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Review Article
Whey as a Feed Ingredient for Lactating Cattle

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Abstract
Whey is the co-product resulting after the production of cheese (cottage or cheddar), casein from milk. Acid, sweet and casein whey is resulted from precipitating the milk by rennet, microbes or mineral acids, respectively. The protein content is 0.75, 0.30 and 0.50%, the lactose content is 4.80, 4.60 and 4.70%, the ash content is 0.60, 0.80, 0.90% and pH value is 6.1, 4.6 and 4.4 for the sweet, acid and casein whey, respectively. Approximately, each 4 kg of raw milk produce 1 kg cheese and 3 kg whey. Whey can be fed to animals in a variety of forms, such as: Liquid whey, condensed whey, dried whey (partially delactosed whey) or as dried whey products. Liquid whey has been added to straw at ensiling as a rehydration medium. Sweet (cheddar cheese) whey may be more palatable than acid (cottage cheese) whey by ruminants. Many of the bacteria in the rumen apparently have a limited ability to ferment lactose. The most important aspect of whey feeding is gradual adaptation and provision of hay to counteract diarrhea. The nutritive value of 1 t of fresh whey was equivalent to that of 71 kg of barley grain as measure from their energy and protein content. It was reported that when sweet whey was given to lactating cows at 12-20 L cow^{-1} daily, milk yield, milk calcium and magnesium increased and the technological properties of milk improved. However, under warm temperature or far farm from cheese plant, liquid whey cannot be fed.

Key words: Acid whey, sweet whey, whey as feed, lactating cattle, milk production

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Whey type either as sweet or acid is depended on the precipitating method of the milk in the cheese plant. Whey contains nearly 7% solids. This is composed of 4.9% lactose, 0.9% total proteins, 0.6% ash and a small amount of fat, lactic acid and vitamins[1-3].

Most of whey is disposed of as a waste product. The challenge to dairy scientists and industry is to find the best methods of utilizing this valuable by-product. The nutritionists have suggested several methods by which whey can be fed to the cattle. These methods vary from feeding liquid whey, dried, whole whey to feeding dried whey products[4,5]. The economic and technical aspects of feeding whey to livestock have been reviewed[6]. Despite whey is a good source of nutrients for lactating cattle feeding, a lack of communication between whey and cattle producers has resulted in a steady decline in the practice of feeding it to cattle. The aim of this study was to explain to what extend whey can be influenced by the feed and to illustrate the forms of whey which could be utilized for the dairy cattle.

INFLUENCING WHEY BY THE FEED

Transfer of aflatoxin B1 from feed to whey: It is notable to report that aflatoxins are a group of fungal toxins, produced mainly by *Aspergillus flavus* and *A. parasiticus* which occur naturally in some feedstuffs. Aflatoxin B1 (AFB1) is considered to be the most toxic compound produced by these molds. In the liver, ingested AFB1 is bio-transformed by hepatic microsomal cytochrome P450 into aflatoxin M1 (AFM1), which is then excreted into the milk of lactating animals.

Transfer of aflatoxin B1 (AFB1) from feed to milk and from milk to curd and whey in dairy ewes fed artificially contaminated concentrate was evaluated[7]. Fifteen ewes were assigned to treatments in replicated 3×3 Latin squares. The experimental groups received 32, 64 and 128 μg day^{-1} of pure AFB1 for 7 days followed by 5 days of clearance. On the 6th day of the 1st period, the total daily milk produced by each ewe was collected separately and processed into cheese. The results indicate that the level of AFB1 used did not adversely affect animal health and milk production traits. The AFM1 concentration was linearly related to the AFB1 intake per kilogram of body weight. The carry-over values of AFB1 from feed into AFM1 in milk (0.26-0.33%) were not influenced by the AFB1 doses. The AFM1 concentrations in curd and whey were linearly related to the AFM1 concentrations in the raw milk.

Transfer of melamine from feed to whey: Melamine (1,3,5-triazine-2,4,6-triamine) is a stable chemical intermediate used to manufacture resin and plastic, such as adhesive components and polymers commonly used in feed packaging and plastic ware. Transfer of melamine from feed to milk and from milk to cheese and whey in lactating dairy cows fed single oral dose was investigated[8]. The results confirmed that melamine contamination of milk and milk products may be related not only to direct contamination, but also to adulteration of animal feeds.

FORMS OF WHEY AS A FEED INGREDIENT

In the present study, it is illustrated the following forms: (a) Liquid whey as water, as a rehydration medium for silage and as a feed additive, (b) Dried whey as a partial replacement of the feed starch, (c) Whey protein emulsion gel to protect the unsaturated fatty acids in the rumen and (d) Recovering water from whey to be used in the cleaning.

LIQUID WHEY USED AS WATER, A REHYDRATION MEDIUM AND AS A FEED ADDITIVE

Liquid acid whey for cows: In the trial of Pinchasov *et al.*[9], 36 Friesian cows were divided into 2 groups. Control cows were fed the basal diet consisting of the concentrate and hay. The experimental cows received the basal diet plus the liquid acid whey. The crude protein content was 16.4, 12.4 and 13.54%, the ash content was 9.4, 12.0 and 15.2 and the nitrogen free extract content was 60.9, 42.6 and 79.6% for the concentrate hay and whey, respectively. Whey was provided three times a day. The average of pH for the fresh acid whey was 4. Fresh water was available at all times for all cows.

The studies have found that the overall mean for the concentration of the volatile fatty acids in the rumen was acetic acid 32.3 vs., 53.3, propionic acid 29.3 vs., 32.6 and butyric acid 13.3 vs., 9.6 mmol L^{-1} for whey vs., control, respectively. Obviously, whey addition significantly increased the ruminal butyric acid. The effect of the whey addition on 3.5% fat corrected milk yield (FCM) and concentrate intake could be illustrated in Fig. 1.

The researchers have suggested that the grains are very expensive, so the use of whey as a partial replacement is most economical.

Sweet whey as water for lactating cattle: It is notable to report that by offering sweet whey as water to lactating cows at 12-20 L head^{-1} day^{-1}, milk yield was significantly increased.

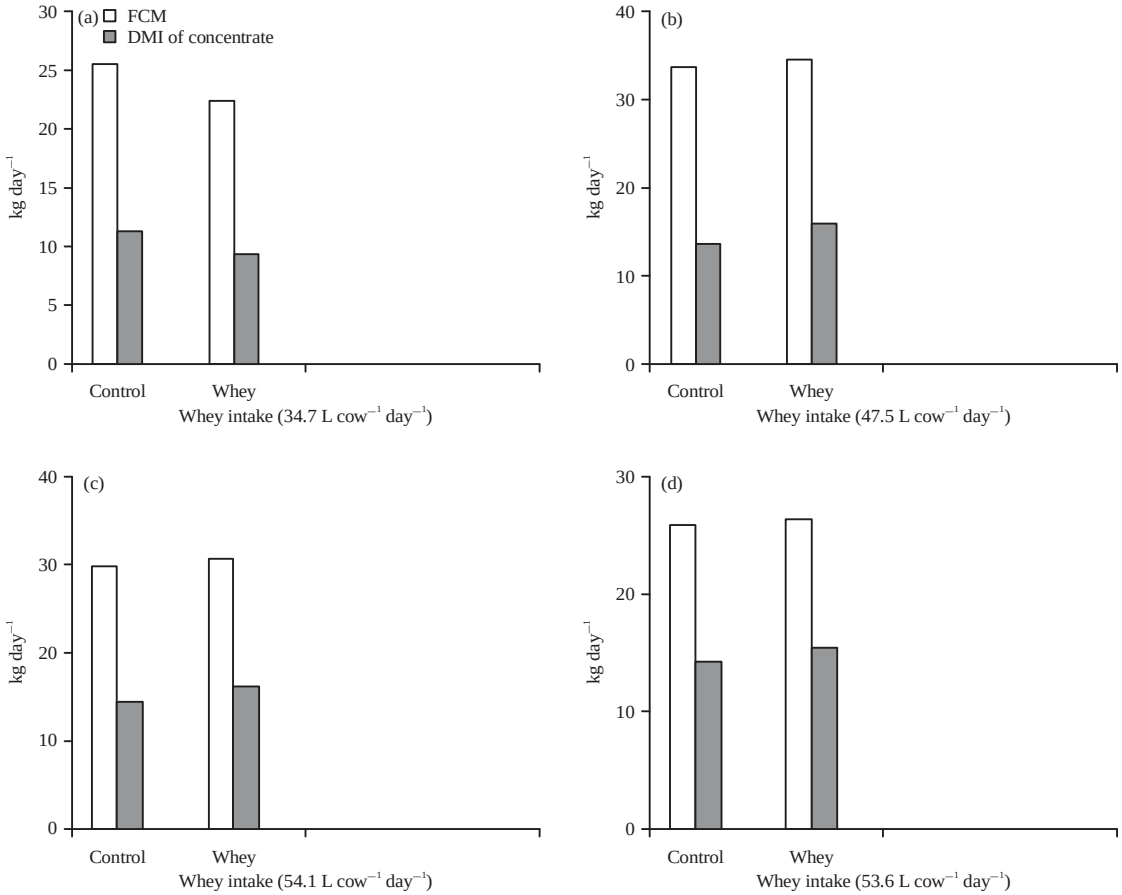

Fig. 1(a-d): Whey addition during (a) 1-15, (b) 16-69, (c) 70-105 and (d) 106-147 days of parturition

This may be explained on the basis that the nutritive value of 1 t of whey equals to that of 71 kg of barely grains as measure from their energy and protein content[1-4]. However, the utilization of the liquid whey for cattle must be conditioned by: (a) Whey should be offered gradually (at the onset 20% whey and 80% water, then whey should be increased by 20% every 3 days), (b) Whey pH at farm gate must be 5.5-6 and it is not allowed to drop below pH 4, (c) Drinking basins should be corrosion resistant, (d) Total coli form counts must not exceed 30/100 mL, (e) Roughage must be provided to counteract diarrhea, (f) Whey must not be introduced over a few weeks and (g) Under warm temperature or far farm from cheese plant, liquid whey cannot be fed[1,4,5].

Whey as a rehydration medium: Liquid whey either as sweet or acid whey (the mean pH for the sweet and acid whey is 5.88 and 4.57, respectively) has great potential to be used in the ensiling process as a rehydration medium. This represents a practical strategy to avoid discarding whey in the ambient. It was suggested that the utilization of sweet or acid whey as a rehydration medium is depended on the temperature of the environment, the buffering capacity of the ensiled material and the inoculation of silage.

Sweet whey as a rehydration medium for straw silage: It is of interest to simplify the experiment of Khattab *et al.*[10] as in Fig. 2.

It is of interest to illustrate the trial, which was conducted in a completely randomized design with four replicates in a factorial arrangement as follows: 3 levels of rehydration (300, 350 and 400 mL kg^{-1} of corn grain)×2 types of silage (inoculated with bacteria or not inoculated)×2 liquid used in the rehydration (acid whey or water)[11]. The results of the trial have been illustrated in the following points.

(1) Corn grain silages rehydrated with acid whey produced more lactic acid than rehydration with water. (2) Increases in the rehydration of corn grain silages reduce the production of lactic and total acids. (3) Neutral detergent fiber decreased due to inoculation in corn grain silages rehydrated

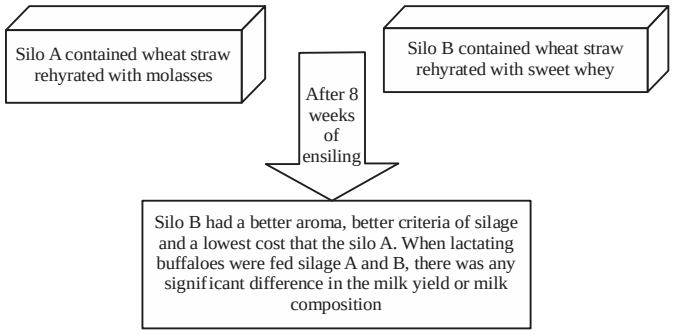

Fig. 2: Acid whey as a rehydration medium

with acid whey. These results reflected that potential of the use of acid whey in ensiling corn grain is high and its addition leads to improvements in the fermentation process and aerobic stability of the silages.

WHEY AS A FEED ADDITIVE

Fresh whey could be used as an additive (not as a rehydration medium) to Lucerne without wilting in the silo at 20, 50 and 100 g of fresh sweet whey kg^{-1} of fresh Lucerne[12]. The effect of this addition on the produced Lucerne silages relative to conservation could be simplified as follows: Addition of fresh whey at up to 100 g kg^{-1} had positive effects evidenced by a decrease of Crude Protein (CP) solubility and pH of silages and it contributed to preservation of the degradable fractions of plant cell walls. However, the increase in the dose of whey above 50 g kg^{-1} led to a general increase in nutrient losses. The effect of whey addition on rumen plant cell wall degradability could be illustrated in Fig. 3.

The researchers have found that the increase of whey addition level led to a linear increase ($p = 0.05$) of Dry Matter (DM) degradability and a quadratic response of Neutral Detergent Fiber (NDF) ($p<0.01$) and Acid Detergent Fiber (ADF) ($p \leq 0.04$) degradability. The highest values of NDF and ADF degradability were at 50 g kg^{-1} of whey addition level. They concluded that fresh whey can be useful as an additive for Lucerne silage production at up to 50 g of fresh whey kg^{-1} of fresh forag[12].

DRIED WHEY AS A REPLACEMENT OF THE FEED STARCH

The effects of replacing 6% of the dietary starch with lactose (as dried whey permeate, DWP) (on DM basis) on ruminal function, short-chain fatty acids (SCFA) absorption and nitrogen (N) utilization in dairy cows were studied in Chibisa *et al.*[13]. The results could be pointed as follows:

- Dry matter intake and milk and milk component yields did not differ with diet
- The dietary addition of DWP tended to increase ruminal butyrate concentration (13.6 vs., 12.2 mmol L^{-1}) and increased the competitive absorption rates for acetate and propionate
- Cows fed the DWP had lower ruminal NH_3-N concentration
- Feeding the DWP diet tended to increase apparent total-tract digestibility of dry matter and organic matters and increased apparent total-tract digestibility of fat

Chibisa *et al.*[13] concluded that partially replacing dietary starch with lactose as DWP regulated the ruminal acetate and propionate absorption.

WHEY PROTEIN EMULSION GEL TO PROTECT THE UNSATURATED FATTY ACIDS IN THE RUMEN

A novel Whey Protein Emulsion Gel (WPEG) complex was developed to protect dietary unsaturated fatty acids from rumen bio-hydrogenation with the goal of modifying the fatty acid composition of milk fat. The method associated with WPEG formulation is described in patent applications[14,15].

Carroll *et al.*[16] have conducted 3 experiments with WPEG complexes made from either whey protein concentrate containing 80% crude protein, whey protein isolate or whey protein concentrate high-gel capacity. Each experiment lasted 3 weeks. All cows received a basal Total Mixed Ration (TMR). During week 1 and 3, all cows received only the TMR. During week 2, 3 control cows received 330 g day^{-1} of soybean oil added to the TMR and the other 3 cows received 330 g day^{-1} of soybean oil in one of the WPEG complexes.

The researchers concluded that when WPEG was added to the diet of lactating cows, it successfully protected a portion of the unsaturated FA in soybean oil and dramatically increased the C18:2 and C18:3 content of milk fat without

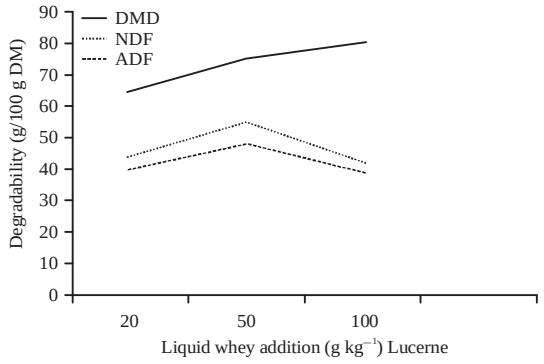

Fig. 3: Effect of whey addition on DMD, NDF and ADF

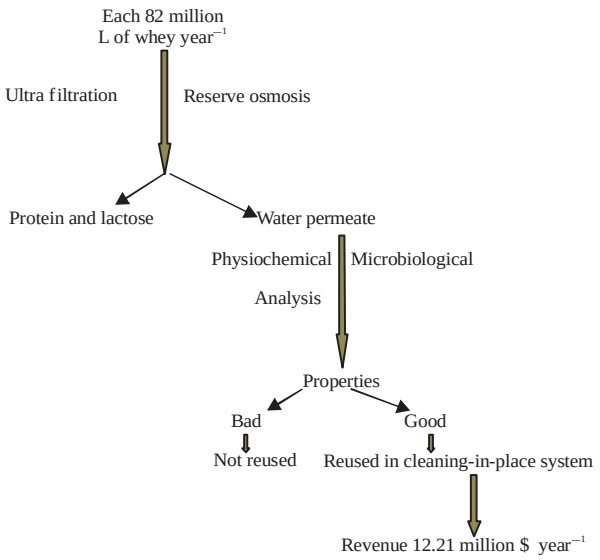

Fig. 4: Viability for recovering good quality water from whey to be reused in cleaning-in-place system

significantly increasing the trans18-carbonmonoenes. The increase in n-3 FA composition may have human health implications because n-3 FA_s have been linked to a reduced risk of coronary heart disease. Using WPEG to modify the FA composition of milk fat for human health could reposition milk fat in a healthy human diet.

Actually, the lack of large-scale manufacturing equipment resulted in shorting of the experimental period. So, determining the effects of prolonged feeding of the Whey Protein Emulsion Gel (WPEG) on milk FA production required further study.

RECOVERING WATER FROM WHEY TO BE USED IN THE CLEANING

Water scarcity is threatening food security. In the dairy sector, most of the water is used in cleaning applications. Therefore, any attempt to support water conservation in these processes will have a considerable effect on the water footprint of dairy products.

The study of Meneses and Flores[17] demonstrates the viability for recovering good quality water from whey to be reused in cleaning-in-place systems as in Fig. 4.

The study indicated that by using a combined ultra filtration and reverse osmosis system, 47% of water can be recovered.

CONCLUSION

- Sweet or acid whey could be utilized as water only under certain conditions
- Whey either as acid or sweet could be used as a rehydration medium for dried forages at ensiling
- Dried whey could be used as a replacement for the concentrate ingredient (starch)
- Whey protein emulsion gel can protect the feed unsaturated fatty acids from the bio hydrogenation in the rumen
- A lack of communication between owners of cheese plants and dairy farms has decreased the practice of feeding whey to cattle

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