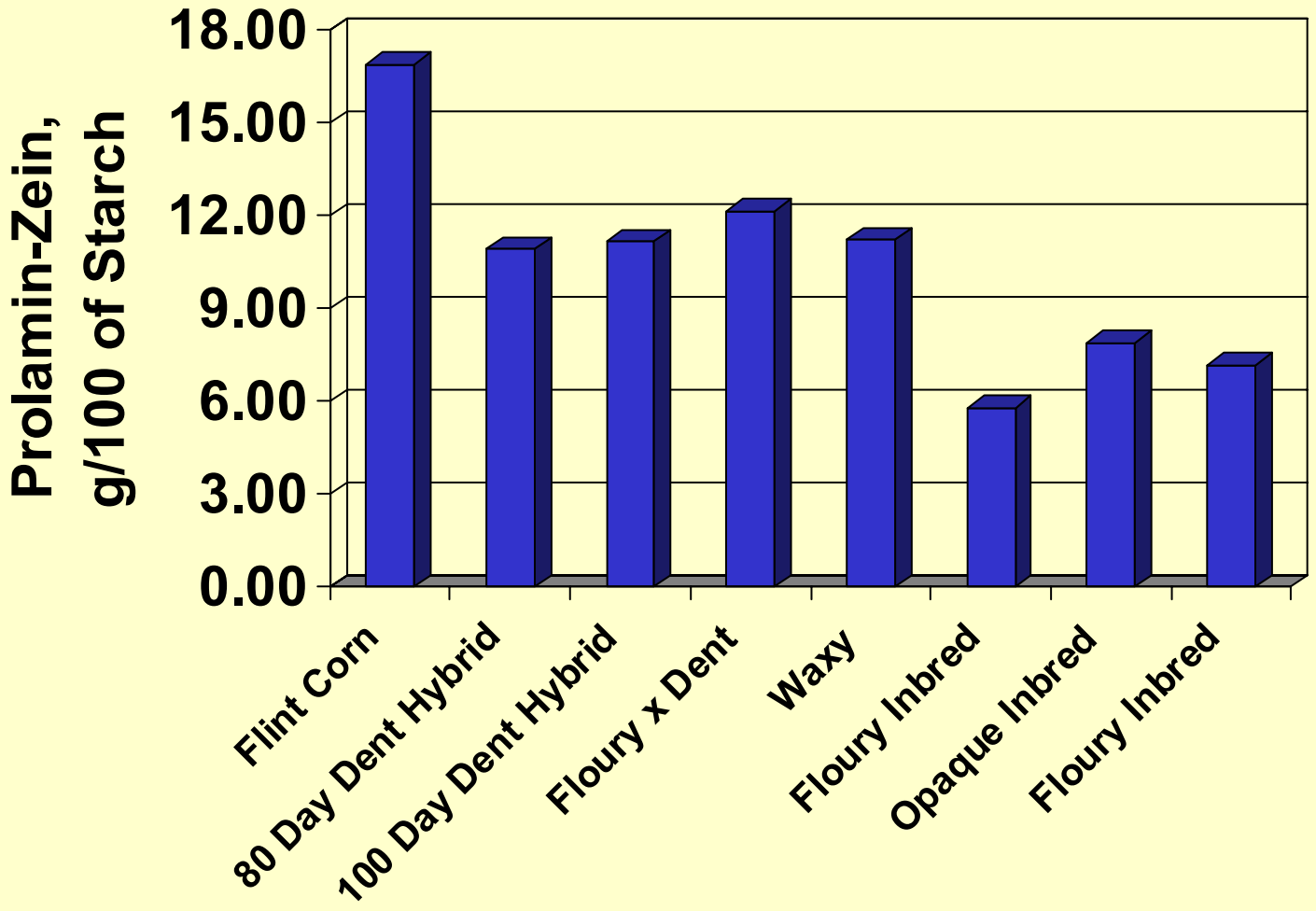
# Prolamin-Zein Advances With Maturity

## In Normal Hybrids but not Floury Corn




Murphy and Dalby. 1971.
Cereal Chem. 48:336-349.

# Corn Types and Varieties Contain Different Amounts of Prolamin-Zein

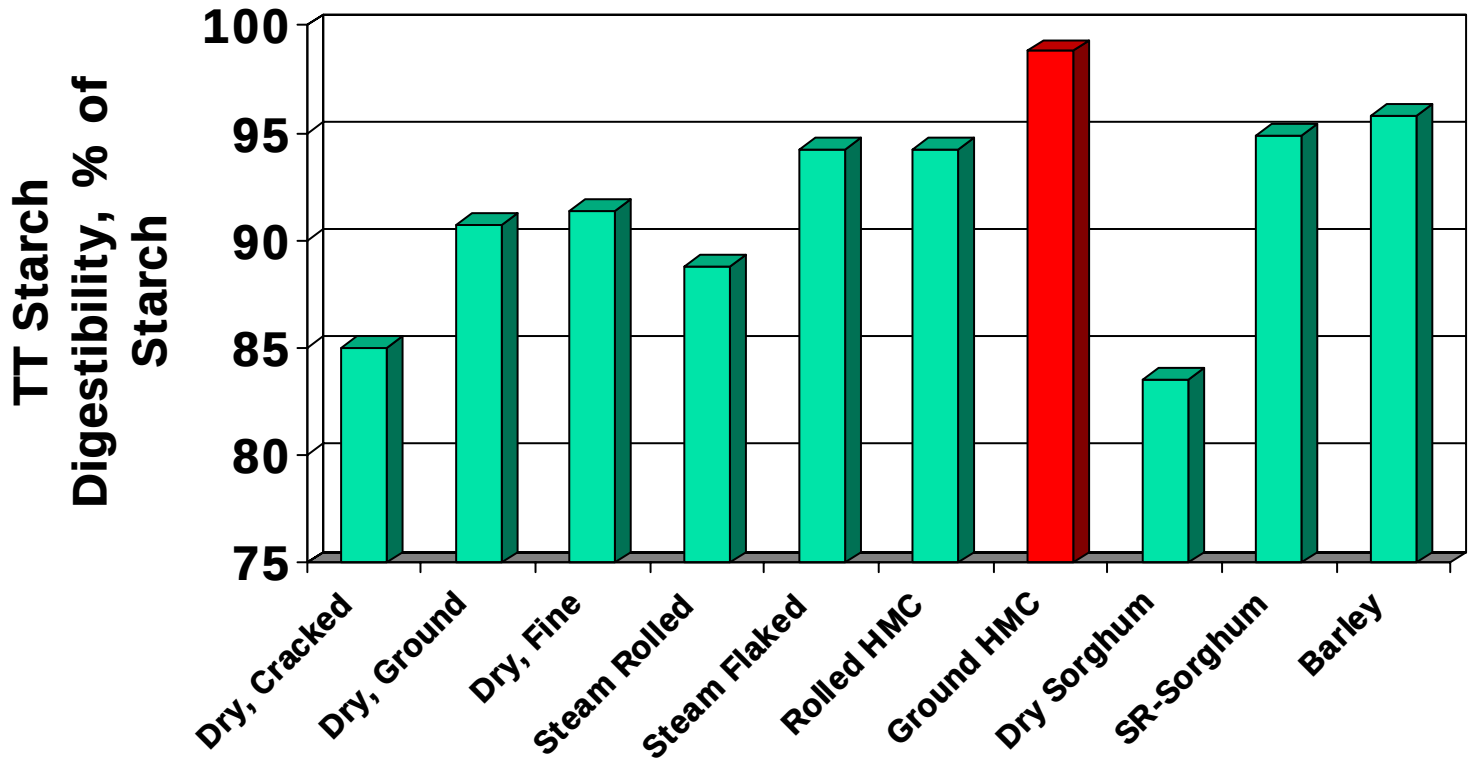


- One More Question

- **What about Prolamins in High Moisture Corn?**

# Variation in Starch Digestibility,

## Firkins et al., 2001



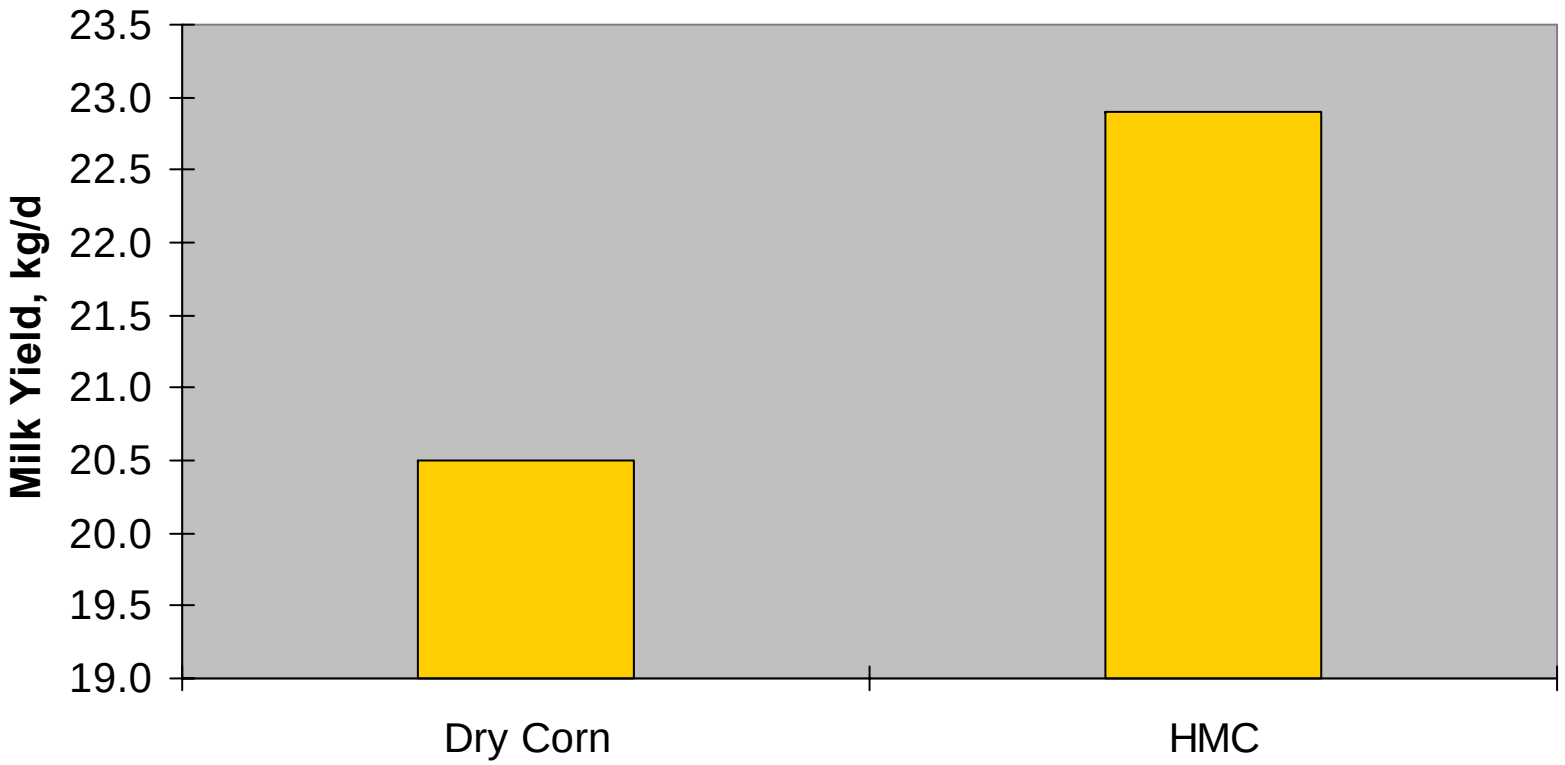
# Performance of Lactating Cows fed Ground or Rolled HMC or Dry Corn. Knowlton et al., 1998

SD = Starch Digestibility

| | Dry Corn | | HMC | |
|---|---|---|---|---|
| Item | Ground | Rolled | Ground | Rolled |
| MPS, $\mu$m | 618 | 1725 | 489 | 1789 |
| DM | 85.0 | 85.0 | 70.0 | 70.0 |
| Ruminal SD | 60.9 | 69.2 | 86.8 | 81.2 |
| Total SD | 88.9 | 76.4 | 98.2 | 95.7 |
| Ruminal pH | 6.14 | 6.27 | 6.14 | 6.16 |
| NDFD | 30.4 | 33.0 | 26.3 | 25.7 |
| Milk Yield, kg | 35.2 | 33.4 | 35.0 | 35.2 |
| Fat, % | 4.36 | 4.36 | 4.10 | 4.46 |

**Forage: All Alfalfa Silage**

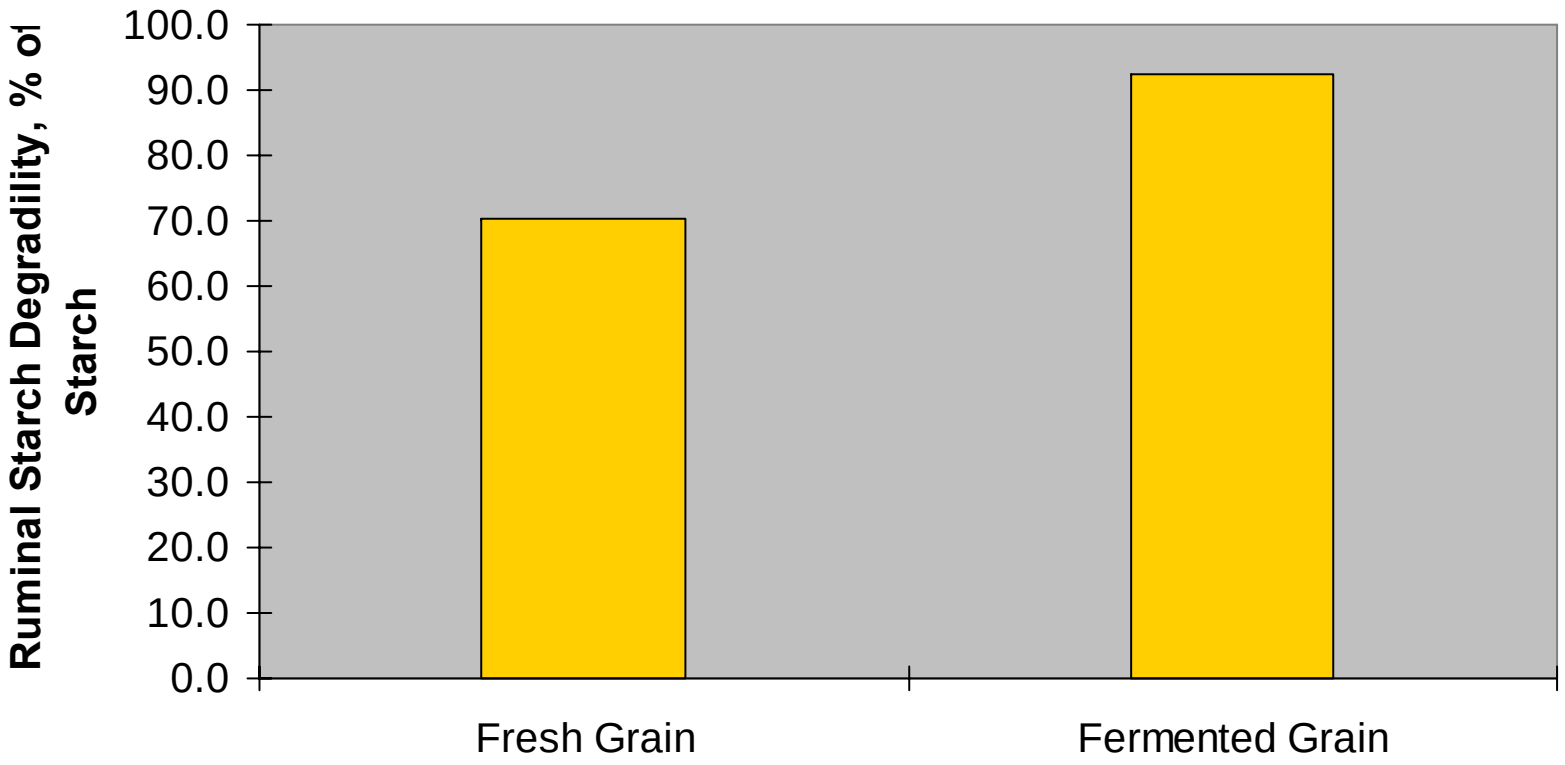
# Supplementation of Grazing Cows with High Moisture Corn or Dry Cracked Corn. Wu et al., 2001



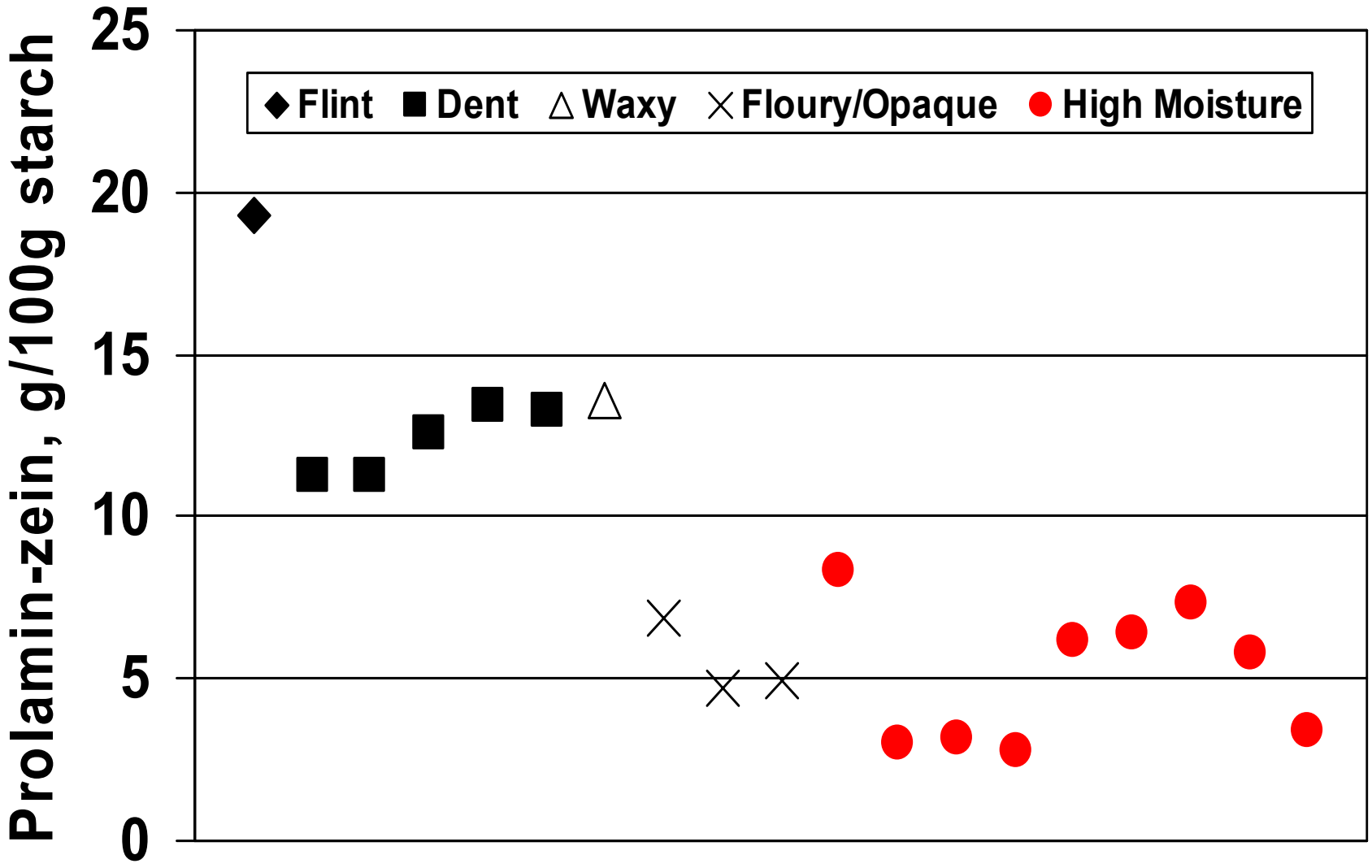

***Grazing Cows Supplemented with 6.3 kg of grain DM/d***

# Fermentation Increases Starch Degradability

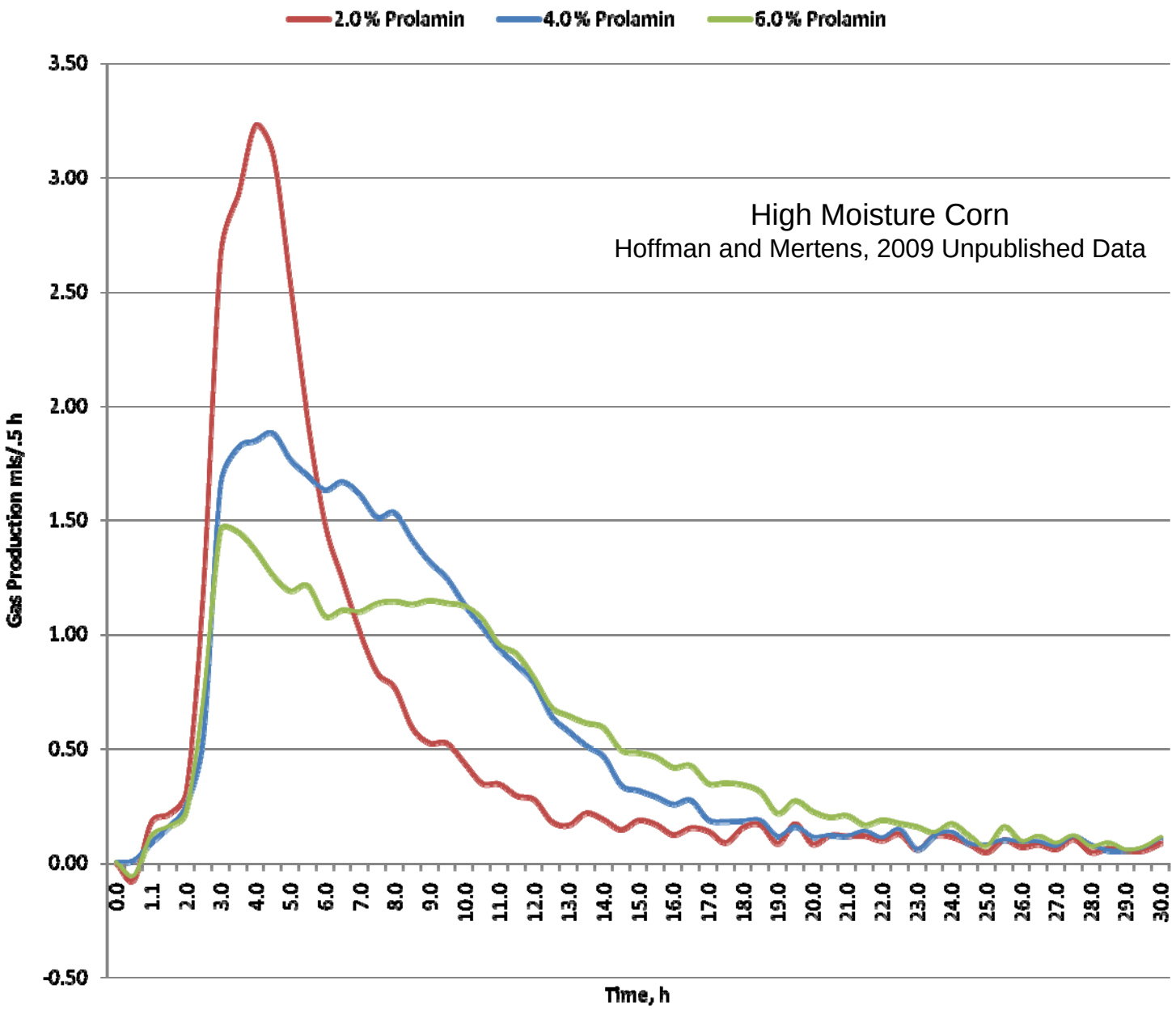
Jurjanz and Montels. 2005.
Anim. Res. 3:15-23.

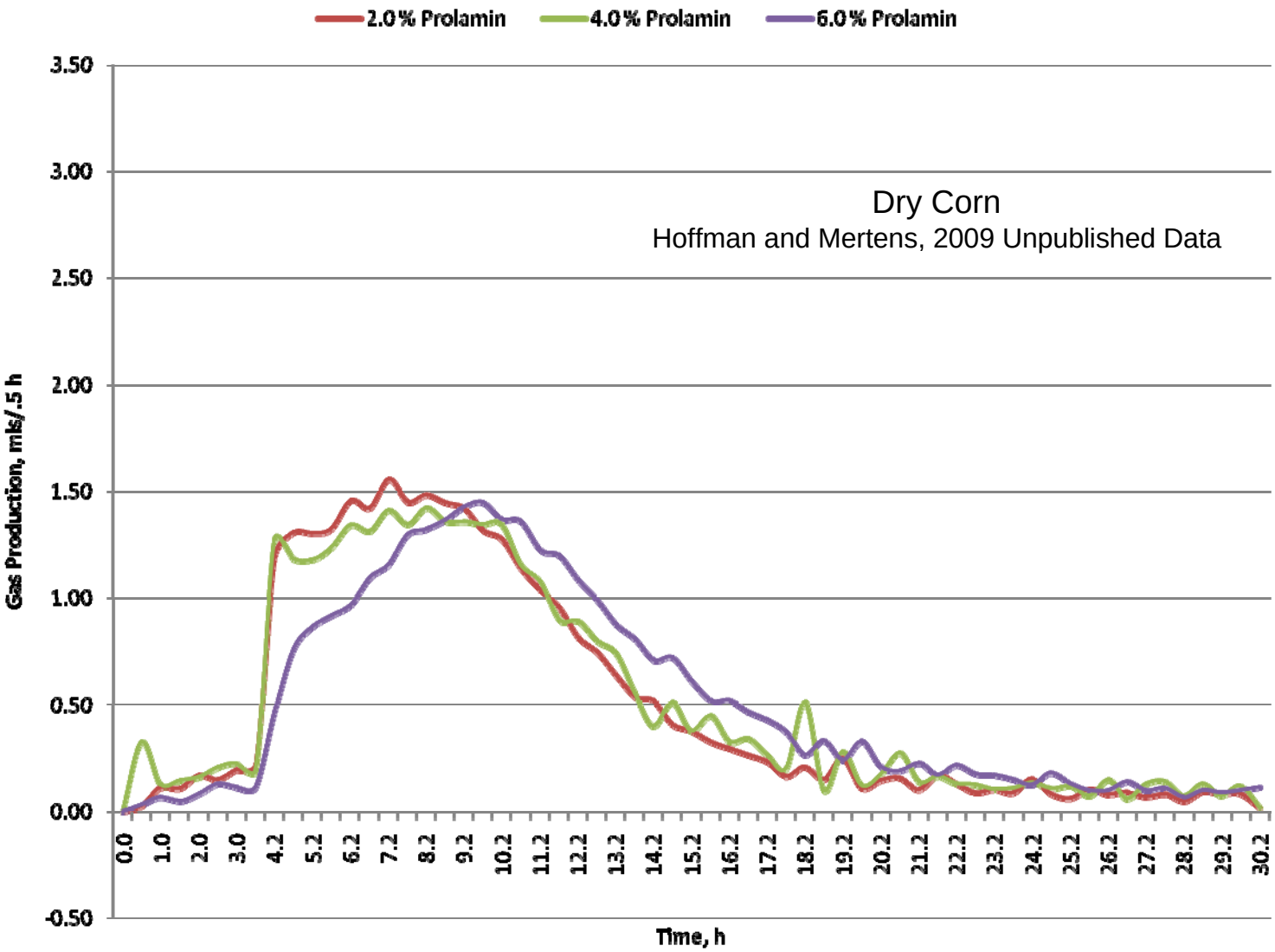


# High Moisture Corn is Low in Prolamins




Larson and Hoffman. 2009.
J. Dairy Sci. (In press).


2.0% Prolamin
4.0% Prolamin
6.0% Prolamin
High Moisture Corn
Hoffman and Mertens, 2009 Unpublished Data
Gas Production mls/.5 h
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
0.0
1.1
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0
15.0
16.0
17.0
18.0
19.0
20.0
21.0
22.0
23.0
24.0
25.0
26.0
27.0
28.0
29.0
30.0
Time, h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3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
0.0
1.0
2.0
3.0
4.2
5.2
6.2
7.2
8.2
9.2
10.2
11.2
12.2
13.2
14.2
15.2
16.2
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19.2
20.2
21.2
22.2
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24.2
25.2
26.2
27.2
28.2
29.2
30.2

# *Fermentation Degrades Prolamins ?*

- ***Dry Corn is Commonly Harvested at 25-30 % Moisture and Mechanically Dried***
- ***High Moisture Corn is Commonly Harvested at 25-30 % Moisture and Ensiled***
- ***Thus High Moisture Corn and Dry Corn are Commonly Harvested at Similar Maturities***

***Proteolysis (Protein Breakdown) is However a Normal Fermentation Process***

***Prolamins are Not Soluble in Water or Rumen Fluid but Lactic and Acetic Acids are Primary Solvents of Prolamins***

# *All Grains Have Prolamins*

***Prolamins for each cereal grain have specific and historical names:***

| ***Grain*** | ***Prolamin Name*** | ***Prolamin Level*** |
|---|---|---|
| ***wheat*** | ***(gliadin)*** | ***Med-Low*** |
| ***barley*** | ***(hordein)*** | ***Low*** |
| ***rye*** | ***(secalin)*** | ***Med-Low*** |
| ***oats*** | ***(avenin)*** | ***Low*** |
| ***corn*** | ***(zein)*** | ***High*** |
| ***sorghum*** | ***(kafirin)*** | ***Very High*** |

# *Vitreousness and Prolamins: Can my Lab Test It?*

## *Vitreousness*

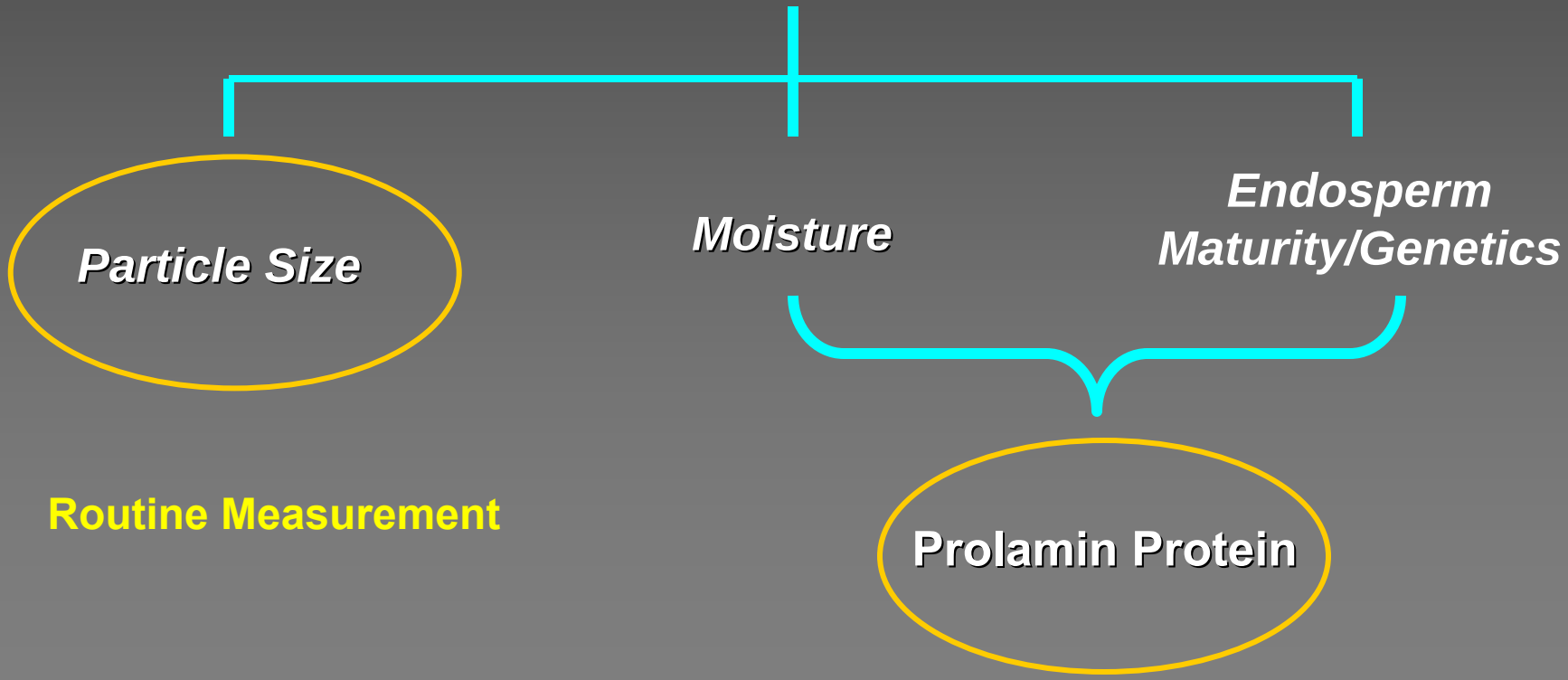
- Evaluated by Manual Dissection of Whole Corn Kernels
- Not Applicable to Ground Feed Samples
- NIRS has Potential to Determine Vitreousness in Ground Samples
- Ngonyamo-Majee, et al., Anim. Feed Sci. Technol. 142:247-258.

## *Prolamins*

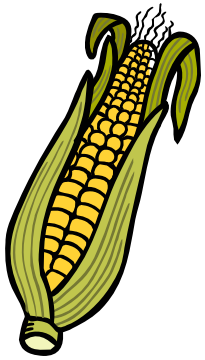
- First Method (Osborne, 1897)
- Landry and Moureaux, 1970
- Labor Intensive
- Simplified Method (Larson and Hoffman, 2009)
- Larson and Hoffman- Potential For Routine Analysis

# Starch Digestibility

## Principal Components of Starch Digestion



# UW Feed Grain Evaluation System

**SOIL and FORAGE ANALYSIS LABORATORY**
*2611 East 29th Street, Marshfield, WI 54449*
*Phone 715-387-2523 ext 4 Fax 715-387-1723*

*UW-Feed Grain Evaluation System*

| | |
|---|---|
| Acct # | 1 |
| Date | 3/1/2009 |

*Comments*: Example High Moisture Grain

*Grain Type*

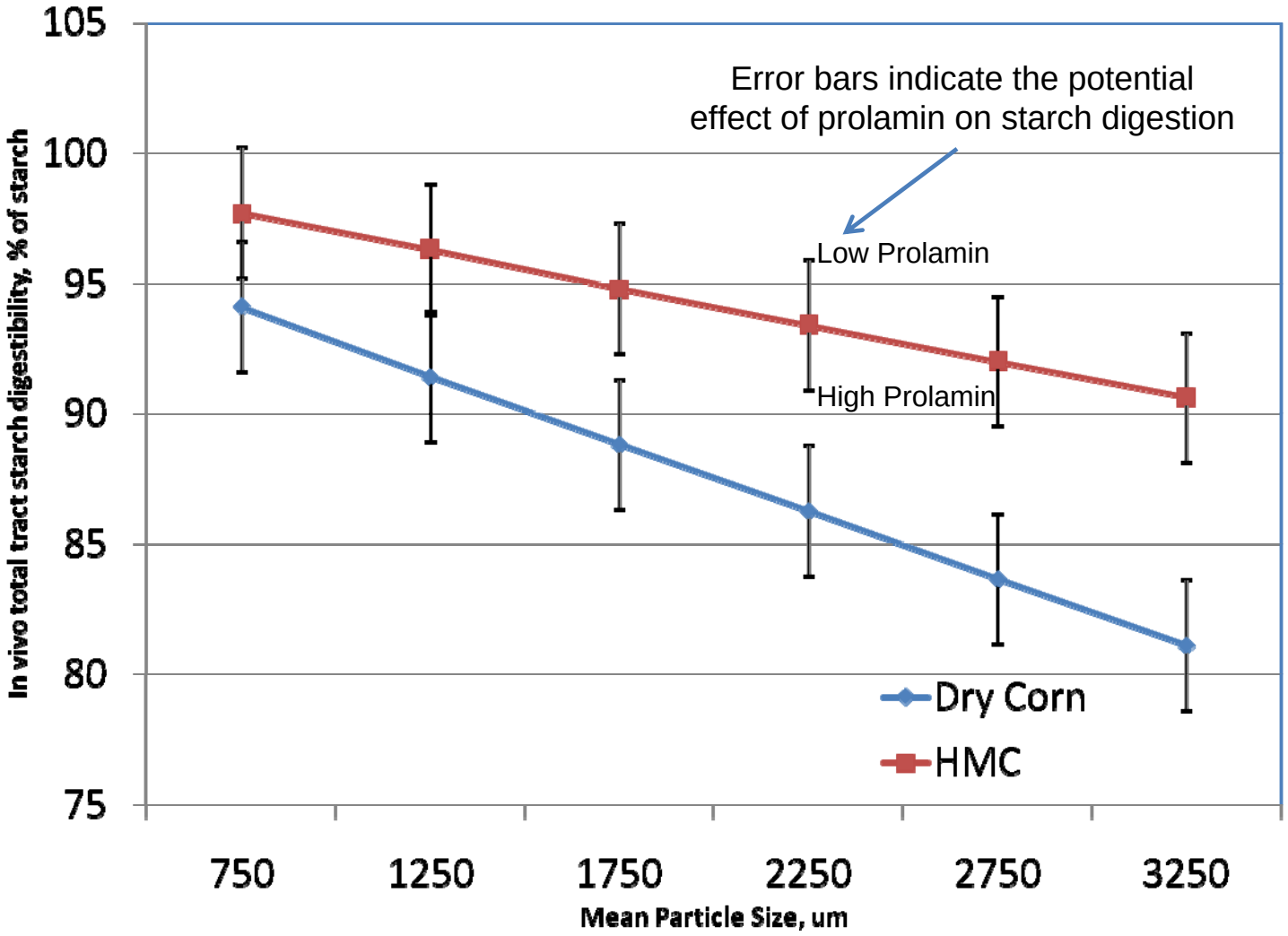
| | |
|---|---|
| Dry or HM Corn | x |
| Small Grain | |
| Sorghum Milo | |
| Steam Flaked Grain | |

Lab Number: 1 Sample Description:

| Item | Abbrev | Unit | Result | Method [1] |
|---|---|---|---|---|
| Dry Matter | DM | % as fed | 70.0 | WC |
| Moisture | | % as fed | 30.0 | C |
| **Protein Fractions** | | | | |
| Crude Protein | CP | % of DM | 9.1 | WC |
| Prolamin Protein | | % of DM | 2.3 | WC |
| Prolamin Protein | | % of Starch | 3.3 | WC |
| **Fiber Fractions** | | | | |
| Neutral Detergent Fiber | aNDF | % of DM | 8.4 | WC |
| **Starch** | | | | |
| Starch | | % of DM | 68.9 | WC |
| Mean Particle Size | MPS | microns | 2000 | WC |
| Processing Classification | | | Med-Coarse Grind | |
| Relative Grain Quality | RGQ | | 174 | C |
| **Carbohydrates and Fats** | | | | |
| Non Fiber Carbohydrate | NFC | % of DM | 76.3 | C |
| Nonstarch NFC | | % of DM | 7.4 | C |
| Fat | | % of DM | 4.2 | WC |
| **Energy Calculations:** | | | | |
| Total Digestible Nutrients, 1X | TDN | % of DM | 89.9 | C |
| Net Energy Lactation, 3X | $NE_L$ | Mcals/lb | 0.91 | C |
| Net Energy Maintenance | $NE_M$ | Mcals/lb | 0.98 | C |
| Net Energy Gain | $NE_G$ | Mcals/lb | 0.67 | C |
| Metabolizable Energy, 3X | ME | Mcals/lb | 1.42 | C |

| Macro Minerals, % of DM | | | Micro Minerals, % of DM | | |
|---|---|---|---|---|---|
| Phosphorus | P | wc | Iron | Fe | wc |
| Calcium | Ca | wc | Manganese | Mn | wc |
| Potassium | K | wc | Zinc | Zn | wc |
| Magnesium | Mg | wc | Copper | Cu | wc |
| Sodium | Na | wc | | | |
| Chloride | Cl | wc | Ash | 2.0 | wc |
| Sulfur | S | wc | | | |

[1] WC = wet chemistry
NIR = near infrared spectroscopy
NR = not requested
NA = not available
C = calculated


105
100
95
90
85
80
75
In vivo total tract starch digestibility, % of starch
Error bars indicate the potential effect of prolamin on starch digestion
Low Prolamin
High Prolamin
Dry Corn
HMC
750
1250
1750
2250
2750
3250
Mean Particle Size, um

# UW Feed Grain Evaluation System

## SOIL and FORAGE ANALYSIS LABORATORY

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*Phone 715-387-2523 ext 4 Fax 715-387-1723*

*Acct #* 1
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*UW-Feed Grain Evaluation System*

*Comments*
Example High Moisture Grain

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| | |
|---|---|
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| Calcium | Ca | WC | Manganese | Mn | | WC |
| Potassium | K | WC | Zinc | Zn | | WC |
| Magnesium | Mg | WC | Copper | Cu | | WC |
| Sodium | Na | WC | | | | |
| Chloride | Cl | WC | Ash | | 2.0 | WC |
| Sulfur | S | WC | | | | |

[1] WC = wet chemistry
NIR = near infrared spectroscopy
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C = calculated

# Conclusions

- **Corn is a seed and is comprised of three basic morphologic parts, pericarp, germ and endosperm. Starch is contained in the endosperm and thus the biochemistry of the endosperm would be most logical in influencing starch digestibility in ruminants.**

- **Vitreous endosperm is negatively related to starch degradability and in vivo starch digestibility in ruminants.**

- **Vitreous endosperm is visually determined and represents a starch-protein matrix where hydrophobic prolamin proteins are commissural with starch.**

- **Dry flint and dent corns contain more hydrophobic prolamin-zein per g of starch as compared to floury or opaque corns. Prolamin-zein contents of high moisture corn are similar or lower than dry opaque or floury corn.**

- **Lower prolamin-zein contents and correspondingly higher starch digestibility of high moisture corn is hypothesized to be the result of degradation starch encapsulating proteins by fermentation acids and proteolysis during fermentation and not solely due to moisture or harvest maturity per se.**

- **Traditional forage-fiber chemistry techniques may not be well suited for cereal grains in determining biochemical factors that influence starch digestibility in ruminants.**

- **Determination and understanding of Prolamins may aid our understanding of starch digestibility but is unlikely to be singular predictor of starch digestibility.**

## *Acknowledgments*

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