ANIMAL SCIENCE (MS)

Fermentation in ruminants

Focus question	How might we maximize digestion in cows by using energy concentrate byproduct materials in the total mixed ration?
Learning target	Students will determine the best energy concentrate by-product to use in a total mixed ration (TMR).
Vocabulary	Enticer/energy concentrate by-product materials, total mixed ration (TMR), total digestible nutrients (TDN)

MS-PS1-2 Matter and its Interactions
MS-LS1-7 From Molecules to Organisms: Structures and Processes

Performance expectation MS-PS1–2	**Classroom connection:** Students create a model of a mini-fermenter to test the amount of gas created due to chemical change within the model.
Performance expectation MS-LS1–7	**Classroom connection:** Students determine the difference between the model and the actual digestive system of a ruminant (i.e. enzymes and outputs) using info from a previous lesson.

Science and engineering practices

Planning and carrying out investigations **Analyzing and Interpreting Data** **Constructing explanations and designing solutions**	**Classroom connection:** Students conduct an experiment to determine the best energy concentrate by-product to use in a TMR, then write an explanation based on evidence for their claim.

Disciplinary core ideas

PS1.B: Chemical Reactions	**Classroom connection:** Students observe the results of a biological and chemical reaction within their model.
LS1.C: Organization for Matter and Energy Flow in Organisms	**Classroom connection:** Students analyze data to describe how the energy concentrate by-product tested might impact digestion in cows.

Cross-cutting concepts

Patterns	**Classroom connection:** Students understand fermentation as an example of digestion that shows chemical changes.
Energy and Matter	**Classroom connection:** Students trap gas to show that atoms are conserved.

Background

The world's population is expected to grow from 7.6 to 10 billion between 2017 and 2067 (United Nations, 2017) while the global demand for milk is expected to increase by 48% between 2005 and 2050 (Alexandratos and Bruinsma, 2012). In addition, global life expectancy (Zijdeman and Ribeira da Silva, 2014), adult height (NCD Risk Factor Collaboration, 2016), and body mass index (Finucane et al., 2011) have consistently increased over the years, thus affecting the overall maintenance nutrient requirements of the human population. A larger and wealthier global population will demand not only more food but also other goods and services that require land, water, energy, and minerals for their production.[1]

The amount of food waste from the producer to the consumer is estimated at 40% in the U.S. Livestock ruminants (cows, goats, sheep) convert fibrous feeds not suitable for many other species, including humans, into protein-rich meat and milk. Up to 30 percent of a U.S. dairy cow's diet is made up of human inedible "by-product feedstuffs," according to a joint study published (https://www.frontiersin.org/articles/10.3389/fsufs.2019.00114/full) by researchers at Kansas State, Texas A&M and Michigan State University. In light of this, several studies have shown diets with higher proportions of these fibrous feeds or byproducts might result in the same or higher ruminant performance. According to one study, cows fed byproducts that completely replaced cereal grains and pulses (seeds from legumes), yet had similar dry matter intake, produced a similar milk yield compared to those fed conventional diets, thereby increasing the conversion ratio of non-suitable food into milk.

If carefully applied, feeding byproducts to ruminants can improve the environmental sustainability of milk production, decrease feed costs, and still produce high levels of productivity. Farmers can potentially improve animal performance or feed efficiency by using these feed by-product enticers (materials that increase a cow's interest in eating the ration). While byproducts allow flexibility in putting together diets, farmers still have to be aware of the basics of ruminant nutrition and create diets that help maintain proper rumination of the digestive system as a part of a Total Mixed Ration (TMR). Producers/nutritionists look for signs of proper fermentation through consistent rumination (regurgitation/chewing cud) and production (maintaining milk production levels). If fermentation is too fast/too much, the cow may experience bloat, decreased rumination, and decreased production levels and have overall health issues. If it's too slow, there will be different health issues and decreased production as well. The middle ground of fermentation is ideal, so that the rumen microbiome can stay healthy and produce precursors that advance digestion or are used in other metabolic processes (i.e. citric acid cycle) to support normal body functions, milk production, and calf fetal development.

The purpose of this procedure is to investigate which food byproducts can help maintain fermentation rate to increase efficiency of feed for maximized milk production.

1. Adapted from **frontiersin.org/journals/sustainable-food-systems/articles/10.3389/fsufs.2019.00114/full**

Prior knowledge

In order to successfully complete this activity, students should know that cows are ruminants and they have a different digestive system than that of humans. Previous study of the differences in digestive systems, including the stomach chambers of ruminants along with the enzymes and the microbiomes, should be reviewed or an activity on these topics should be completed before this activity. (See digestive system activity *Ruminating on digestion.*)

Students should also know the nutritional needs of dairy cows and how much energy concentrate is suggested. (See *Simulating a TMR* activity.)

Providing students with this information may help them determine which by-product is the best for use in a lactating cow vs a non-lactating cow. Lactating cows have different energy requirements than ones that are not currently producing milk. A non-lactating cow requires 9–11 lbs of Total Digestible Nutrients (TDN) per day while a lactating cow requires 15–16 lbs of TDN. The nutrient needed in the highest concentration also changes from protein in a non-lactating cow to energy in a lactating cow.

Suggested timing

This activity can be completed in one class period.

Materials

- Small plastic bottles or flat-bottomed tubes
- Animal feed sample (Purina® dairy or other brand, available at Tractor Supply or local feed store)
- Distilled water
- 9-in. balloons
- By-product feedstuffs (Skittles, chocolate, citrus pulp, stale donuts, and/or other bakery products)
- Yeast
- Cellulase
- Measuring tape
- Water bath
- Thermometer
- Timer

Teacher preparation

1. Organize all materials.
2. Print off student document.
3. Set the water bath(s) at 39 °C.
4. Prepare warmed water for mixing (39 °C).
5. Review procedure before class.

Procedure

1. Once students arrive, spend some time reviewing principles they may need: components of a TMR, the differences between ruminant digestion and that of humans, and the overall goal of the activity (to create a mini-fermenter that models cow digestion in the rumen).
2. Engage students by asking them to taste grass, a leaf from a corn plant, or clover. Ask if they would be able to digest that easily. Discuss why or why not.
3. Have them make a diagram showing how a grazing cow converts forage into meat and milk, two high protein products (i.e,. protein from cellulose).
4. Ask students to examine the feed stuffs you have provided, then have them follow the procedure on the student handout to test which byproducts would be best.

Student handout

Reflection

1. Which by-product created the most energy? Explain your reasoning based on evidence from your experiment or the class data.

Answers will vary based on the byproducts tested. Generally, the by-product with the highest *glucose* content will produce the most energy in the shortest amount of time.

2. Which by-product would be best for providing the most energy over the longest period of time? Explain your reasoning based on evidence from your experiment or the class data.

Answers will vary based on the byproducts tested. Generally, the by-product with the highest *starch* content will produce energy over a longer period of time.

3. When choosing an energy concentrate, which of the substances would be the best for a dairy cow? Explain your reasoning based on evidence from your experiment or the class data.

Answers will vary based on the byproducts tested. As these are byproducts to replace the energy concentrate in the TMR, students should address the specific needs for energy in a lactating cow.

Differentiation

Other ways to connect with students with various needs:

- **Local community:** Students could visit a local dairy or dairy processor. Invite a dairy farmer from your state to talk with your class virtually. Look for virtual tours of dairy farms online.
- **Students with special needs (language/reading/auditory/visual):** A video of the experiment could be filmed and shared with students along with a translated transcript or voice over in their native language.
- **Extra support:** Students who need additional support should be able to discuss their ideas verbally, rather than being asked to write them out, or should be able to work with a partner who will record their ideas. Graphing from data can be accomplished using a spreadsheet program.
- **Extensions:** Students could present or share the information gathered with younger students, making it a fun way to talk about taking grass or cottonseed and turning it into milk.
  In addition, students may complete research on other enticers:
  - Cargill and Hershey: **cargill.com/story/how-cargill-turns-hersheys-leftover-chocolate-into-food-for-cows**
  - UC Davis: **clear.ucdavis.edu/explainers/dairy-cows-original-upcyclers**
  - Skittles: **beefmagazine.com/cattle-nutrition/dairy-farmer-explains-why-cattle-can-eat-skittles**

Assessments

Rubric for assessment

Skill	Developing	Satisfactory	Exemplary
Students create a model of a mini-fermenter.	Student was successful in creating a model, but did not successfully trap gas to analyze.	Student was successful in creating a model.	Student was successful in creating a model and can compare the model to cow digestive systems.
Students conduct an experiment to determine the best energy concentrate by-product to use in a TMR, then write an explanation based on evidence for their claim.	Student conducted an experiment but was unable to use data to construct an explanation.	Student conducted an experiment and wrote a cohesive explanation based on the data collected but did not describe the impact of the by-product on cow digestion.	Student conducted an experiment, wrote a cohesive explanation based on the data collected, and described the impact of the by-product on cow digestion.
Students observe the results of a biological and chemical reaction (fermentation) within their model and can explain how it happened.	Student observed the chemical reaction but cannot explain how it occurred.	Student observed the chemical reaction and can explain the biological (yeast) and chemical (enzyme) reactions.	Student observed the chemical reaction and can explain the biological (yeast) and chemical (enzyme) reactions and how the experiment conserved atoms.

Rubric for self-assessment

Skill	Yes	No	Unsure
I created a model of a mini fermenter.			
I collected data to determine the best by-product and wrote a CER supported by my data.			
I explained how the reaction within the model happened.			