Silage Volatile Organic Compounds – Effects on the Environment and Animal Performance

Karl-Heinz Südekum
University of Bonn, Bonn, Germany

ksue@itw.uni-bonn.de

Background

- Preservation of forage: minimize dry matter (DM), energy, and quality losses
- Maintaining resource cycle and nutritional quality of harvested material
- DM losses occur similtaneously with shifts in chemical composition, accompanied by gaseous emissions
- What are volatile organic compounds (VOC)?
- Several definitions exist for VOC
- World Health Organization (WHO): Any substance having a boiling point of less than 250°C when calculated at 101.3 kPa standard atmospheric pressure

Silage VOC

Routinely measured	Major producers/pathway
Acetic acid	heLAB, Enterobacterales
Butyric acid	*Clostridia*, *Bacillus*
Ethanol	Yeast, heLAB, Enterobacterales, *Clostridia*
Propionic acid	LAB, *Clostridia*, Enterobacterales, PAB

Non-routinely measured	Major producers/pathway
2,3 -Butanediol	Enterobacterales, LAB, bacilli, yeast
Propanol	heLAB, yeast, *Clostridia*
1,2 -Propanediol	heLAB, *Clostridia*
Esters	LAB, yeast, abiotic pathway
Iso-butyric acid	heLAB
Methanol	Crop maceration
Ketones	LAB, bacilli
Aldehydes	Crop maceration, abiotic, LAB, yeast

By Alexander Rahm – https://commons.wikimedia.org/w/index.php?curid=3640352

By Ellywa https://commons.wikimedia.org/wiki/File:Aanleg_van_kuilgras_juli_2012.JPG

Bandla et al. 2024; Anim. Feed Sci. Technol. 307, 115853

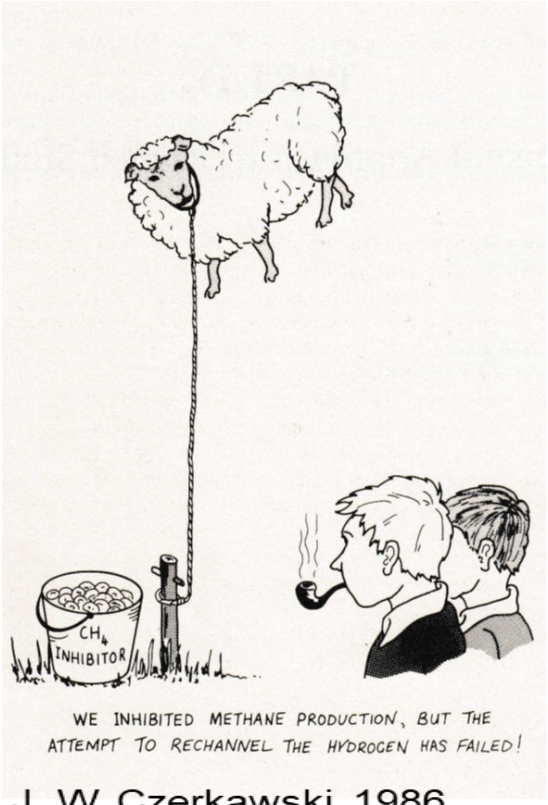
Silage VOC

- Shifts in chemical composition and gaseous emissions

Direct or indirect impact on

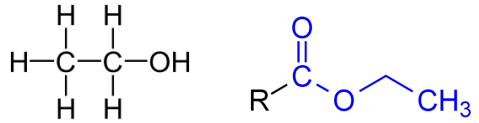
- Environment
- Animal performance

Silage VOC and Environment



J. W. Czerkawski, 1986. An Introduction to Rumen Studies. Pergamon Press

- Climate and environmentally relevant gases during anaerobic fermentation and after silo opening
- Predominantly CO_2, nitrous oxide and methane formed during the anaerobic phase
- VOC, e.g., ethanol, ethyl esters, produced at various stages



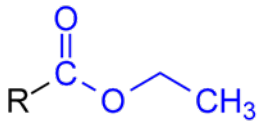
- Emissions after silo opening
- Direct effect of emissions from silage on the environment? Climate-neutral
- CO_2 emits from CO_2, captured recently through photosyn-thetic pathways

Silage VOC and Environment

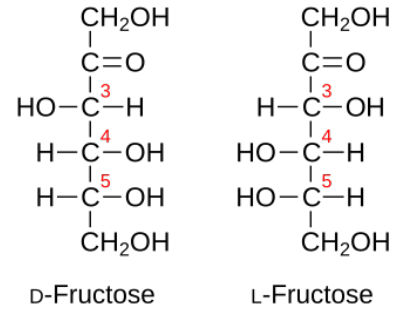
- Indirect carbon footprint of CO_2 emission from silage?
- Proportional to formation and release – mass losses
- Discounts per unit of harvested forage, balanced by additional forage or other dietary ingredients
- Additional carbon footprint, food–feed–… competition ("human edible fraction")

- **Indirect carbon footprint of VOC emission from silage?**
- VOC from numerous sources and (bio)chemical pathways
- Quantification challenging

Silage VOC and Environment – Quantification



- Large range of results depending on which VOC are concerned
- Major compounds, i.e., acetic acid and propionic acid, mainly formed from monomeric carbohydrates (‘sugar‘)
- CO_2 emissions **much lower** than
- Ester formation from ethanol, because ethanol formation is associated with huge losses of CO_2



- **Conclusion**
- Reduce or prevent VOC generation and emission, even if adverse effects of VOC on dry matter intake (DMI) and feed choice behavior are <u>not</u> considered

Silage VOC and Environment

- Future studies on climate relevant and environmentally relevant gaseous emissions from silage may help to answer the question:

- "**Can silage absorb more carbon than it emits during fermentation?**" (Schmidt and Vigne 2023; XIX ISC, Beijing, China, 67–73)

Silage VOC and Animal Performance

- Aerobic, fermentation, feed-out phases of ensiling and silage use all allow formation of non-volatile organic acids (lactic!), protein and amino acid degradation compounds, and other microbial metabolites
- **Plus:** Desirable and undesirable VOC at different concentrations and variable effects on silage quality

Frank Vincentz creativecommons.org/licenses/by-sa/3.0/>, , CC BY-SA 3.0 <http://via Wikimedia Commons

- VOC impact on silage preference and DM intake

via

- Palatability and physiological effects: osmolality changes, rumen motility, hepatic oxidation, postingestive feedback, …

Silage VOC and Animal Performance

- VOC effects on animal performance are largely indirect – mediated through (negative) impact on overall and rate of DM intake, or forage preference in a choice situation.

- Direct undesirable effects of VOC on animal performance and health much less frequently observed

because

- "Ruminants possess a degree of nutritional wisdom in the sense that they generally select foods that meet nutritional needs and avoid foods that may cause toxicosis" (Provenza 1995; J. Range Manage. 48,2-17)

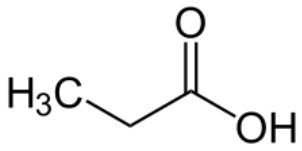
Silage VOC and Animal Performance

- Variety of VOC during different stages of ensiling
- Concentrations typically ranging from (<) 1 to 200 g/kg DM
- Inconsistent results, yet available evidence from silage intake models

suggest

- At ‘normal‘ concentrations, acetic acid and (to some extent) propionic acid might be major contributors to ⇓ DM intake
- In contrast, when these VOC are added to the diet or when heterofermentative bacteria increased acetic acid in the silage

  ⇛Impact of acetic acid is less pronounced
- Propionic acid rarely used as pure substance in forage to determine effects on preference and DM intake



Silage VOC and Animal Performance

- **Suggestion (recommendation?)**

- Test VOC effects for their role in DM intake by adding the VOC to a non-fermented forage or diet

and

- Just before feeding to have negligible losses

Silage VOC and Animal Performance

- Metabolomics have (partly) revolutionized the health and food sector

- Quantification of a detailed silage metabolome is a relatively new approach
- Even less studies have linked metabolomic data and silage preference in animals
- In addition to routinely measured metabolites, several thousand metabolites (up to 6,000), including VOC, can be detected in silage

- Detection is ≠ annotation (identification) ≠ quantification

- Relative abundance of (volatile) metabolites can change

  Species of ensiled forage crop, use and type of inoculants, …

Silage VOC and Animal Performance

- **Much** emphasis on the occurrence of VOC in silage
- **Less** emphasis on the formation (synthesis) of VOC

- Most notably, precise knowledge on non-routinely measured VOC – aldehydes, esters, and ketones – is still very scant
- Aldehydes and esters show peculiarities

- Aldehydes – expensive and tedious analysis **and**
- No dominant compound – no pattern recognition

Silage VOC and Animal Performance

- Esters – debate on the major route of synthesis: biotic or abiotic

- Biotic synthesis: Lactic acid bacteria and yeasts synthesize esters using different biochemical pathways

- Abiotic synthesis: Esters such as ethyl lactate produced at slow pace but rapidly generated when surplus lactic acid and ethanol in the presence of charged hydrogen ions

Silage VOC and Animal Performance

- Direction and magnitude of response of animals to VOC
- Type of response (i.e., positive, negative, neutral) to an individual VOC likely similar among different ruminant species

- Magnitude of the response?
- Taste perception may vary – sweetness has a positive hedonic value in cattle but not in sheep, goats are more tolerant of a bitter taste than sheep and cattle
- Lack of simultaneously conducted comparative studies with identical silages on 2 or 3 ruminant species
- Room for further studies

Conclusions

- Future studies that employ metabolomic analysis in addition to or combination with substantial ‘routine‘ chemical and microbiological analysis may help
- To reveal the potential of other unidentified VOC that can impact silage preference and intake

- Discovering these VOC and developing proper management strategies to control them may help
- To reduce undesirable effects on the environment and contribute to the improvement of productivity, profitability, and sustainability of ruminant production

Questions?

Tyrolese grey cattle

Source: KHS