2026 CIDERCON PROVIDENCE

CRAFTING CIDER'S FUTURE TOGETHER

Cider Genesis: The Nitrogen Saga

Brighid O'Keane

Gregory Peck

Amanda Stewart

Dave Takush

EST. CIDER INSTITUTE 2016 — THE SCIENCE AND ART OF CIDERMAKING

Cornell CALS — College of Agriculture and Life Sciences

VT — COLLEGE OF AGRICULTURE AND LIFE SCIENCES, VIRGINIA TECH.

2 TOWNS CIDERHOUSE

f

Visit us at booth 628/630

ciderinstitute.com

@ciderinstitute

Poster Session
Thursday
8:30–10:30

EST. CIDER 2016
INSTITUTE
THE SCIENCE AND ART OF CIDERMAKING

PRESENTERS

Brighid O'Keane
Executive Director
Cider Institute

Dr. Gregory Peck
Associate Professor
School of Integrative Plant Science
Cornell University

Dr. Amanda Stewart
Associate Professor
Food Science & Technology
Virginia Tech

Dave Takush
Head Cidermaker & Co-Owner
2 Towns Ciderhouse

Agenda

- Introductions
- Nitrogen in the Orchard
- Nitrogen and Fermentation
- Nitrogen in Practice

Takeaways

- Nitrogen is a system, not a target
- Orchard decisions set the boundaries
- Yeast response matters as much as nitrogen amount
- More nitrogen is not always better
- Effective nitrogen management is about alignment

Cider Research is Supported by:

- Virginia Wine Board
- USDA Specialty Crop Block Grant Program
- USDA National Institute of Food and Agriculture (NIFA)
- Virginia Tech
    - CALS Graduate Teaching Scholars Program
    - Library Open Access Fee Subvention Fund
    - Virginia Cooperative Extension
- Partnerships and collaboration
    - Albemarle CiderWorks
    - Foggy Ridge
    - Silver Creek Orchards
    - Scott Laboratories
    - Cornell University
    - Lallemand
    - CINA

The Peck Lab

USDA-Hatch Federal Formula Funds

USDA-Multi-State Funds

New York State Department of Agriculture and Markets

New York State Apple Research Development Program

New York Farm Viability Institute

Angry Orchard Cider Company, LLC

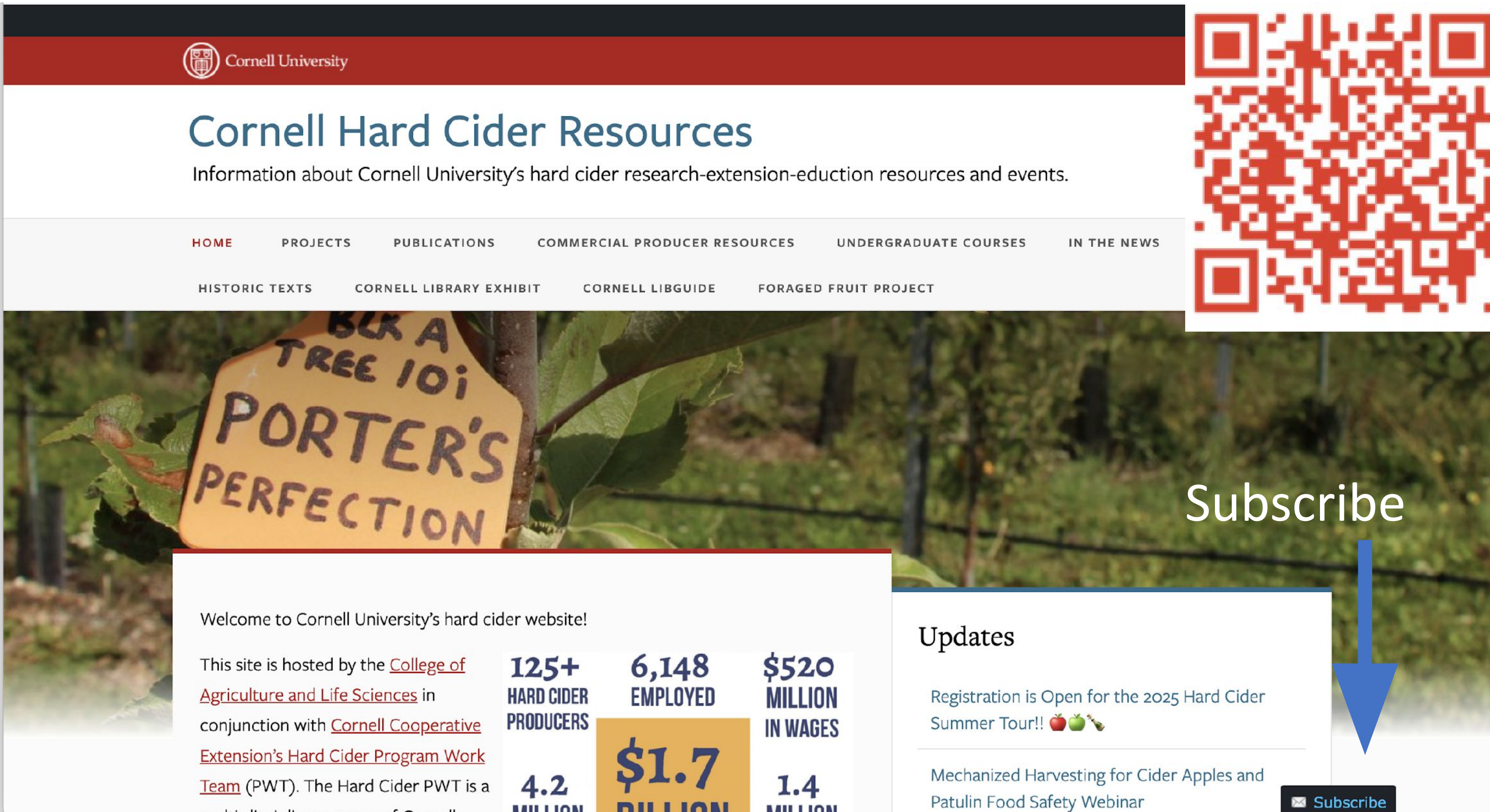
Cornell, CALS, SIPS, Horticulture

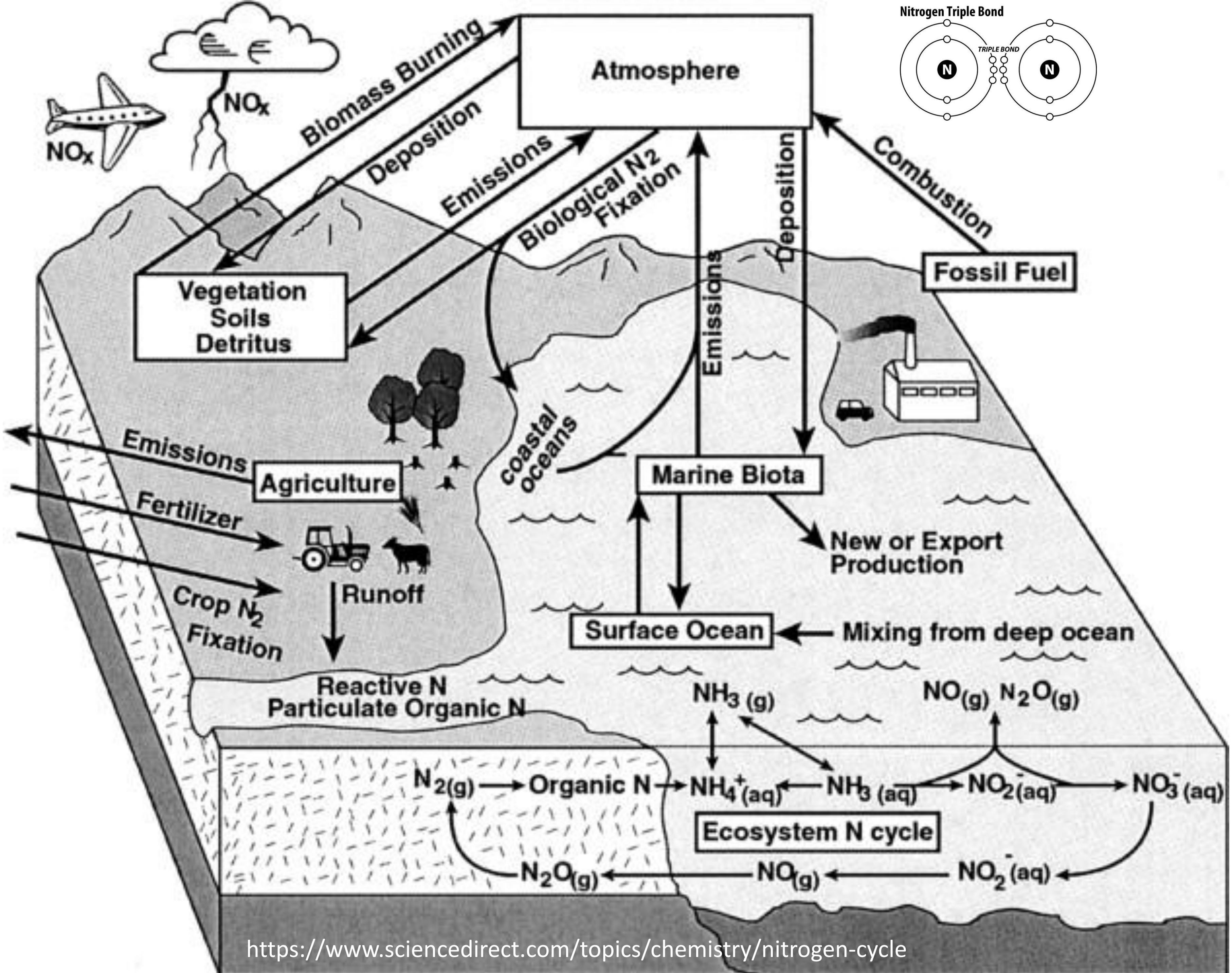
Cornell University Agricultural Experiment Station

Virginia Tech and the Virginia Agricultural Experiment Station

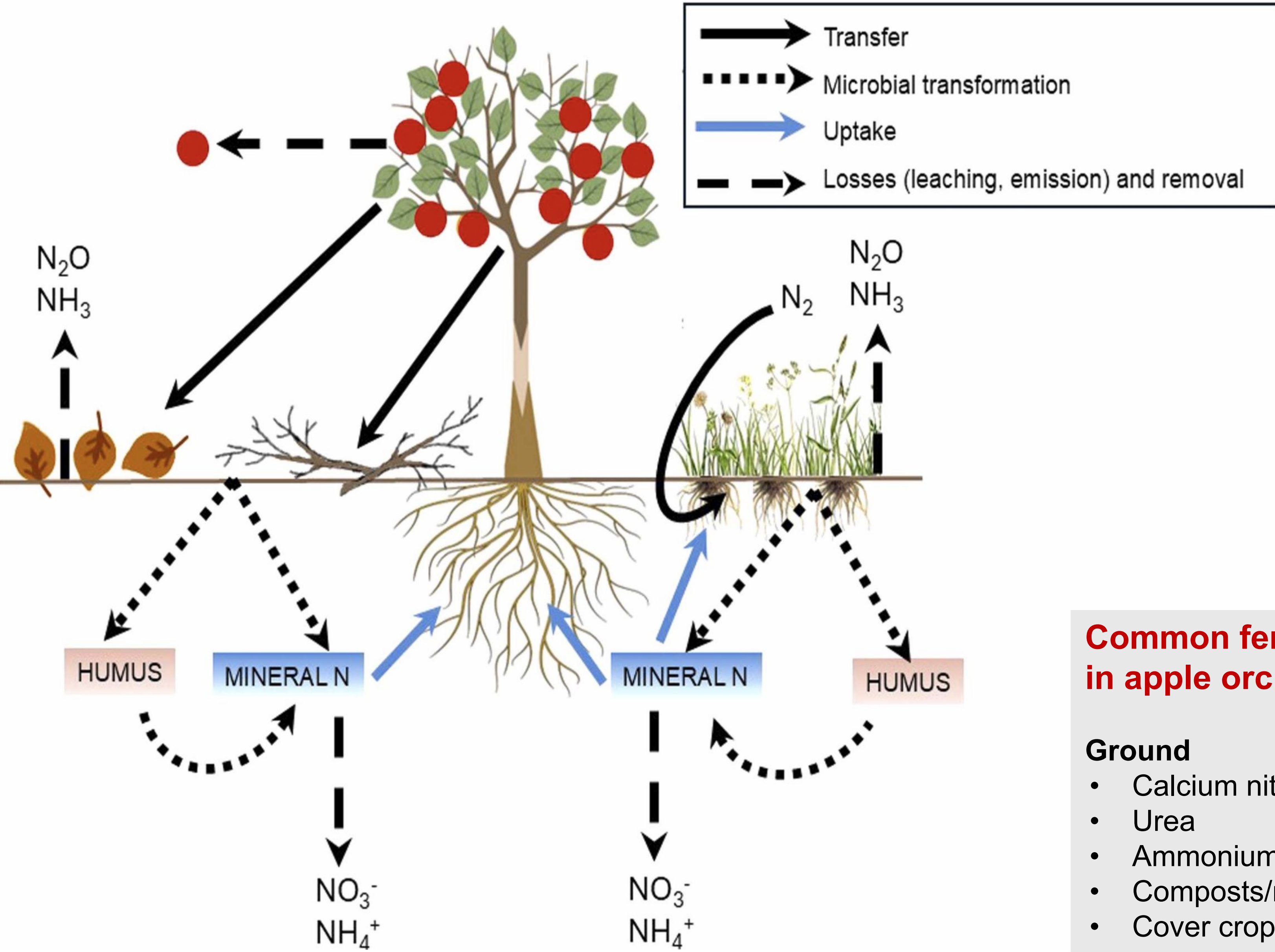
Virginia Wine Board

Cornell CALS College of Agriculture and Life Sciences


Cornell University
Cornell Hard Cider Resources
Information about Cornell University's hard cider research-extension-eduction resources and events.
HOME
PROJECTS
PUBLICATIONS
COMMERCIAL PRODUCER RESOURCES
UNDERGRADUATE COURSES
IN THE NEWS
HISTORIC TEXTS
CORNELL LIBRARY EXHIBIT
CORNELL LIBGUIDE
FORAGED FRUIT PROJECT
TREE 101
PORTER'S PERFECTION
Welcome to Cornell University's hard cider website!
This site is hosted by the College of Agriculture and Life Sciences in conjunction with Cornell Cooperative Extension's Hard Cider Program Work Team (PWT). The Hard Cider PWT is a
125+ HARD CIDER PRODUCERS
6,148 EMPLOYED
$520 MILLION IN WAGES
$1.7
4.2
1.4
Updates
Registration is Open for the 2025 Hard Cider Summer Tour!!
Mechanized Harvesting for Cider Apples and Patulin Food Safety Webinar
Subscribe
Subscribe



https://www.sciencedirect.com/topics/chemistry/nitrogen-cycle



Tagliavini et al., 2025 https://doi.org/10.1016/j.eja.2025.127561

Common fertilizers used in apple orchards

Ground

- Calcium nitrate
- Urea
- Ammonium nitrate
- Composts/manures
- Cover crops

Foliar

- Urea
- Fish emulsion
- Compost teas

Nitrogen—Apple Tree Growth and Yield

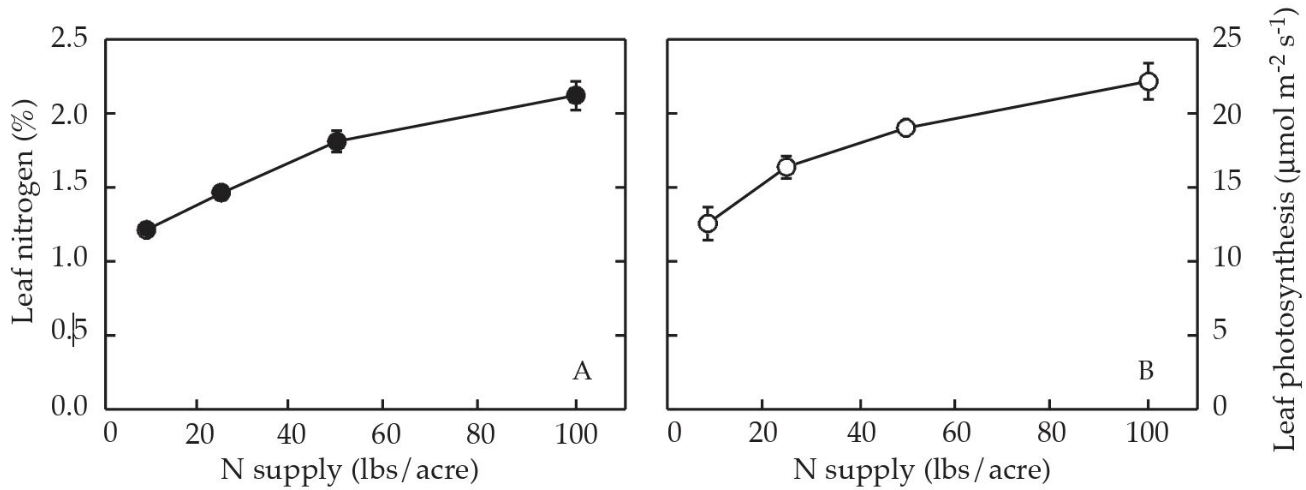


Figure 1. Leaf N content (A) and photosynthesis (B) in response to N supply

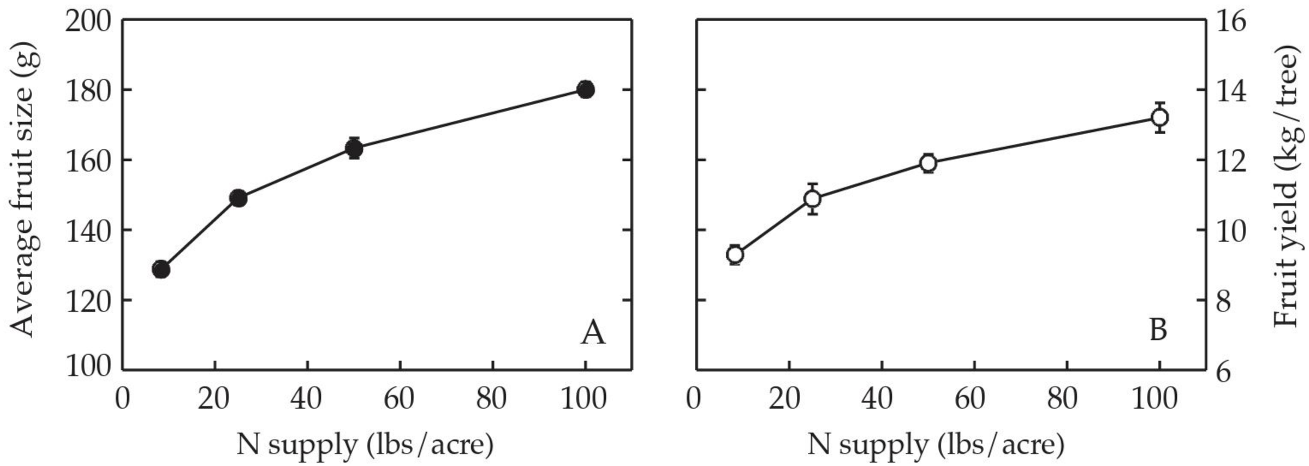


Figure 4. Average fruit size (A) and fruit yield per tree (B) in response to nitrogen supply.

Cheng et al., 2007. Fruit Quarterly 15(3)

What is Yeast Assimilable Nitrogen (YAN)?

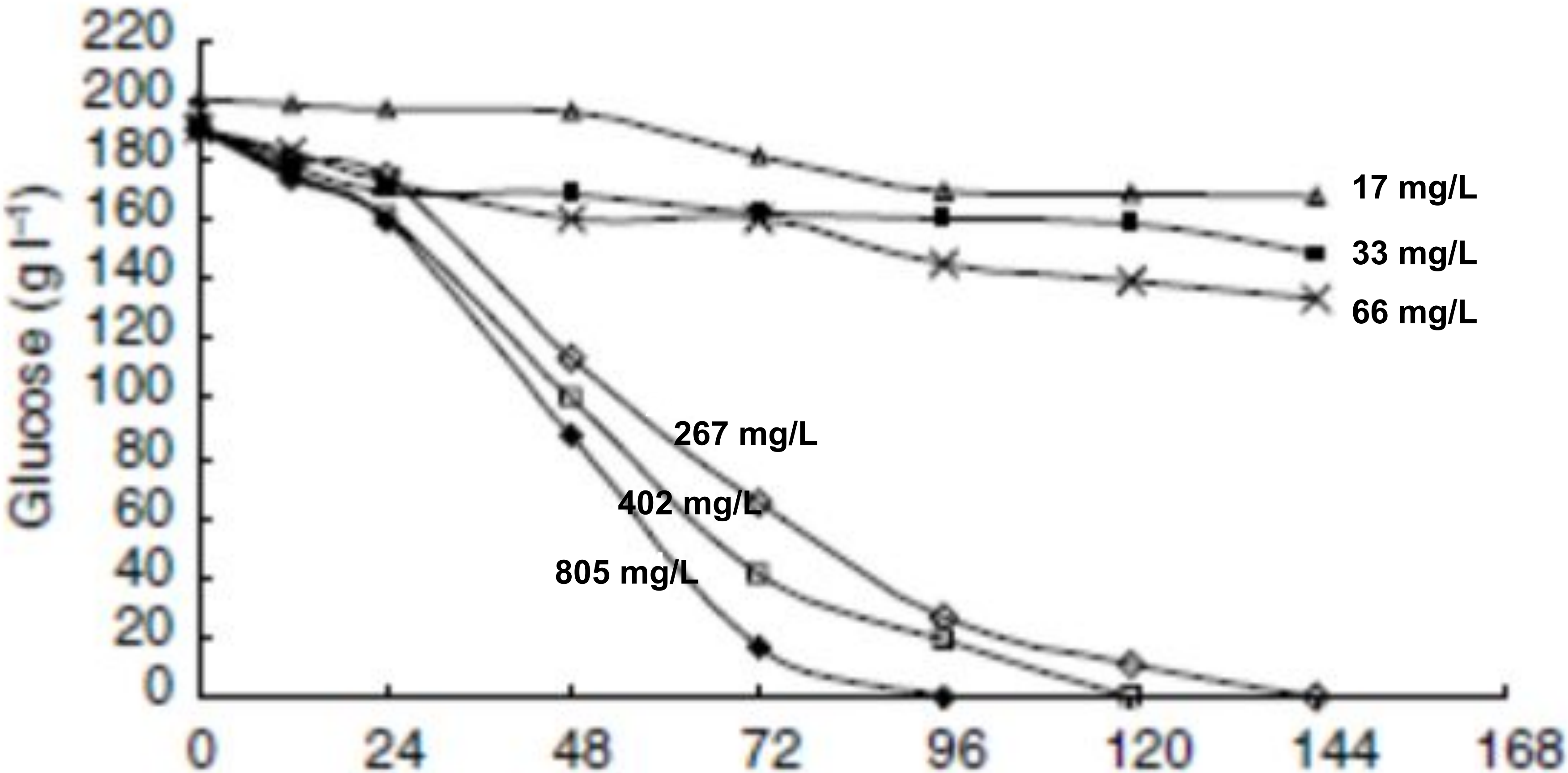
- Nitrogen sources utilized by yeast during fermentation
  - Free amino acids (aka PAN or FAN), except proline
  - Ammonium ions (NH_4^+)
  - Small peptides???
  - NOT protein, NOT large peptides
- Yeast need nitrogen in addition to sugar for growth and metabolism

- ***YAN Concentration*** effects
  - Insufficient YAN □ stuck fermentation, H_2S production

- ***YAN Composition*** effects
  - Relative concentrations of ammonium ions and amino acids □ rate, volatile aroma production
  - Amino acid composition □ volatile aroma production

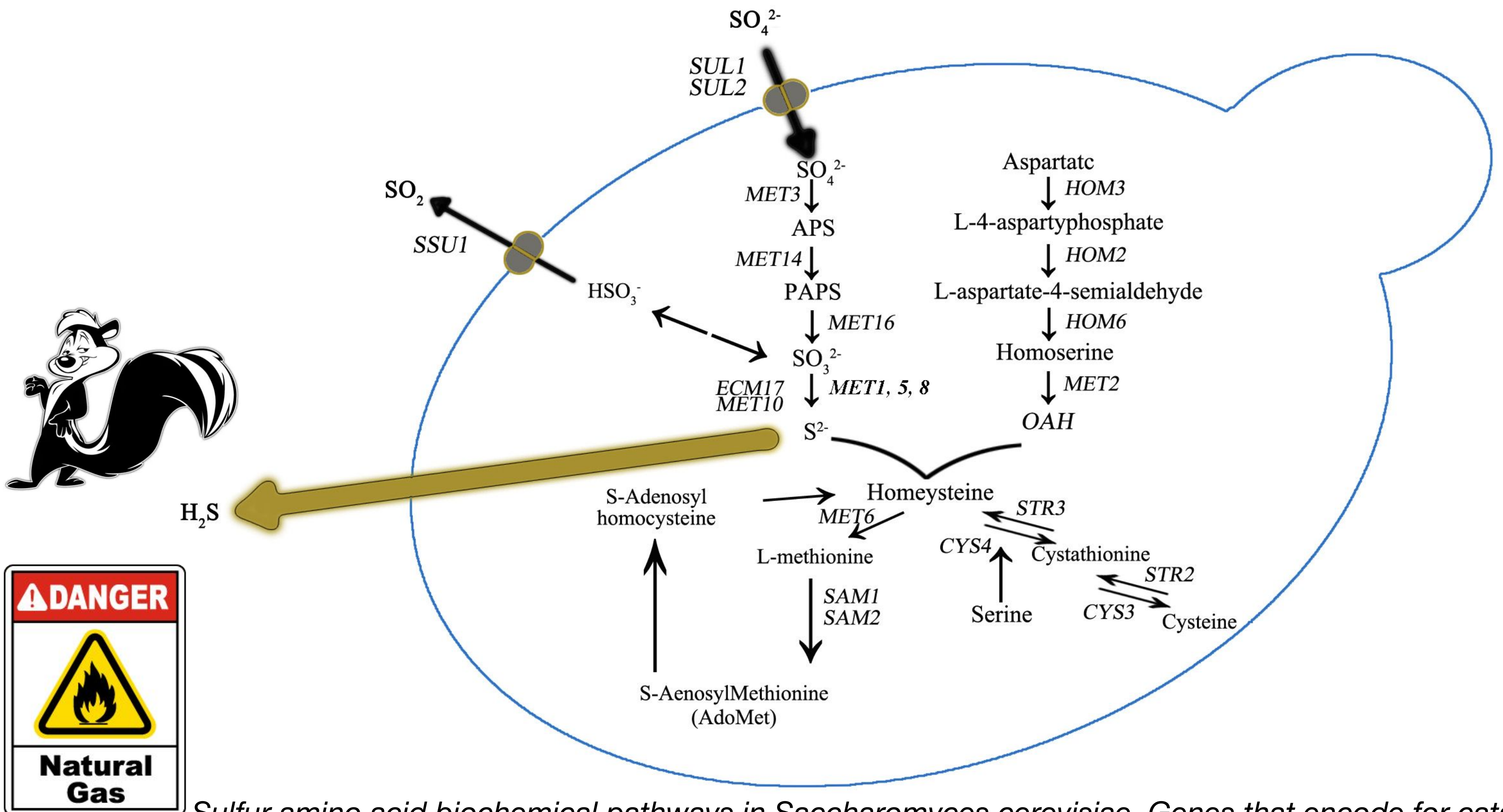
Why Does YAN Matter?

- Lack of YAN can lead to stuck or sluggish fermentation



Mendes-Ferreira, A., A. Mendes-Faia, C. Leao. 2004.

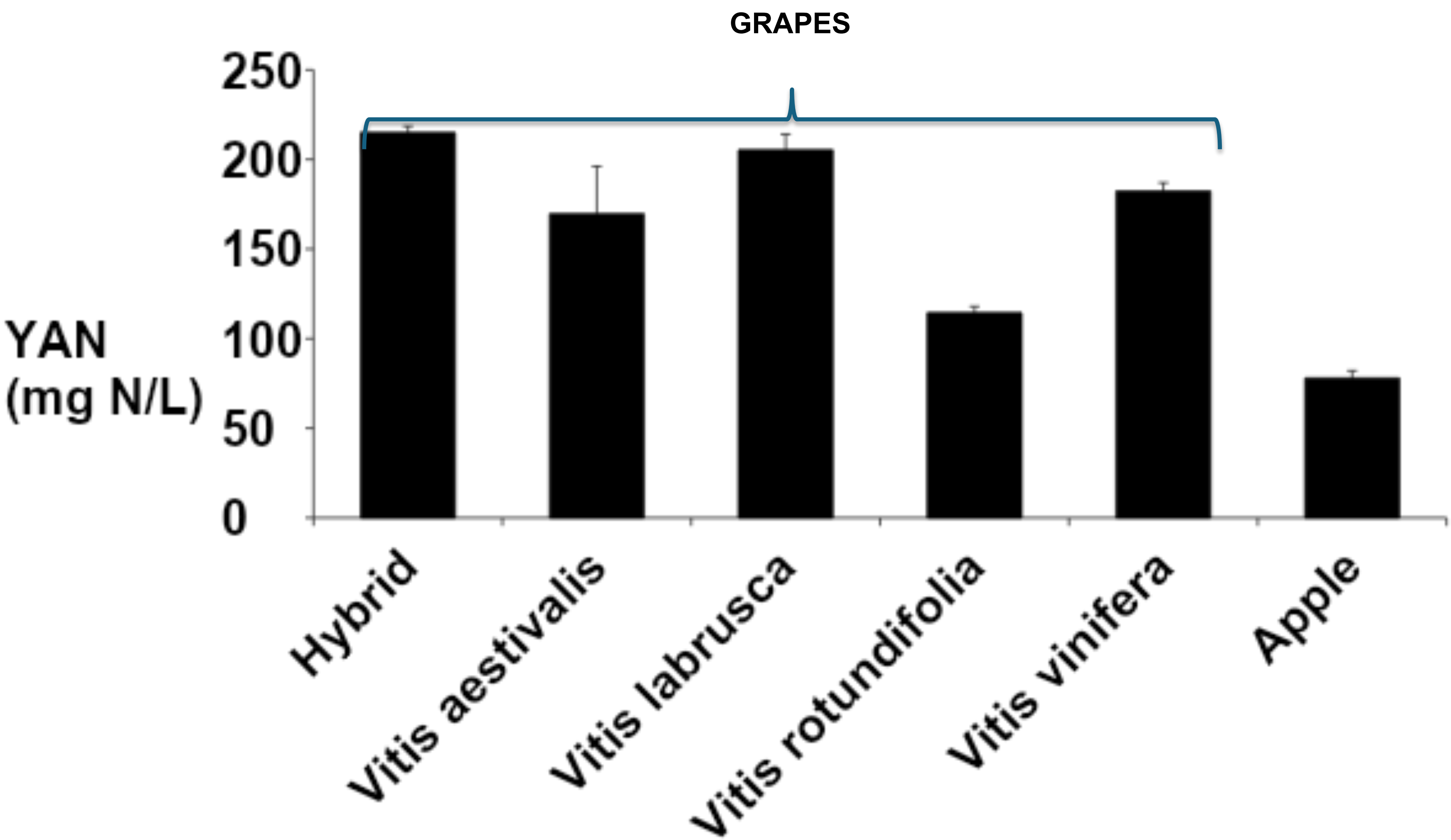
When YAN is too low, yeast will deposit electrons onto sulfur compounds (reduce) instead of nitrogen



Sulfur amino acid biochemical pathways in Saccharomyces cerevisiae. Genes that encode for catalyzing enzymes are shown in italic.

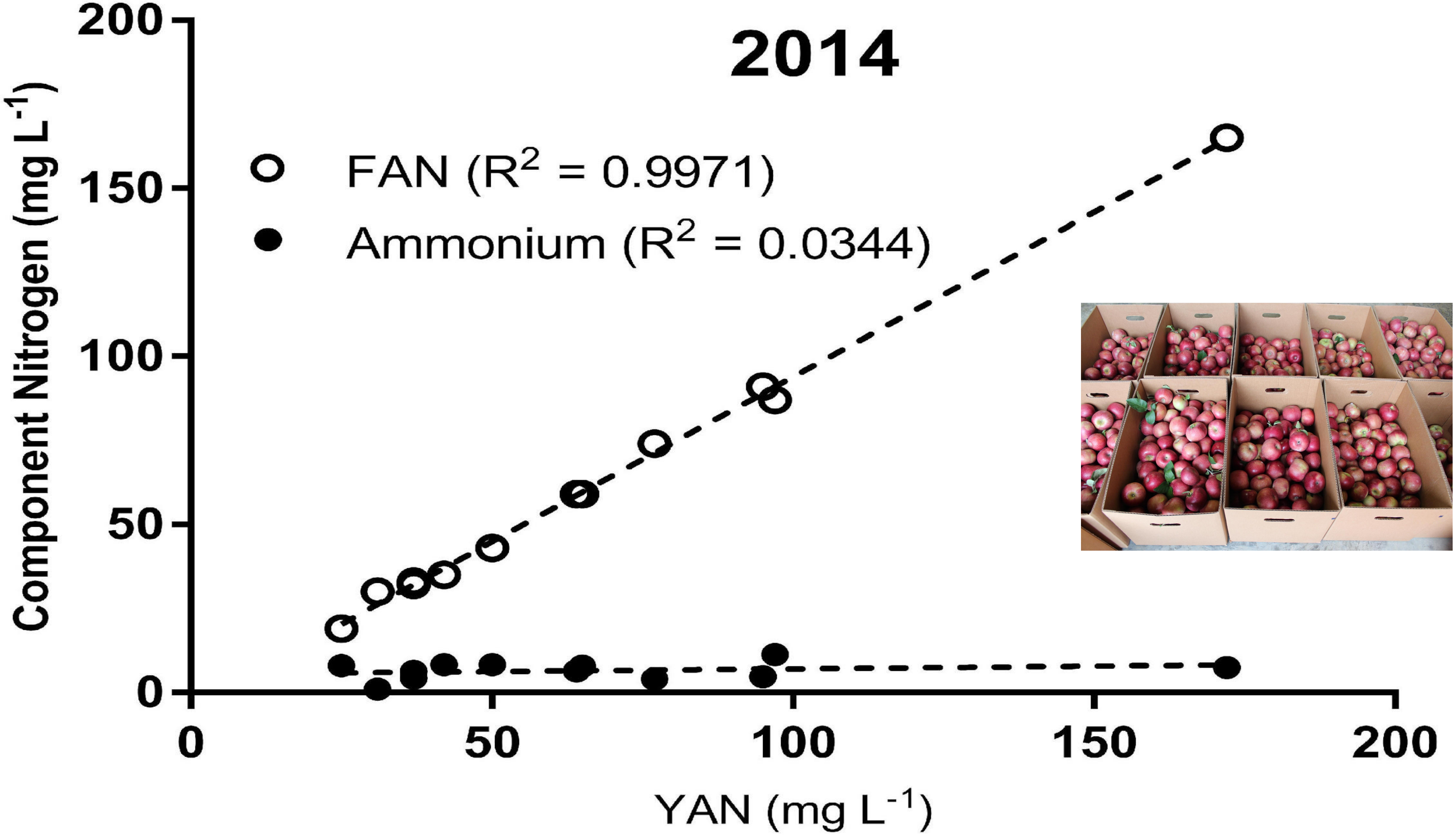
Song, Y.L., Gibney, P., Cheng, L., Shuwen, and **G. Peck**. 2020. Yeast assimilable nitrogen concentrations influences yeast gene expression and hydrogen sulfide production during cider fermentation. Frontiers in Microbiology 11(1264). https://doi.org/10.3389/fmicb.2020.01264

YAN by Fruit Species



Stewart, Hurley, Sandbrook et al. 2010 – 2014, data collected at Virginia Tech, Purdue

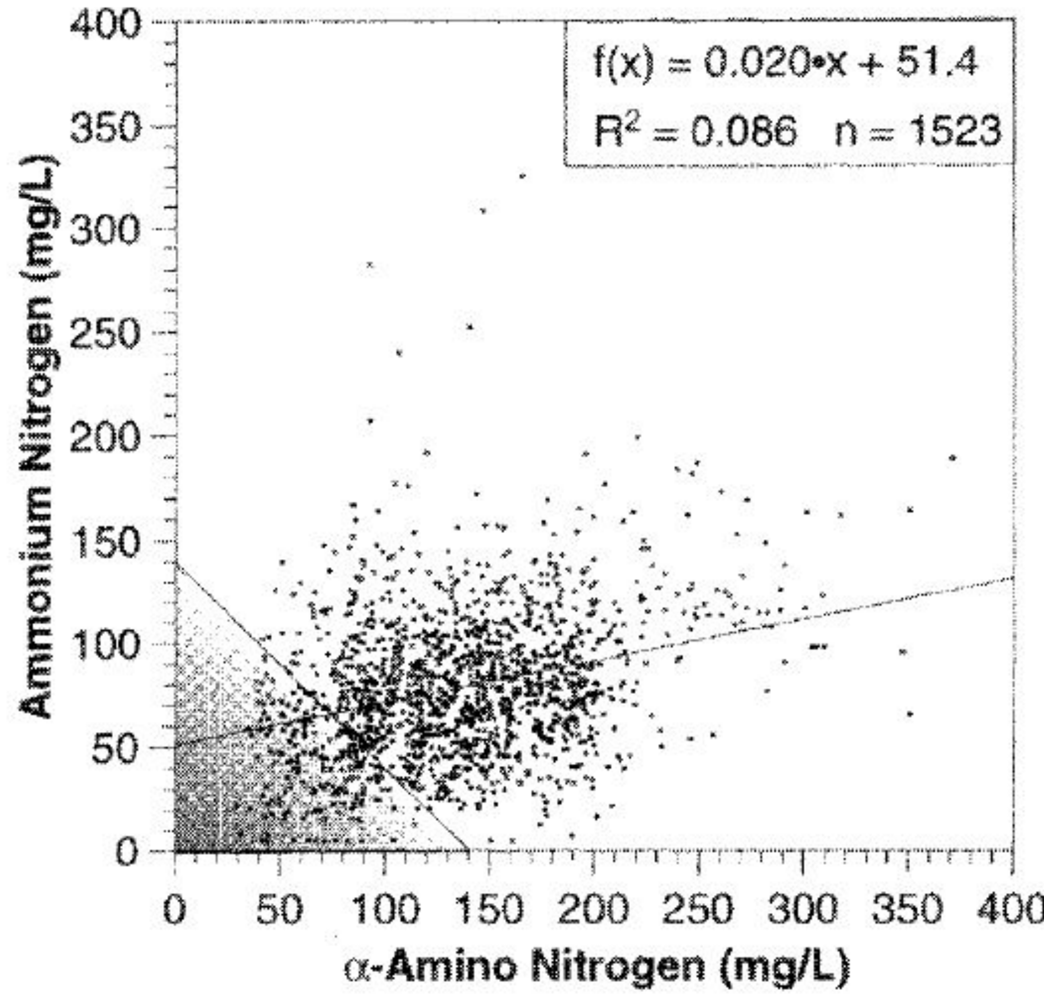
Apples contain very little NH_4^+



Boudreau, et al. 2017, J. Food Sci. & Nutr. DOI:10.1002/fsn3.536/full

COLLEGE OF AGRICULTURE AND LIFE SCIENCES
FOOD SCIENCE
AND TECHNOLOGY
VIRGINIA TECH.

YAN composition varies in GRAPES: Ammonium, NH_4^+ is a substantial factor



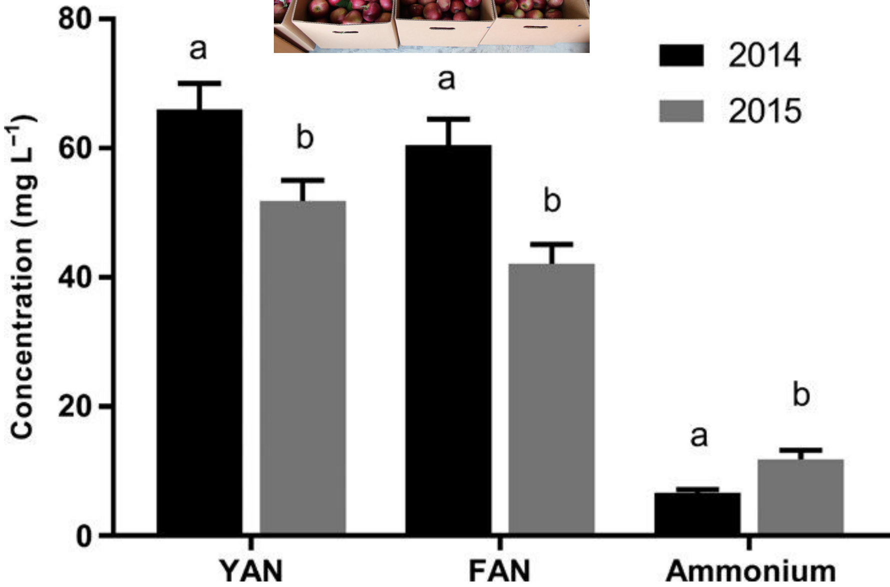
Butzke, 1998. Survey of Yeast Assimilable Nitrogen Status in Musts from CA OR and WA. AJEV. 49(2): 220-224

YAN Survey of Virginia-Grown Apples

- Yeast Assimilable Nitrogen (YAN)
  - Primary Amino Nitrogen (PAN)
    - Also known as Free Amino Nitrogen (FAN)
    - The organic nitrogen fraction—amino acids
  - Ammonium
    - The inorganic nitrogen fraction

- Typical minimum YAN threshold for grape-based white wines is 140 ppm

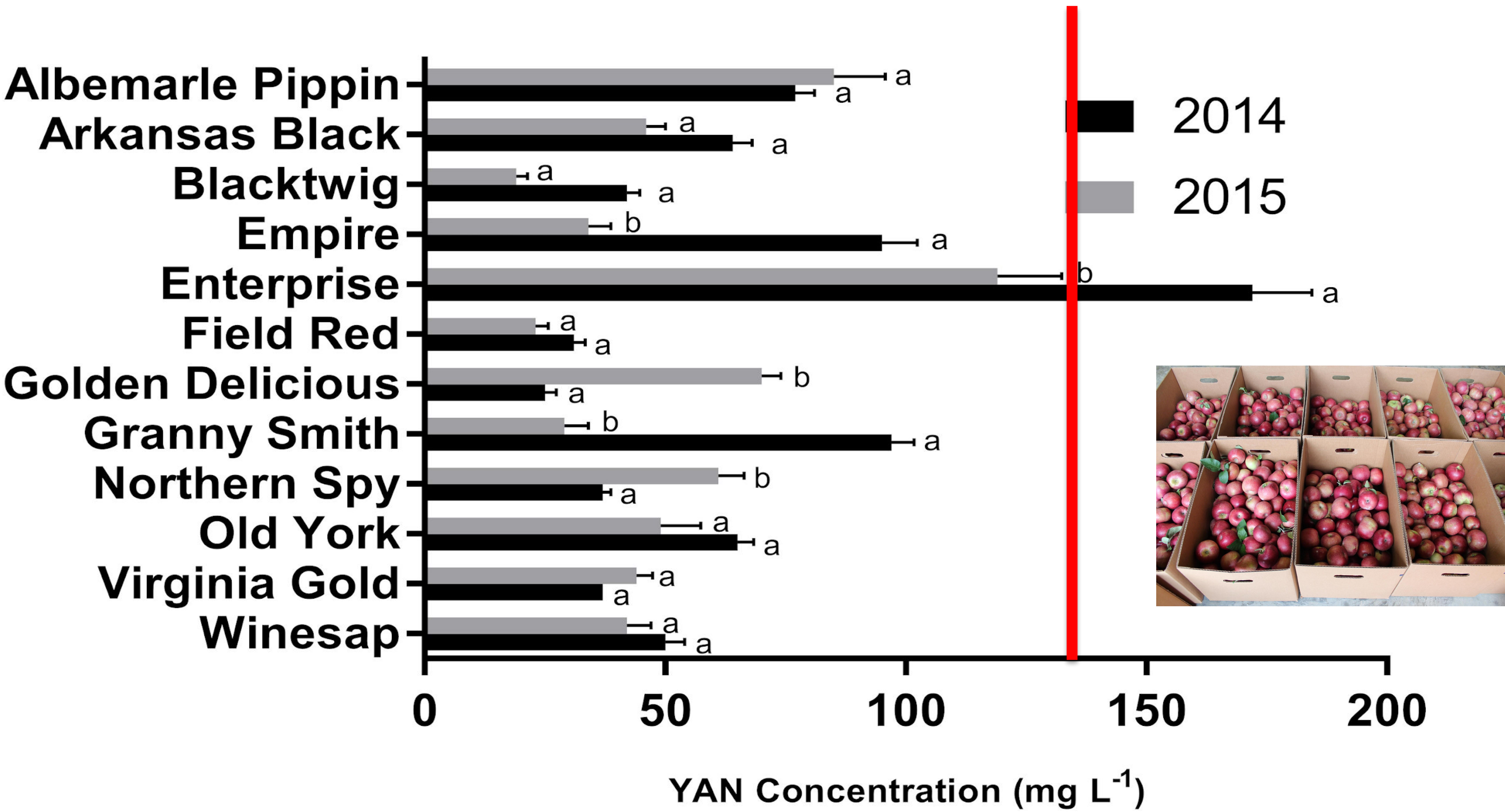
- Thresholds not established for cider fermentation



Comparison of average yeast assimilable nitrogen (YAN), free amino nitrogen (FAN) and ammonium concentrations observed in the 2014 and 2015 seasons (n=108 total apple samples). Error bars signify standard error of the mean, and different lowercase letters indicate differences in a given value between the 2014 and 2015 seasons (two-way t-test with significance defined as $p<0.05$)

Boudreau IV, T.F., **G.M. Peck**, S.F. O'Keefe, and A.C. Stewart. 2018. Free amino nitrogen concentration correlates to total yeast assimilable nitrogen concentration in apple juice. Food Science and Nutrition 6(1):119–123. https://doi.org/10.1002/fsn3.536

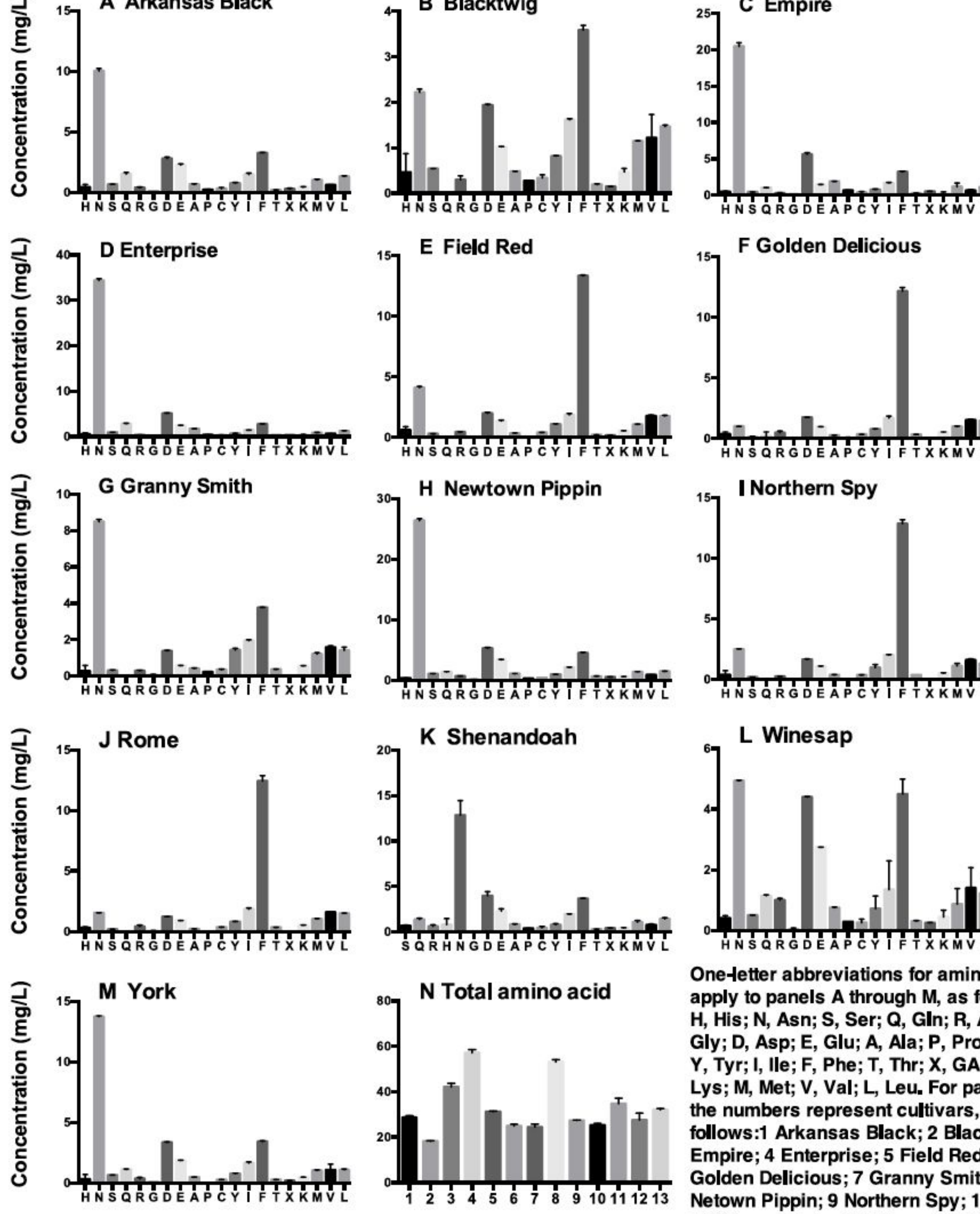
YAN Survey of Virginia-Grown Apples



Boudreau, 2015

COLLEGE OF AGRICULTURE AND LIFE SCIENCES
FOOD SCIENCE
AND TECHNOLOGY
VIRGINIA TECH.

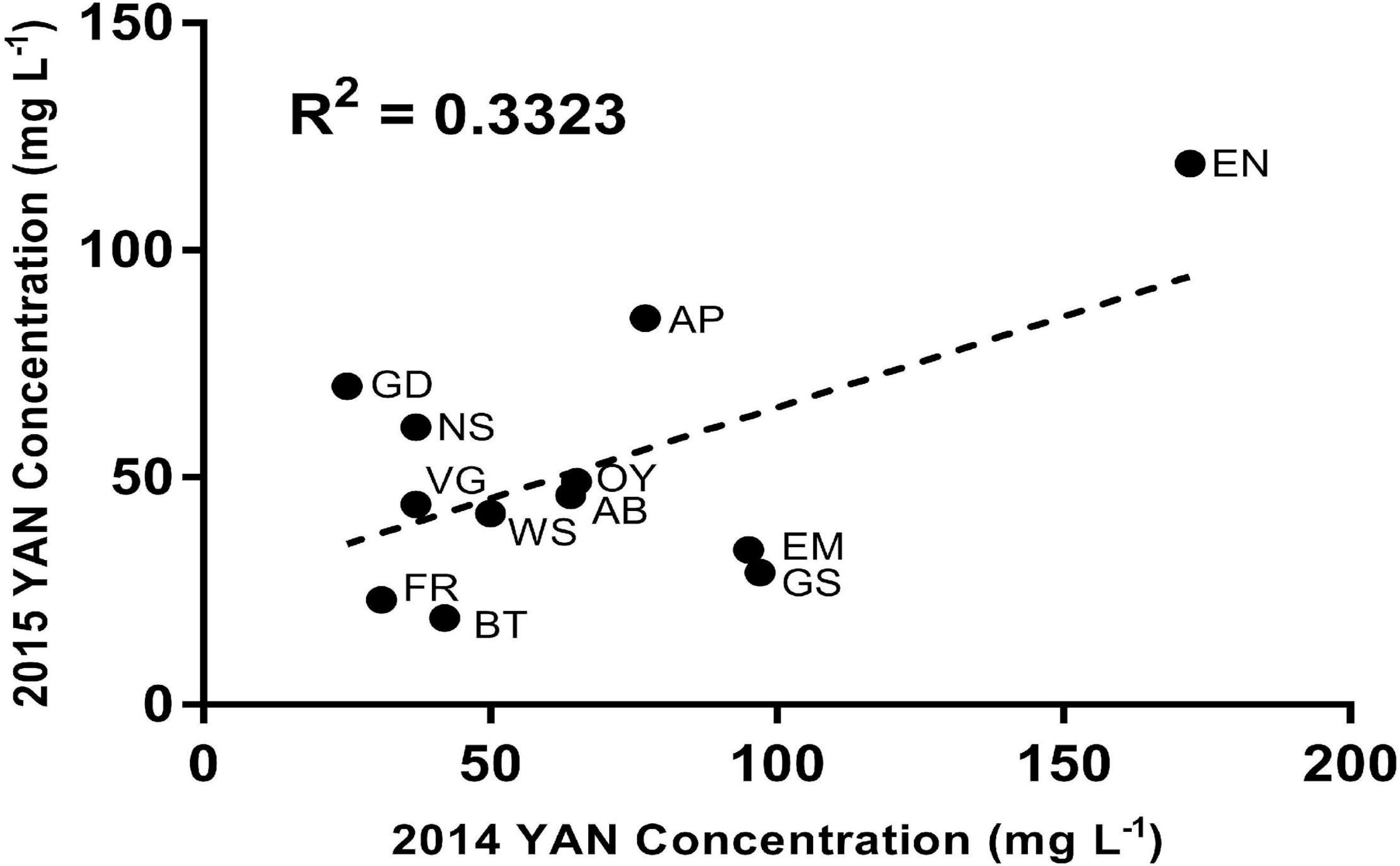
Amino Acid Composition of Apples Grown in Virginia



One-letter abbreviations for amino acid apply to panels A through M, as follows H, His; N, Asn; S, Ser; Q, Gln; R, Arg; G, Gly; D, Asp; E, Glu; A, Ala; P, Pro; C, Cy Y, Tyr; I, Ile; F, Phe; T, Thr; X, GABA; K, Lys; M, Met; V, Val; L, Leu. For panel N the numbers represent cultivars, as follows:1 Arkansas Black; 2 Blacktwig; Empire; 4 Enterprise; 5 Field Red; 6 Golden Delicious; 7 Granny Smith; 8 Netown Pippin; 9 Northern Spy; 10 Rom 11 Shenandoah; 12 Winesap; 13 York.

COLLEGE OF AGRICULTURE AND LIFE SCIENCES
FOOD SCIENCE
AND TECHNOLOGY
VIRGINIA TECH.

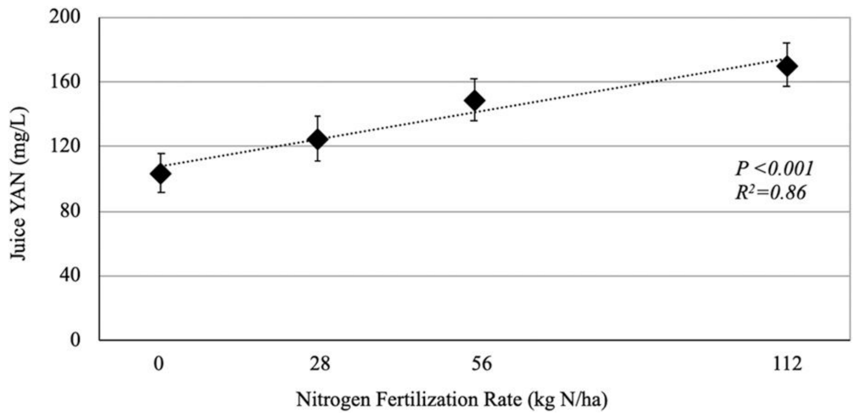
YAN varies from year to year



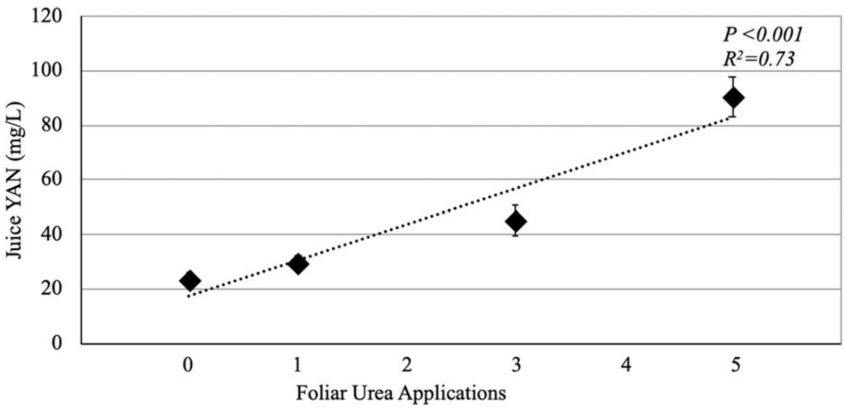
Cider producers can adjust YAN by adding diammonium phosphate (inorganic nitrogen) and/or various proprietary organic products (e.g. Fermaid-K and Fermaid-O)

Can YAN be effectively managed by pre-harvest management?

Both ground (calcium nitrate) and foliar (urea) applications increased apple juice YAN



Yeast assimilable nitrogen (YAN) concentration in 'Golden Russet' apple juice from trees with no, low (28 kg·ha^{-1}), medium (56 kg·ha^{-1}), and high (112 kg·ha^{-1}) calcium nitrate fertilizer application rates in Ithaca, NY. Values are means ± SE (n = 4 per year in 2017 and in 2018).

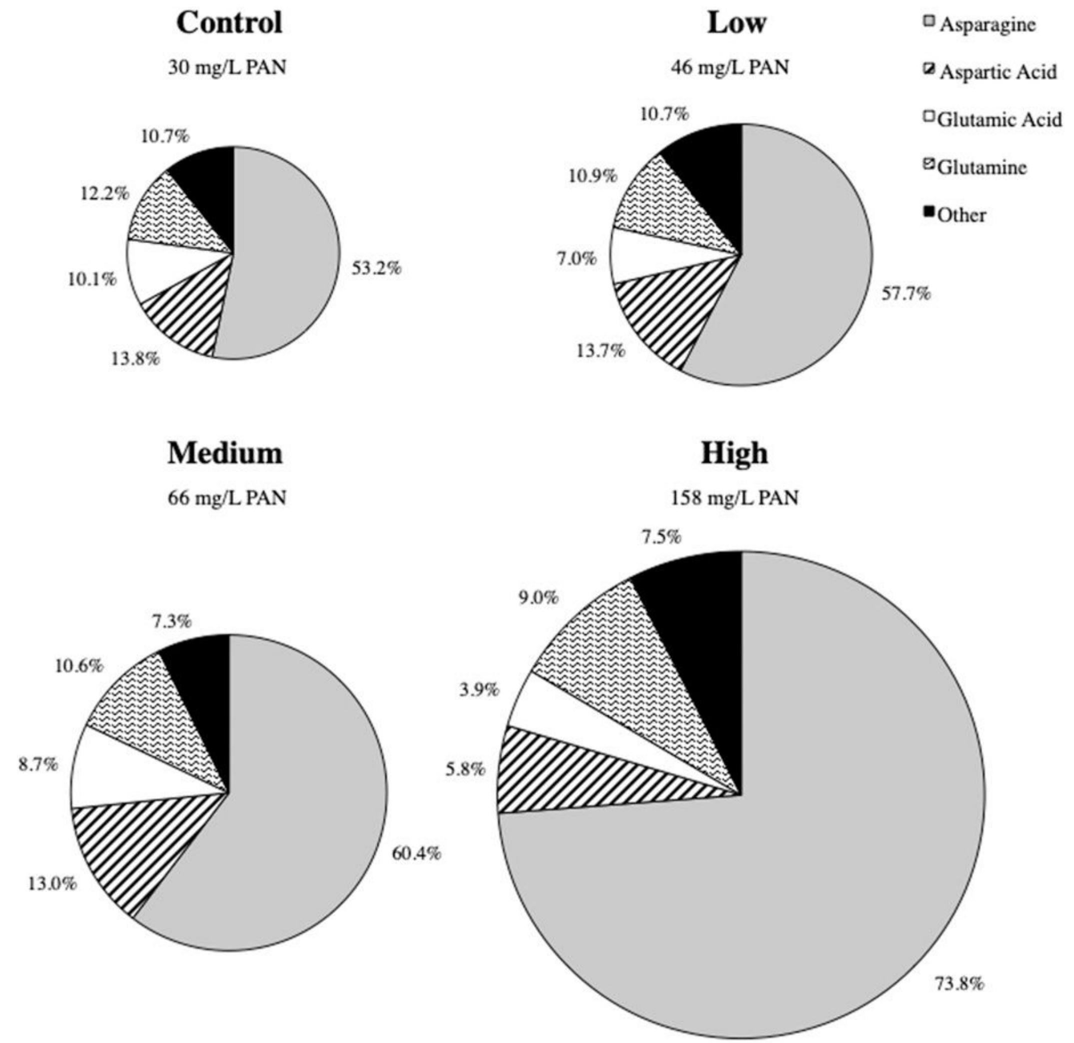


Yeast assimilable nitrogen (YAN) concentrations in 'Red Spy' apple juice from trees in Lansing, NY, that had 0 (control), 1 (low), 3 (medium), or 5 (high) foliar urea applications (10 g·L^{-1}). Values are means ± SE (n = 6 per year).

Karl, A.D., M.G. Brown, S. Ma, A. Sandbrook, A.C. Stewart, L. Cheng, A.K. Mansfield, and **G.M. Peck**. 2020. Foliar urea applications increase yeast assimilable nitrogen concentration and alcoholic fermentation rate in 'Red Spy' apples used for cider production. HortScience 55(8):1356–1364. https://doi.org/10.21273/HORTSCI15029-20

Karl, A.D., M.G. Brown, S. Ma, A. Sandbrook, A.C. Stewart, L. Cheng, A.K. Mansfield, and **G.M. Peck**. 2020. Soil nitrogen fertilization increases yeast assimilable nitrogen concentrations in 'Golden Russet' and 'Medaille d'Or' apples used for cider production. HortScience 55(8):1345-1355. https://doi.org/10.21273/HORTSCI15028-20

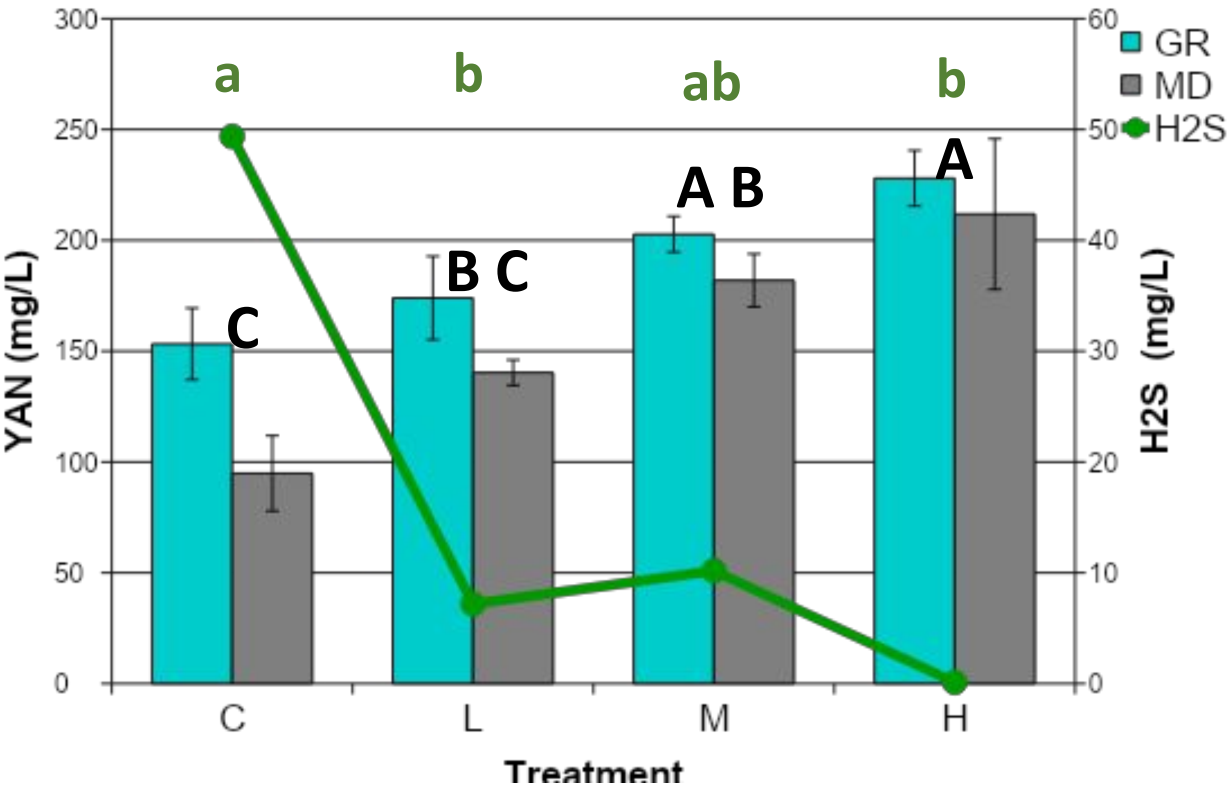
The YAN increases mostly consist of amino acids



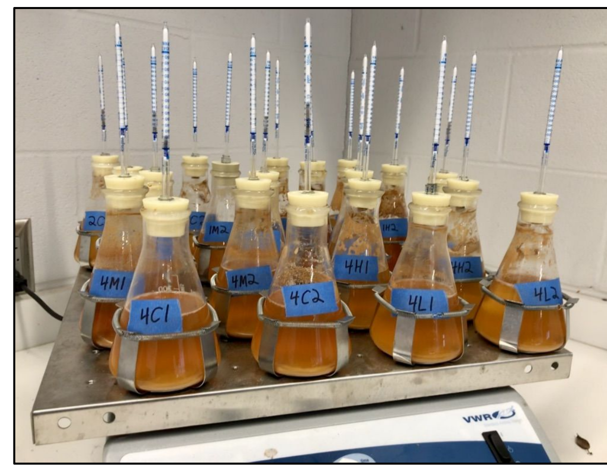
Total concentrations of primary amino nitrogen (PAN) and proportions of amino acids constituting apple juice PAN from 'Red Spy' apple trees in Lansing, NY, that had 0 (control), 1 (low), 3 (medium), or 5 (high) foliar urea applications. Pie chart sizes are to scale of PAN concentration among the treatments. Data represent a "combined" mean from both years of the study.

Karl, A.D., M.G. Brown, S. Ma, A. Sandbrook, A.C. Stewart, L. Cheng, A.K. Mansfield, and **G.M. Peck**. 2020. Foliar urea applications increase yeast assimilable nitrogen concentration and alcoholic fermentation rate in 'Red Spy' apples used for cider production. HortScience 55(8):1356–1364. https://doi.org/10.21273/HORTSCI15029-20

Yeast Assimilable Nitrogen and H_2S Production



Yeast Assimilable Nitrogen (YAN) concentration of Golden Russet and Medaille d'Or juice, and H_2S production of Golden Russet cider during fermentation. Connecting letters report for H_2S in lower case, and primary amino nitrogen in upper case. Errors bars represent SEM.



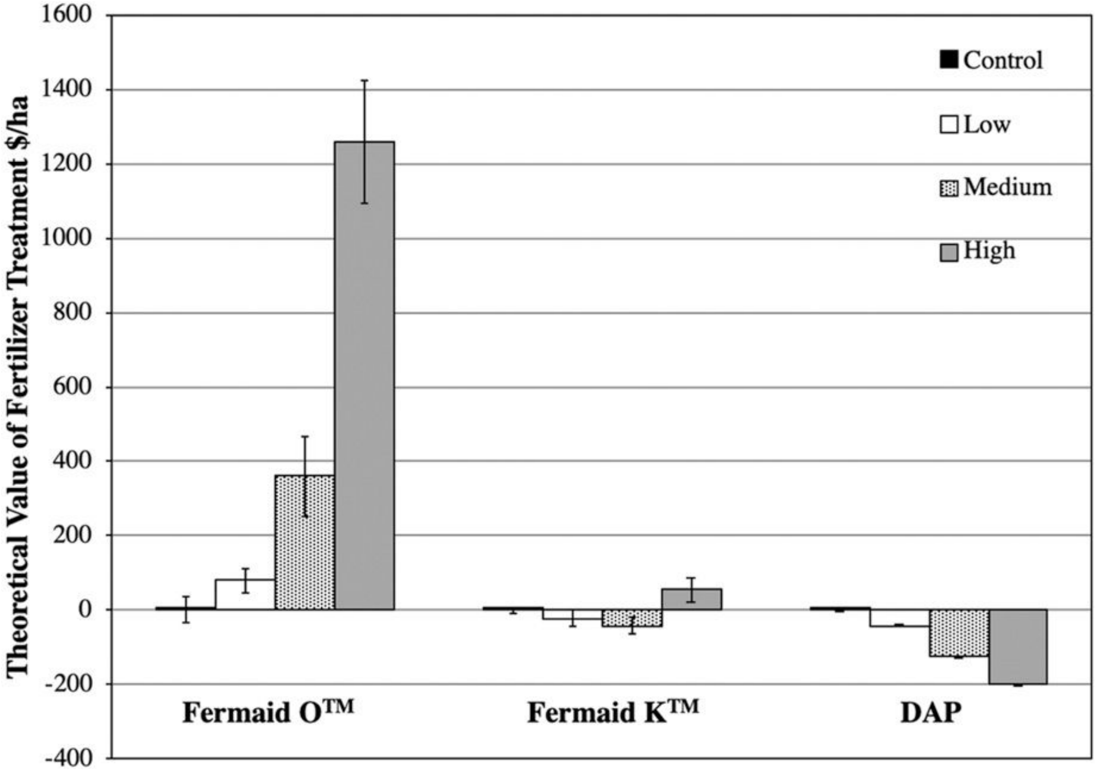
Cornell CALS College of Agriculture and Life Sciences

Karl, A.D., M.G. Brown, S. Ma, A. Sandbrook, A.C. Stewart, L. Cheng, A.K. Mansfield, and **G.M. Peck**. 2020. Soil nitrogen fertilization increases yeast assimilable nitrogen concentrations in 'Golden Russet' and 'Medaille d'Or' apples used for cider production. HortScience 55(8):1345-1355. https://doi.org/10.21273/HORTSCI15028-20

Pre-harvest nitrogen applications do not always lead to lower hydrogen sulfide production

- Often, the YAN increases were below the 140 ppm threshold developed for white wine
- Even when we were able to double the YAN, H_2S production still occurred during cider fermentations
- Fermentation rates increased when YAN was increased
    - Can be a positive or negative depending upon production goals
- No effects on other juice quality attributes, such as soluble solids concentration, titratable acidity, and total polyphenols
- No effects on yield or return bloom, but these were short-term studies (2 years)

Are pre-harvest nitrogen applications cost effective?



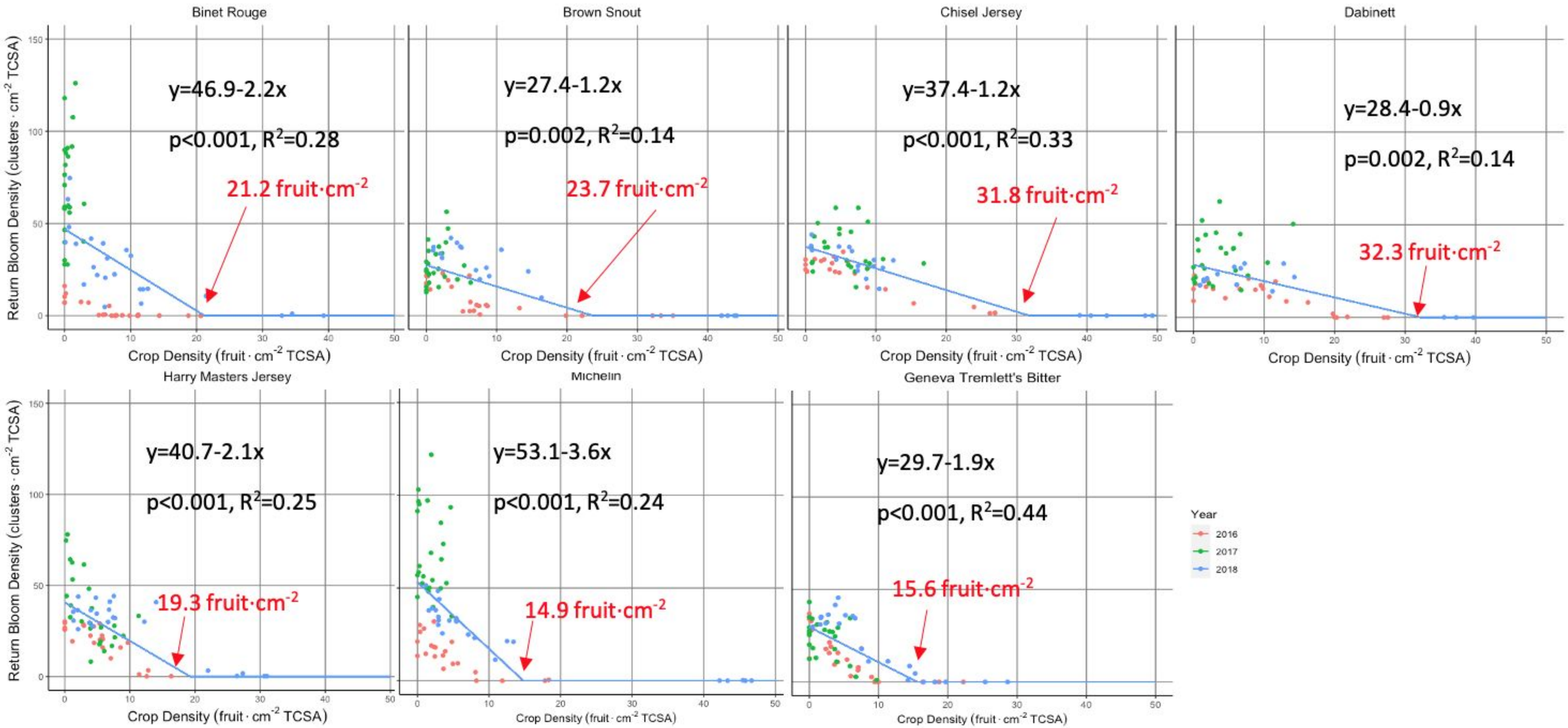
The theoretical cost of applying foliar urea to 'Red Spy' apple trees grown in in Lansing, NY, that had 0 (control), 1 (low), 3 (medium), or 5 (high) foliar urea applications vs. adding exogenous yeast assimilable nitrogen in the form of Fermaid O , Fermaid K , or diammonium phosphate (DAP). Values are means ± SE (n = 6 per year).

Cornell CALS College of Agriculture and Life Sciences

Karl, A.D., M.G. Brown, S. Ma, A. Sandbrook, A.C. Stewart, L. Cheng, A.K. Mansfield, and **G.M. Peck**. 2020. Foliar urea applications increase yeast assimilable nitrogen concentration and alcoholic fermentation rate in 'Red Spy' apples used for cider production. HortScience 55(8):1356–1364. https://doi.org/10.21273/HORTSCI15029-20

Precision Crop Load Management

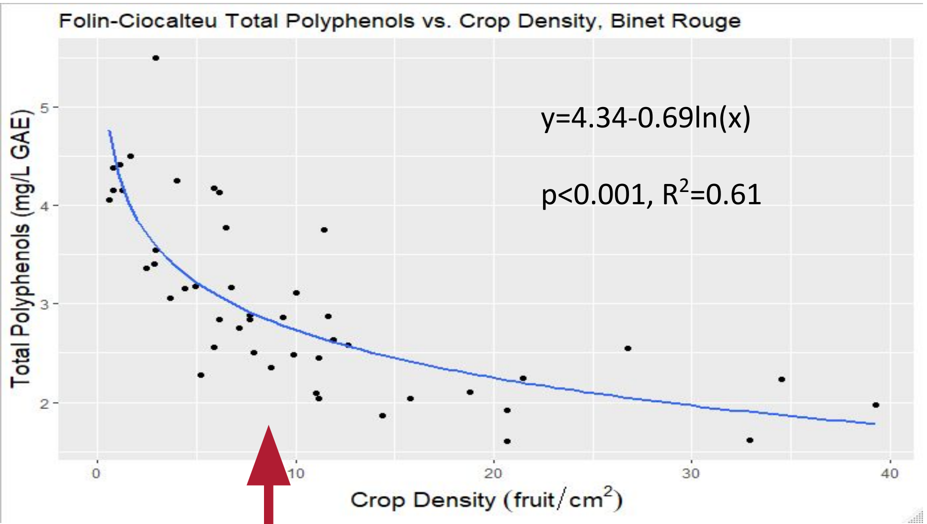
Many cider cultivars are biennial, but they can and should be thinned

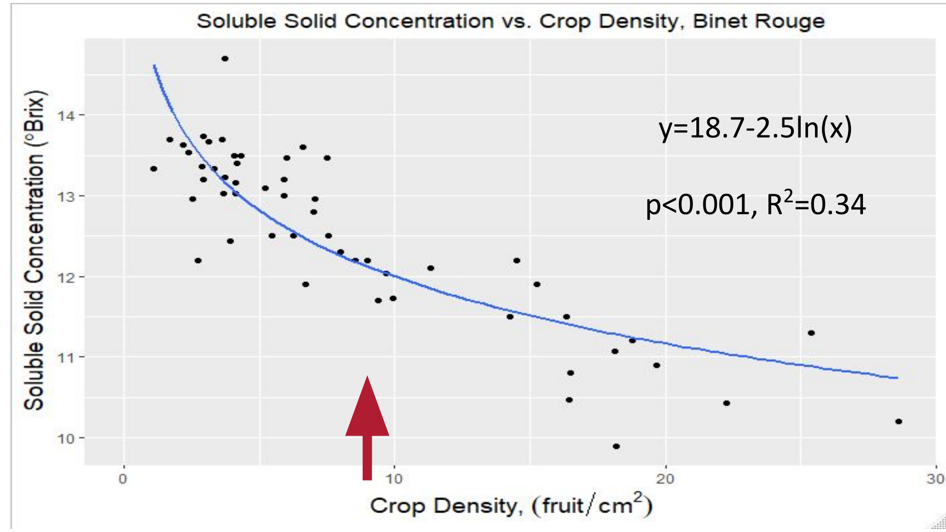


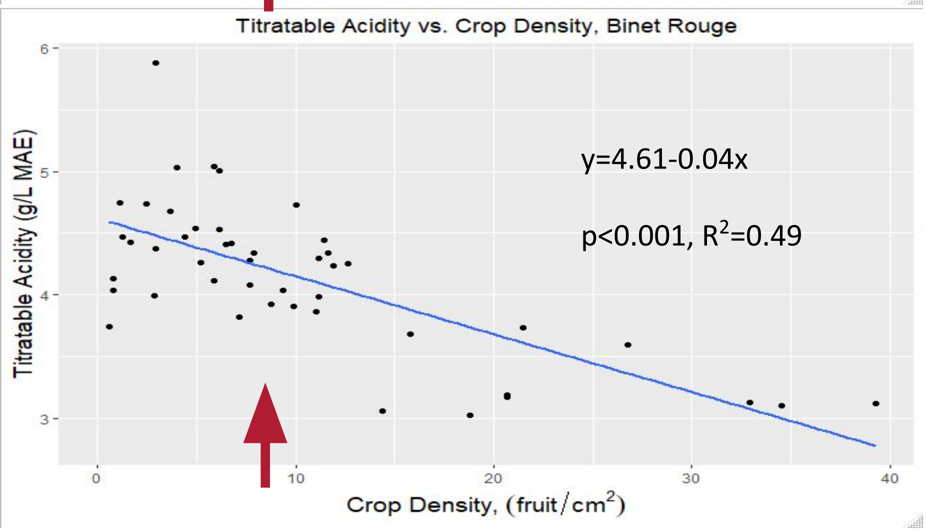
Three-year hand-thinning experiment at a commercial apple orchard in Lyndonville, NY, 2016-2018. Each point represents a single measurement of one tree in one year. Trunk cross sectional area (TCSA) measured 40 cm above the graft union

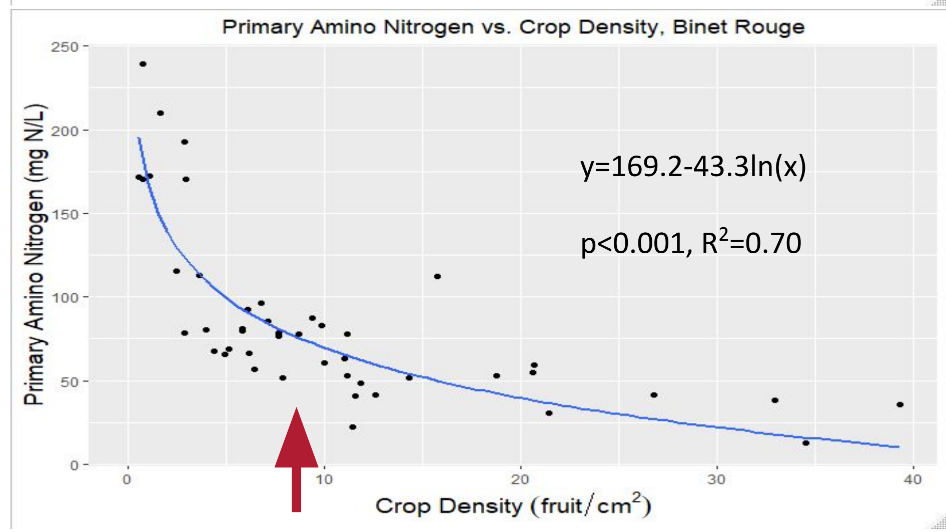
Zakalik, D., M. Brown, and G.M. Peck. Fruitlet Thinning Reduces Biennial Bearing in Seven High-Tannin Cider Apple Cultivars. HortScience. (Accepted)

Increasing Crop Load Reduces Juice Quality









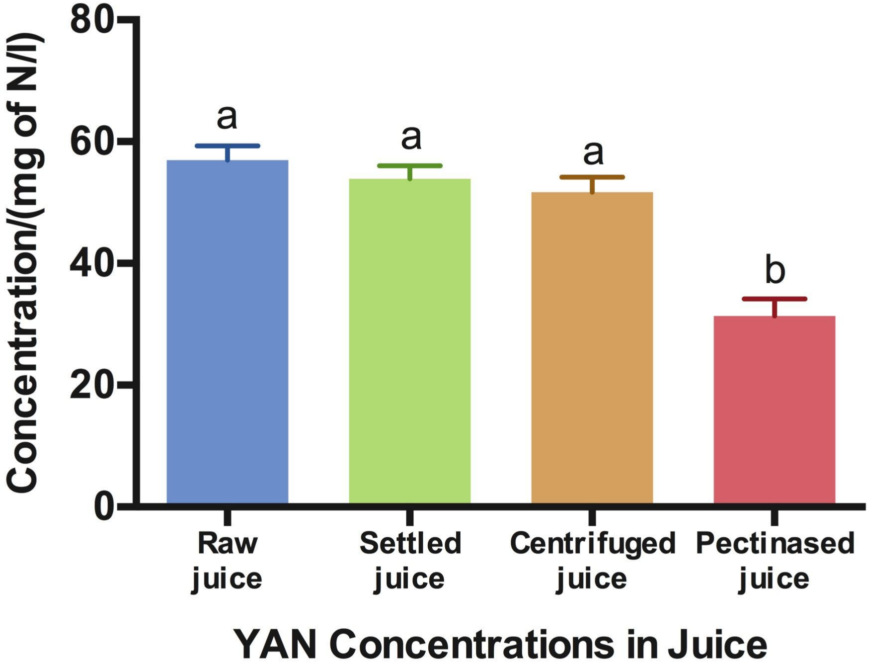
As crop density (number of fruit relative to TCSA) increased, all parameters of juice quality decreased, typically logarithmically.

Cornell CALS College of Agriculture and Life Sciences

Zakalik, D., M. Brown, and G.M. Peck. 2023. Fruitlet thinning improves juice quality in seven high-tannin cider cultivars. Hortscience. 58(10):1119-1128.

Juice Clarification and YAN

- Juice clarification can change chemistry
- Pectinase decreased YAN by ~30%
- Pectinase did not decrease polyphenols
- More research is required



Ma et al. 2018. Juice clarification with pectinase reduces yeast assimilable nitrogen in apple juice without affecting the polyphenol composition in cider. J. Food Sci. 83(11): 2772-2781

Many factors contribute to YAN variability

- Fruit Species, Cultivar
- Orchard management
  - Fertilizer
  - Irrigation/rainfall
  - Crop Load
  - Pest Management
- Processing/Storage
  - Juice clarification?
  - Postharvest storage?
- Others?

How YAN Affects Cider

- ***Concentration*** of YAN affects:
    - Fermentation rate
    - H_2S production by yeast during fermentation
- Nitrogen ***composition*** affects yeast metabolism, too:
    - Balance of ammonium ions and amino acids
    - Amino acid composition
    - Impacts both fermentation rate and aromas produced by yeast, both good and bad!

Factors that interact with YAN to influence cider sensory outcomes

- Yeast strain
- pH
- Biotin
- Pantothenic acid
- Amino acid composition?
- Fungicide residues?
- Phenolic compounds?

YAN Composition and Wine Aroma: *Some research exists…*

- Ammonium additions to juice/must (DAP)
  - Decreased sulfur-like aromas
  - More citrus character
- Amino acid additions to juice/must (organic Nitrogen)
  - Decreased sulfur-like aromas
  - Richer in fruity notes
- *Does YAN composition affect varietal character?*

Hernandez-Orte et al. 2004, Hernandez-Orte et al. 2006, Garde-Cerdan 2008

Methionine and H_2S

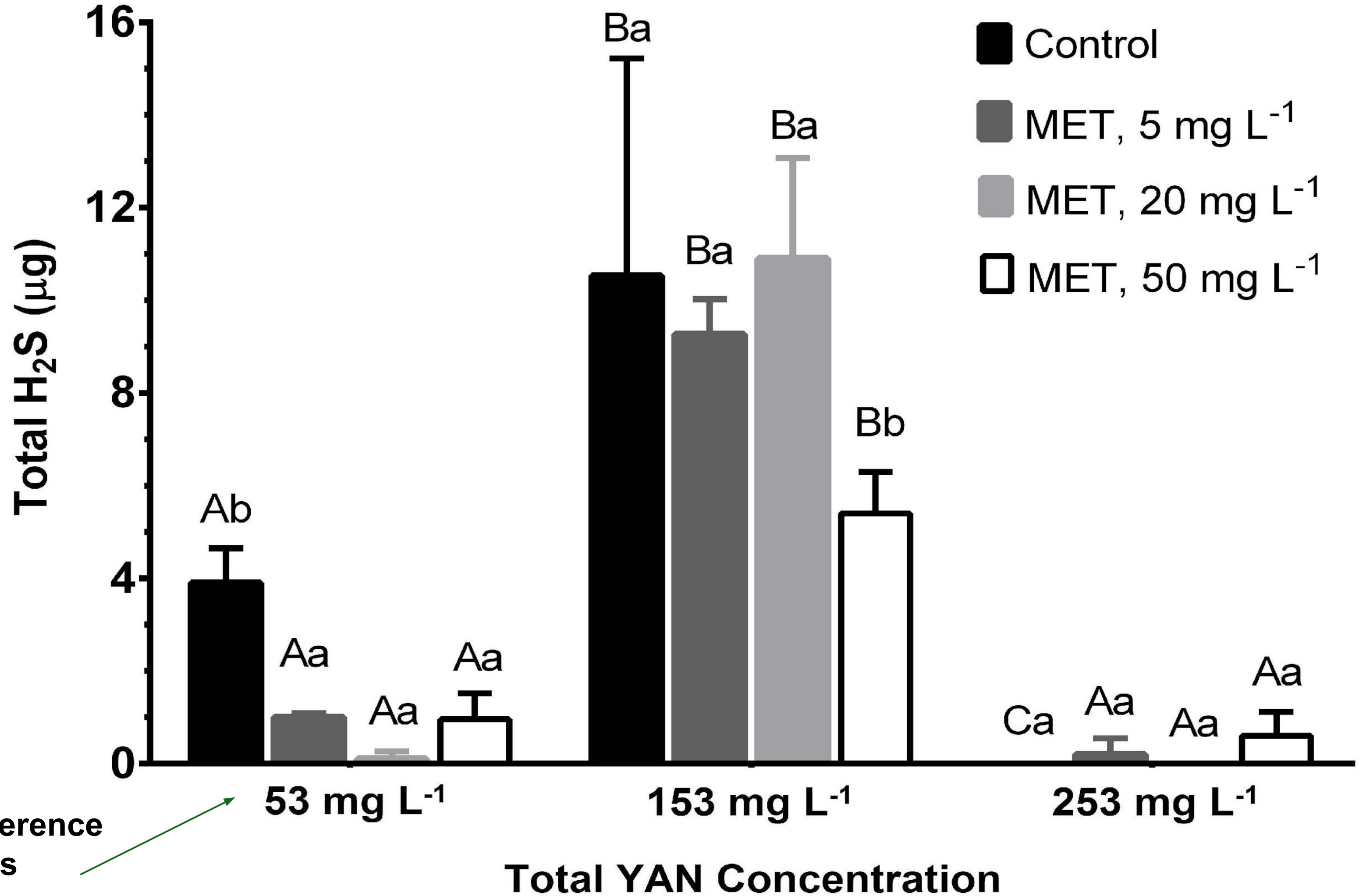
- Sulfate Reduction Sequence (SRS) activity can lead to H_2S production by some yeast strains
- Presence of methionine can inhibit SRS
- <20mg/L has been linked to H_2S production
- Grapes generally contain more than 20mg/L Met
- We observed <5mg/L Met in 15 cultivars of apple

(Ma and Boudreau 2015, Eschenbruch 1974, Ye et al. 2014)

Methionine and H_2S

- Started with 3 YAN levels:
  - 53 mg/L (endogenous in apple juice)
  - 153 mg/L (YAN added as diammonium phosphate)
  - 253 mg/L (YAN added as diammonium phosphate)
- Added methionine to each:
  - 0 mg/L (control)
  - 5 mg/L
  - 20 mg/L
  - 50 mg/L
- Hypothesis 1: Addition of methionine will result in lower H_2S production during fermentation
- Hypothesis 2: Effects of methionine addition on H_2S production will differ at different total YAN concentrations

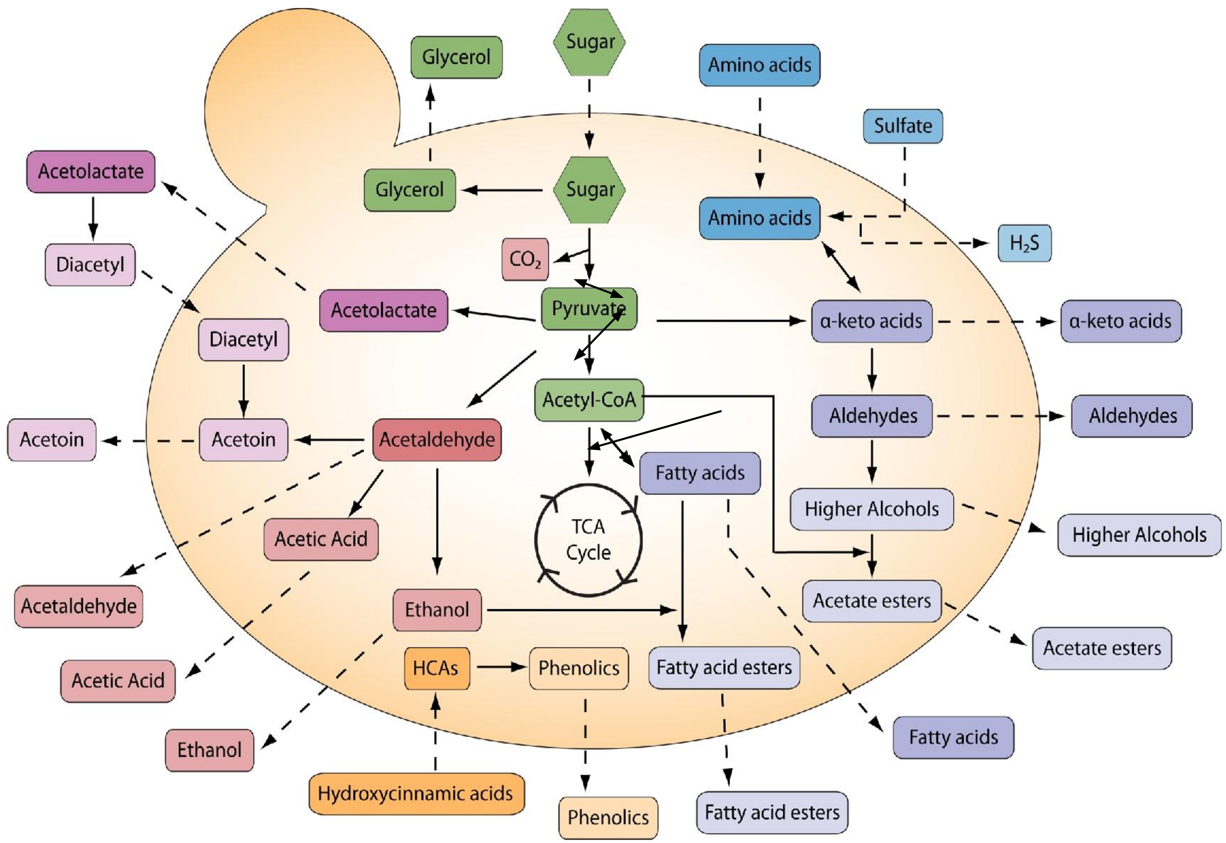
EC1118: Interactive Effect of Met and YAN



Sensory difference perceived b/s Control vs. methionine added at 20mg/L

Journal of the Institute of Brewing, 2017, Volume 123, Issue 4, Pages 553–561

Yeast Assimilable Nitrogen and Aromatic Volatile Synthesis

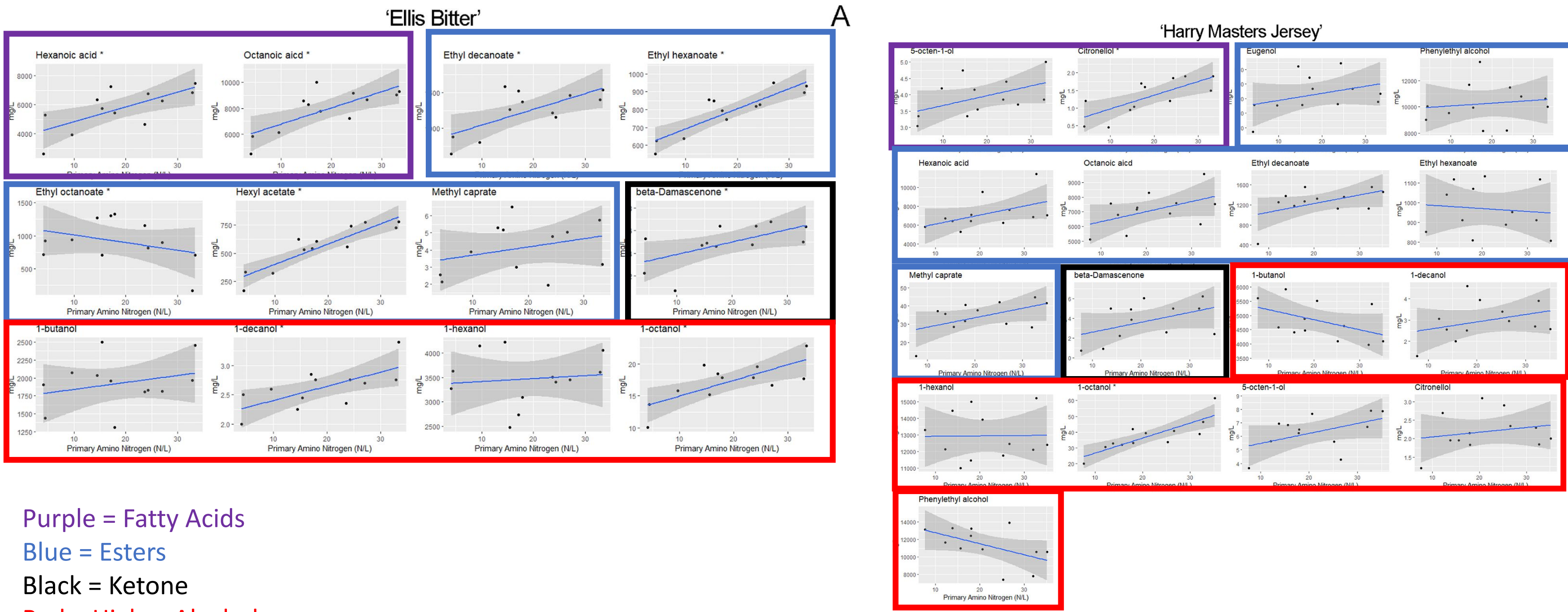


Yeast play a crucial role in the **production of aromatic volatiles** during **fermentation**.

Most of the aromas found in cider are **secondary aromas produced by yeast**.

Dzialo et. al

Aromatic volatiles are mostly increased with increasing juice YAN concentration



Purple = Fatty Acids
Blue = Esters
Black = Ketone
Red = Higher Alcohols

Concentration of targeted volatiles with respect to primary amino nitrogen in 'Ellis Bitter' (A) and 'Harry Masters Jersey' (B) hard cider samples from an experiment conducted in 2021 in Ithaca, NY. Values are mean ± standard error (n = 4). Compounds that had a significant regression (P ≤ 0.05) are indicated with an asterisk. Shaded band represents 95% confidence interval for the fitted values. Extreme outliers (several hundred magnitudes from the median) were omitted.

Cook, B.S., M.G. Brown, Y. Lin, M.T. Kwasniewski, M. Ac-Pangan, A.C. Stewart, and **G.M. Peck**. 2024. Foliar urea applications to apple trees increase yeast assimilable nitrogen, amino acids, and flavor volatiles in fruit and hard cider. Journal of Agriculture and Food Research. 16:101136
https://doi.org/10.1016/j.jafr.2024.101136

Main factors for fermentative aromas production

2. Nitrogen




Aromas production by Su	Low YAN 40 to 80 mg/L	High YAN 150 to 250 mg/L
Isoamyl acetate	-	+
Hexyl acetate	-	+
2-phenylethanol	+	-
2-phenylethylacetate	+	-

Nitrogen in Apple depends on various factors : Variety, Age of the orchard, Fertilization (what, how, and when), Climate&Soil context, post harvest storage, etc.

Yan addition -> organic form or complex mineral/organic/vitamin

Slide provided by Yann Gilles

Nitrogen Recommendations

- Young trees:
  - Ground application: 20-40 lbs N/acre ~1 month before bloom
  - Foliar: 4 lbs/acre urea until mid-summer

- Mature trees (as needed based on leaf analysis):
  - 20-40 lbs N/acre late winter or early spring
  - Foliar: 4 lbs/acre urea if needed for vigor and there's minimal risk of fireblight

- Some rules of thumb
  - Increase N application rate by 10% for each 0.1% increase in leaf N
  - For every 1% OM in the soil, expect ~20 lbs of N released into the soil

Philosophy on Nitrogen

- Too little nitrogen will lead to stuck or sluggish fermentation, and/or H_2S production
- YAN profile can be modified by both orchard AND cidery practices
- Apples naturally contain little to no ammonium ion YAN
- Changing the concentration and composition of the YAN available to yeast may change your cider aroma and flavor

Consider the role of nitrogen management in the whole system on cider terroir!

Nitrogen in Practice

- ***Production philosophy & goals***: *what is your philosophy and goal?*
- ***Tools & tactics:*** *DAP vs. organic nutrients; balancing yeast choice & load*
- ***Managing low-nitrogen fermentations:*** *keeving*
- ***Risk management:*** *H_2S, reduction, and other nitrogen-related faults*
- ***Operational reality:*** *adapting nitrogen decisions to your facility, fruit, yeast, production philosophy, and desired outcomes*

You must do what works for you!

CIDER INSTITUTE

Thank you!

ciderinstitute.com

@ciderinstitute