Role Of Carbohydarte In Nutrition Ruminant: A Review

S.Masoud Davoudi[1], MahDi EdalatiNasab[2], Hamed AminiPour[2]

Department of Animal Science, Islamic Azad University of Shahrkord, Shahrkord, Iran.
Department of Animal Science, Ferdowsi University of Mashhad, Mashhad, Iran.
h.aminipor@gmail.com

Abstract: Carbohydrates (CHO) are the major source of energy for rumen microorganism and the single excessively component of a dairy cow's diet. They represent the major component of net energy for astound of keep and milk production. Those are as important to the ruminant animal as they are to non-ruminants, thus they provide the glucose necessary for the adequate function of cells. However, in the ruminant, ruminal fermentation transforms most of the cell wall polysaccharides and all of the intracellular carbohydrates present in the forage into short-chain volatile fatty acids that are then absorbed by the rumen epithelium. Plant tissues contain about 75% carbohydrates, providing the primary sources of energy for both the rumen organisms and the host animal. The carbohydrates found in plant tissues are primarily polysaccharides, cellulose, hemicellulose, pectin, fructan and starches, with slight amounts of other compounds. Cellulose is the most abundant. However, grains are widely used in diets used in intensive production systems with highly productive animals, providing an appreciable amount of starch for ruminal and intestinal digestion. The purpose of this review is to scrutinize the present science on starch digestion in the ruminant, as well as glucose metabolism in the rumen, post-ruminal absorption of starch and glucose requirements of the ruminant.

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Introduction

Carbohydrate is an organic compound with the empirical formula Cm(H2O)n that is, consists only of carbon, hydrogen, and oxygen, with a hydrogen: oxygen atom ratio of 2:1. Carbohydrates can be viewed as hydrates of carbon, hence their name. Structurally however, it's more accurate to view them as poly hydroxy aldehydes and ketones. The term is most common in biochemistry; it is a synonym of saccharide. The carbohydrates are divided into 4 chemical groupings: mono saccharides, disaccharides, oligosaccharides, and polysaccharides. In general, the mono saccharides and disaccharides, which are smaller carbohydrates, are commonly referred to as sugars. The word saccharide comes from the Greek word σάκχαρον (sákkharon), meaning "sugar". Thus the scientific nomenclature of carbohydrates is complex; the names of the mono saccharides and disaccharides very often end in the suffix ose. For example, blood sugar is the monosaccharide glucose, table sugar is the disaccharide sucrose, and milk sugar is the disaccharide lactose. Carbohydrates perform numerous roles in living things. Polysaccharides serve for the storage of energy, and as structural components. The 5-carbon monosaccharide ribose is important component of coenzyme and the backbone of genetic molecule known as RNA. The associate de oxy ribose is a component of DNA. Saccharides and their derivatives include many other important biomolecules that play key roles in the immune system, fertilization, preventing pathogenesis, blood clotting, and development. In food science and in many informal contexts, the term carbohydrate often means any food that is particularly rich in the complex carbohydrate starch or simple carbohydrates, such as sugar. Carbohydrate nutrition influences the composition of milk as precursors for lactose, fat and protein. The structural CHO consist of elements found in the plant cell wall. The nonstructural CHO are located inside the cells of plants and are usually more digestible than the structural CHO [29, 59 and 13].

Chemical structure

Formerly the name "carbohydrate" was used in chemistry for any compound with the formula Cm (H2O) n. Following this definition, some chemists considered formaldehyde (CH2O) to be the simplest carbohydrate, thus other claimed which title for glycol aldehyde. Recent the term is generally understood in the biochemistry sense, which excludes compounds with only one or two carbons. Natural saccharides are generally built of simple carbohydrates called mono saccharides with general formula (CH2O)n where n is three or more. A typical monosaccharide has the structure H-(CHOH)x(C=O)-(CHOH)y-H, that is, an aldehyde or ketone by many hydroxyl groups added, usually one on each carbon atom that is not part of the aldehyde or ketone utilization group. Examples of mono saccharides are glucose, fructose, and glyceraldehyde. However, some biological materials commonly called "mono saccharides" do not conform to this formula, there are many chemicals that do

conform to this formula but aren't considered to be mono saccharides. The open-chain form of a monosaccharide often coexists with a closed ring form where the aldehyde/ketone carbonyl group carbon (C=O) and hydroxyl group (-OH) react forming a hemiacetal by a new C-O-C bridge. Mono saccharides can be connected together into what are called polysaccharides in a large strain of ways. Some carbohydrates contain one or more modified monosaccharide units that have one or more groups replaced or removed. For example, de oxy ribose, a component of DNA, is a modified version of ribose; chitin is composed of repeating unit of N-acetyl glucosamine, a nitrogen-containing form of glucose [20, 50, 61, and72].

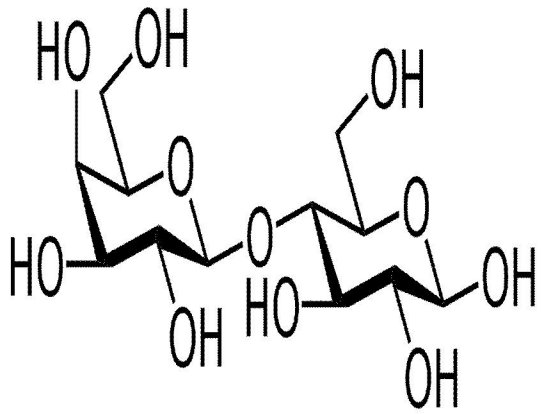

Fig.1: Lactose is a disaccharide found in milk. It consists of a molecule of D-galactose and a molecule of D-glucose bonded by beta-1-4 glycosidic linkage. It has a formula of $C_{12}H_{22}O_{11}$, from www.wikipedi.com.

Classification

Mono saccharides

Mono saccharides are the simplest carbohydrates in which they cannot be hydrolyzed to smaller carbohydrates. They are aldehydes or ketones with two or more hydroxyl groups. The general chemical formula of an unmodified monosaccharide is $(C•H_2O)_n$, literally a "carbon hydrate." Mono saccharides are important fuel molecules as well as building blocks for nucleic acids. The smallest mono saccharides, for which n = 3, are di hydroxyl acetone and D- and L-glyceraldehyde. Mono saccharides are categorized in line 3 diverse characteristics: the placement of its carbonyl group, the number of carbon atoms it contains, and its chiral handedness. If the carbonyl group is an aldehyde, the monosaccharide is an aldose; if the carbonyl group is a ketone, the monosaccharide is a ketose. Mono saccharides with three carbon atoms are called trioses, those with 4 are called tetroses, five are called pentoses, six are hexoses, and so on. These 2 systems of classification are often combined. For example, glucose is an aldohexose and fructose is a ketohexose. Each carbon atom bearing a hydroxyl group (-OH), with the exception of the first and last carbons, are asymmetric, making them stereocenters by 2 possible configurations each. Therefore of this asymmetry, a number of isomers may exist for any given monosaccharide formula. The aldohexose D-glucose, for example, has the formula $(C·H_2O)_6$, of that all but 2 of its 6 carbons atoms are stereogenic, making D-glucose one of $2^4 = 16$ possible stereoisomers. In the case of glyceraldehyde, an aldotriose, there is one pair of possible stereoisomers, that are enantiomers and epimers. 1, 3-dihydroxyacetone, the ketose corresponding to the aldose glyceraldehyde, is a symmetric molecule with no stereocenters. The assignment of D or L is made in line the orientation of the asymmetric carbon furthest from the carbonyl group: in a standard Fischer projection if the hydroxyl group is on the right the molecule is a D sugar, otherwise it is an L sugar. The "D-" and "L-" prefixes should not be confused by "d-" or "l-", that indicates the orient that the sugar rotates plane polarized light. This usage of "d-" and "l-" is no longer followed in carbohydrate chemistry [2, 3, 6, 23 and 39].

Disaccharide

2 joined mono saccharides are called a disaccharide and these are the simplest polysaccharides. Examples include sucrose and lactose. They are composed of 2 monosaccharide units bound together whit a covalent bond known as a glycosidic linkage formed via a dehydration reaction, resulting in the loss of a hydrogen atom from one monosaccharide and a hydroxyl group from the other. The formula of unmodified disaccharides is $C_{12}H_{22}O_{11}$. Although there are plentiful kinds of disaccharides, a handful of disaccharides are especially notable. Sucrose, pictured to the right, is the most abundant disaccharide, and the core form that carbohydrates are transported in plants. It is composed of one D-glucose molecule and one D-fructose molecule. Lactose, a disaccharide composed of one D-galactose molecule and one D-glucose molecule, occurs naturally in mammalian milk. The systematic name for lactose is *O*-β-D-galactopyranosyl-(1→4)-D-glucopyranose. Other notable disaccharides include maltose and cellulobiose. Disaccharides can be classified into 2 strains. They are reducing and non-reducing disaccahrides if the functional group is present in bonding by another sugar unit it is called as reducing disaccharide [42, 56, 66, and 70].

Metabolism

Carbohydrate metabolism denotes the various biochemical processes responsible for the formation, breakdown and inter alternation of carbohydrates in living organisms. The most important carbohydrate is glucose, a simple sugar which is metabolized whit

nearly all known organisms. Glucose and other carbohydrates are part of a wide type of metabolic pathways across species: plants synthesize carbohydrates from atmospheric gases by photosynthesis storing the absorbed energy internally, often in the form of starch or lipids. Plant components are eaten by animals and fungi, and used as fuel for cellular respiration. Oxidation of one gram of carbohydrate yields approximately 4 kcal of energy and from lipids about 9 kcal. Energy obtained from metabolism is usually stored temporarily into cells in the form of ATP. Organisms capable of aerobic respiration metabolize glucose and oxygen to release energy by carbon dioxide and water as byproducts [10, 26, 28, 57, and 72]. In animals, the most important carbohydrate is glucose; so much so, that the level of glucose is used as the prime control for the central metabolic hormone, insulin. Starch and cellulose in a few organisms, both being glucose polymers, are disassembled during digestion and absorbed as glucose. Some simple carbohydrates have their own enzymatic oxidation pathways, as do only a few of the more complex carbohydrates. The disaccharide lactose, for instance, requires the enzyme lactase to be broken within its mono saccharides components; some animals lack this enzyme in adulthood. Carbohydrates are typically stored as long polymers of glucose molecules with glycosidic bonds for structural support or for energy storage. Thus, the strong affinity of most carbohydrates for water makes storage of large quantities of carbohydrates inefficient due to the large molecular weight of the solvated water-carbohydrate complex. In most organisms, extreme carbohydrates are regularly catabolised to form acetyl-CoA, that is a feed stock for the fatty acid synthesis pathway; fatty acids, triglycerides, and other lipids are commonly used for long-term energy storage. All carbohydrates share a general formula of approximately $C_nH_{2n}O_n$; glucose is $C_6H_{12}O_6$. Mono saccharides may be chemically bonded together to form disaccharides such as sucrose and longer polysaccharides such as starch and cellulose [7, 21, 58 and 67].

Plant carbohydrates

The structural or cell wall material contains cellulose, hemicellulose, lignin, pectic substances and β-glucans. The cell contents contain starches, sugars, and fructans and for ensiled feeds, organic acids. The most common measures of fiber analysis are acid detergent fiber (ADF) and neutral detergent fiber (NDF). The structural components in the plant like cellulose, hemicellulose and lignin are measured by NDF. Acid detergent fiber measures lignin and cellulose. Even though pectins are a part of the cell wall, they are considered a nonstructural CHO because compared to hemicellulose, the rumen microorganisms completely and rapidly ferment the pectin [1, 17 and 22].

Analytical procedures for NDF

Wet chemistry analysis for ADF and NDF are based on the differential solubility of plant components. The NDF concentration of a feed is measured whit refluxing the sample in a buffered solution (pH 7) that contains detergent. Water and detergent soluble compounds are removed. Included in this residue are sugars, lipids, some ash, non-protein nitrogen and some protein. Therefore, variable amounts of ash and protein can remain by the NDF. Ash contamination can contribute up to four percentage units to the NDF value. Ideally, both ADF and NDF should be expressed on an ash-free basis. Soil is often the culprit in mineral contamination.

There have been several modifications to the analytical procedure for NDF. The first was the inclusion of heat-stable amylase in the procedure to remove starch. The other was the use of sodium sulfite to minimize protein contamination.There is some controversy over the use of sulfite in the standard procedure for NDF determination. Adding sulfite to the NDF solution reduces crude protein contamination but does not quantitatively remove all of it. Using sodium sulfite in the NDF procedure is discouraged if the residues are to be assayed for neutral detergent insoluble protein. Sulfite also attacks lignin and should not be used in a sequential analysis for lignin or for subsequent in vitro digestion.

Whenever samples are sent out for analysis, scrutinize both ADF and NDF values. In addition to ash and protein inflating NDF, feeds with lipid contents greater than 10% can be a problem and some kinds of samples advance filtering problems [5, 40 and 65].

In vitro NDF digestibility

The *in vitro* NDF digestibility procedure is done in a test tube. Slight amounts of dry, ground samples are incubated with ruminal fluid and buffer in a temperature-controlled system. Most labs look at NDF digestibility after the sample has been incubated in rumen fluid for 30 hours. The assumption is that this represents the NDF digested in the rumen of higher producing cows with moderately fast rumen turnover. Currently the system provides an endpoint value for in vitro digestible NDF.

As with any procedure there are several factors, which could affect results. They include the dilution of the ruminal inoculum; strain of buffer used, particle size of the sample, type of mill used for grinding and variety of diet the donor cow is fed. It may be difficult to make any meaningful interpretation on one *in vitro* NDF digestibility value.

To understand how these values influence animal performance in a particular farm situation almost requires several in vitro tests throughout the year and on a yearly basis. Digestibility of forage fiber

components varies due to hybrids, maturity, temperature, moisture, fertilization, fermentation and processing methods.

One disadvantage with the *in vitro* procedure is using a dry, ground sample. This may decrease the difference between samples or result in higher digestibility than unground wet samples [4, 55, and 71].

Nonstructural CHO

The more readily digestible CHO are not recovered in the NDF. The non-fiber CHO (NFC) includes sugars, starches and the other reserve CHO such as galactans and pectins. The NFC for feeds is calculated whit difference: 100 – (%NDF + % crude protein + % fat + % ash) or 100 – [(%NDF-NDFCP) + % crude protein + % fat + % ash).

NDFCP is the neutral detergent insoluble crude protein. The first equation is most commonly used, the second equation is preferred because it corrects for crude protein in the NDF. The nonstructural CHO or NSC is measured by enzymatic methods and includes only starch and sugars.

The concentrations of NFC and NSC in many feeds are not equal and the terms should not be used interchangeably. Much of the diverse is caused whit the contribution of pectin and organic acids. Pectin is included in NFC but not in NSC.

When using the enzymatic method to measure NSC, sucrose and fructans appear in the starch fraction. This applies mainly to forage, particularly grasses, as they contain little if any starch. Sucrose is found in beet and citrus pulp and probably some other byproducts. For these feeds, the total sugar and starch is likely all sugar. For corn silage, grains and most byproducts, the fraction is usually all starch [14, 43 and 48].

The University of Florida has developed a system for partitioning the neutral detergent soluble carbohydrates (NDSC) or the CHO fractions excluding hemicellulose and cellulose. The system uses extraction with 80% ethanol to separate low molecular weight sugars and organic acids from the starch and non-starch polysaccharides. The sugars are measured directly in the ethanol extract and starch on the ethanol insoluble residue. The organic acids and non-starch polysaccharides, that can be the most diverse fractions, are calculated whit diverse [11, 41, 62 and 63].

Carbohydrate digestibility

Starch Digestion in the Ruminant

In the non-ruminant, starch digestion occurs primly in the small intestine. The situation in the ruminant differs due to the action of microorganisms in the rumen. Digestion of starch to glucose requires the action of several enzymes produced whit the salivary glands, the rumen microorganisms or the pancreas and small intestine. Amylase secreted by the nasolabial glands is found at relatively high levels in the saliva of some ruminants, such as the buffalo [8, 37].

Alpha-amylase is secreted by the pancreas, while is omaltase, maltase-glucoamylase, trehalase and lactase are secreted by the intestinal mucosa. Alpha-amylases, beta-amylase, R-enzyme, pullulanase, iso-amylase or alpha-limit dextrinase are produced by the rumen microorganisms. Several species of ruminal bacteria are able to digest starch. Amylolitic organisms are found in larger percentages of the total microbial population when rations high in starch are fed. Important species that have been enumerated in cattle fed high grain diets are *Bacteroides amylophilus, Butyrivibrio fibrisolvens, Bacteroides ruminocola, Selenomona lactylitica, Streptococcus bovis, Prevotella ruminocola, Eubacterium ruminantium, Ruminobacter amylophilus, Ruminococcus bromii, Succinimonas amylolytica* and *Lactobacillus* sp [15, 54].

In studies that ruminants are switched abruptly from forage- based diets to grain based rations an acute ruminal lactic acidosis occurs, the numbers of *Streptococcus* sp. increase by 2-3 orders of magnitude within hours after feeding, protozoa populations are eliminated and lactobacilli become dominant into 24h .Ciliated protozoa are found in large quantities in grain-fed ruminants. Low ruminal pH occurring during all or part of the daily feeding cycle is thought to limit protozoa populations, thus many are unable to survive under pH 6.0 [36, 52].

In grain-fed animals, protozoa can exert an influence on ruminal starch hydrolysis rates in at least two respects: 1) whit ingesting bacteria in numbers sufficient to decrease ruminal fermentation rates whit ingesting starch granules and soluble sugars, thus decreasing the accessibility of these substrates to fermentation by the faster growing bacteria.

The presence of ciliates influences the site of starch digestion. It has been reported that protozoa reduce the rate of starch digestion and ruminal starch digestibility, shifting the site of starch digestion to the small intestine [9, 16].

Most amilolytic microorganisms possess extracellular amylases, usually of the alpha-type, which is endoenzyme acting randomly in the interior parts of the starch chain. The fragmentation by alpha-amylase initially leads to a rapid reduction in the molecular size of the starch by formation of water soluble dextrins and oligosaccharides. The final products from amylose are maltose, maltotriose and sometimes small amounts of free glucose. Maltotriose is generally stable to the action of both alpha and beta-amylases, unless massive quantities of enzyme are added. The marginal products from amylopectin are maltose, maltotriose, a few glucose and a blend of alpha-limit dextrins. These latter oligosaccharides consist of 4-8 glucose moieties and still contain the alpha-(1-6) linkage(s) which cannot be hydrolyzed by amylases. Debranching enzymes are necessary to break these bonds [12, 32].

Starch digestion in the total digestive tract of ruminants exceeds 95%. With roughage diets only small quantities of alpha-linked glucose polymers pass to the abomasums and it is very likely which such material, that does leave the rumen, is mostly of microbial origin.

Both rumen protozoa and bacteria store alphalinked glucose polymers when available energy is in excess of growth requirements [19, 46 and 68].

By roughage diets this would occur shortly after feeding, due to the rapid fermentation of the soluble sugars present in the higher quality roughages. Calculations based on these estimates yield a value of 3-6g alpha-dextran per day and per kg hay consumed, that is close to reported values of 5g·day-1 by sheep [30, 31 and 45].

Therefore, on hay diets the quantity of glucose available for absorption in the small intestine would be of minimal importance. When diets containing grains are fed, depending on the strain of the grain, the extent of processing prior feeding, and the type of animal fed, an appreciable amount of starch and protozoal glycogen may inert fermentation in the rumen and enter the small intestine [27, 34].

It has been observed that the degree of processing is an important factor which influences the degree of fermentation of grains in the rumen and their post-ruminal digestibility.

Ionophores usually reduce intake, which results in less starch being fermented in the rumen, reducing incidence of acidosis in feedlot diets. Combination of slow (25- 33%) and fast (75-66%) digesting grains improve gain and feed efficiency presumably because those combinations stimulate protozoal numbers reducing ruminal starch digestion and acidosis. Manipulation of starch fermentation in the rumen is important when slow digested grains such as sorghum are fed. The use of exogenous amyolytic enzymes from *Bacillus licheniformis* increased ruminal starch digestion and feed efficiency in sorghum based diets, thus, exogenous enzymes could be considered as an alternative treatment to improve ruminal starch digestion when diets by high grain content are fed to ruminants. It has been calculated that when rolled barley or ground maize is fed to sheep the total starch digestibility was 99.9% and the proportion of starch disappearance before the small intestine was 91.8%, whilst in cattle fed ground corn the total starch digestibility was 98.5% with 68.0% of the starch disappearing before the small intestine [33,47].

Ruminal starch digestion and dry matter intake and milk yield

Increased starch digestion in the rumen has been observed to decrease DMI in ruminants. Decreased DMI was observed in steers fed steam flaked corn compared by those fed diets containing a less digestible starch sources such as dry rolled corn [35].

A low rumen-available nonstructural carbohydrate diet containing dry ear corn fed to lactating dairy cows caused an increase in DMI compared by cows fed a high rumen-available nonstructural carbohydrate diet containing high moisture shelled corn. Others have reported no significant change in DMI when lactating dairy cows were fed steam flaked corn or steam flaked sorghum replacing dry rolled corn or sorghum in the diet [60, 69].

Starch sources that increase ruminal starch digestion have been observed to increase milk yield in lactating dairy cows. Some experiments observed no change in milk production when cows were fed the more digestible starch source [25].

Small intestinal starch digestion

Starch fermentation in the rumen may be incomplete due to many factors that will then allow starch to be more available for digestion and absorption in the small intestine.

When starch reaches the small intestine it is broken down to glucose. Carbohydras from the pancreas and in the intestinal mucosa allow degradation of starch to glucose. Amylose is broken down whit pancreatic amylase within the oligosaccharides maltriose and maltose. Amylopectin is broken down into maltose and isomaltose by isomaltase that breaks α 1-6 bond. Maltose, isomaltose, and maltriose are then degraded to glucose by maltase, which is located on the brush border membrane of the intestinal microvilli .The small intestine has been reported to be more efficient at converting starch to energy compared with ruminal starch digestion [38, 62].

Processing of grain can influence the site and extent of digestion in ruminants. Steam flaking of grain will cause more starch to be digested in the rumen and causes the starch entering the small intestine to be very digestible. When Theurer compared nineteen lactating cow studies that compared steam flaked grain and dry rolled grain, he found that post-ruminal starch digestion increased by steam flaking from 61 to 93% [51].

These studies have observed an increase in digestibility when starch entered the small intestine, but the quantity of starch digested did not increase. Grain not digested in the rumen will pass and move to the small intestine. The increase in starch flow from the rumen to the small intestine can cause an increase in starch digested in the small intestine. Grain type can influence the digestion of starch in the small intestine. This caused the corn-based diets to have a higher starch digestibility in the small intestine than the barley-based diets, Also, sorghum-based diets were found to have a higher post-ruminal digestion of starch when compared to barley- or wheat-based diets [44, 64].

This was due to the increase in starch that inert rumen fermentation and entered the small intestine

when cows were fed the sorghum-based diets compared with the other two diets. Conventional yellow dent corn was found to have a higher starch disappearance from the small intestine compared with waxy corn, but the waxy corn hybrid had a higher apparent starch digestion in the small intestines (95.9% vs. 83.3% of duodenal starch flow [49].

In a study with rats, a high carbohydrate, low protein diet produced significantly more amylase when compared to a low carbohydrate, high protein diet. They also discovered that when a high quality protein, casein, was added to a high carbohydrate diet, there was a significant increase in amylase synthesis compared to diets that contained the poorer quality proteins gelatin, gluten, or zein [53].

Large intestinal starch fermentation

Starch that inert ruminal and small intestinal digestion becomes available for fermentation in the large intestine. Starch flowing to the large intestine may be fermented into VFA. Volatile fatty acids produced in the large intestine are similar to those produced in the rumen, by acetic, propionic, and butyric produced in the highest concentration. Ruminants can use the VFA that are produced in the large intestine, but the microbial N produced cannot be absorbed. Processing method and grain strain can affect starch digestion in the large intestine.

Ensiling corn decreased starch disappearance from the large intestine compared with dry rolled corn. Fecal starch flow decreased when cows were fed a high moisture corn diet compared with a dry corn diet. Cows fed diets that were ground had a higher starch disappearance from the large intestine compared with cows fed diets that were rolled [23, 58].

Factors that contribute to increasing starch digestion in the rumen and small intestine are very worthwhile as shown whit previous studies. Starch broken down in the rumen and small intestine is used for microbial growth and energy requirements. Starch digested in the rumen and small intestine is used very efficiently when compared to starch that escapes and enters the large intestine. Fermentation of starch in the large intestine is excreted into feces as microbial N, so it is important to minimize starch fermentation in the lower gut of ruminants.

Fiber Digestibility

Fiber digestibility is usually defined as the proportion of consumed fiber that is not excreted in the feces. Fiber contains an indigestible fraction and one or more potentially digestible fractions, each of which is degraded at its own rate. The extent of fiber digestion depends on the size of the indigestible fraction and the competition between the rates of degradation and passage out of the rumen [30]. Ruminal fiber digestibility is affected whit the passage rate of special matter out of the rumen. Rate of passage is affected primarily whit intake. Therefore, feed particle size, particle buoyancy, concentrations of dietary fiber and NFC, and rate of digestion of the potentially digestible fiber fraction may affect passage rate. There is a vast range in ruminal fiber digestibility between and among forage and non-forage sources. Although fiber digestibility of forages is not constant for all animals and feeding conditions, much of the variation is due to composition and structural differences of the forage, harvest date and height at harvest. The indigestible fraction of NDF is a major factor affecting the utilization of fiber CHO sources as it varies largely and may exceed more than one half of the total NDF in the rumen. As a result, fiber digestibility generally decreases as forages mature within a cutting. In addition, environmental factors such as light intensity, day length, and temperature and soil moisture affect the relationship between fiber digestibility and maturity [53]. Particle buoyancy in the rumen may be another factor affecting digestibility. Particles are buoyant when they are actively fermenting. Carbon dioxide and methane gas produced during fermentation and related by feed particles, make them buoyant in the rumen. Buoyant particles become suspended in the fiber mat. As the fermentable fiber fraction of feed particles decreases, less gas is produced and particles may become less buoyant and sink. Particles that have low concentrations of fermentable fiber that ferment quickly, such as alfalfa, might pass more quickly than particles that have more fermentable fiber, that ferment slowly, such as grasses [57, 71]. Grasses generally have a lower indigestible NDF fraction than do legumes that may give grass NDF higher digestibilities at longer ruminal retention times. Longer ruminal retention times of grasses due to greater buoyancy over time will tend to increase the digestibility of grass NDF, compared by legume NDF. Although grass NDF is generally more digestible than legume NDF, it may also be more filling and reduce intake because of an increased ruminal retention time. When intake is limited whit ruminal fill of undigested feeds, legumes may allow higher intake than grasses as legume NDF ferments faster and probably sinks and passes from the rumen faster than grass NDF [11]. A practical feeding strategy can be applied from this information. Assuming a rumen retention time for NDF of 30 hours for early lactation cows and 48 hours for late lactation cows, the potential digestible NDF fraction of alfalfa may be nearly completely digested in the rumen of early lactation cows while that of grass is not. At shorter ruminal retention times, legume may have greater dry matter digestibility because of their lower NDF contents and similar NDF digestibility compared with grasses. Grass forages may have greater NDF digestibility when fed to cows with longer ruminal retention times, such as late lactation and dry cows. Grasses may have similar or

greater dry matter digestibility than legumes when offered to cows by longer ruminal retention times. Dry matter intake in early lactation cows is usually limited by physical fill. Offering fiber sources that digest and pass from the rumen more quickly may increase energy intake. Mid to late lactation cows, because of their longer ruminal retention times, can serve grass forages that may ferment more slowly, but have a higher potential digestibility [23, 54].

NSC Digestibility

Starch and sugar make up the NSC component. Soluble sugars ferment very quickly in the rumen. When sugars are contained within plant cell walls, they are retained in the rumen a sufficient length of time to be extensively fermented. Starch digestibility has the largest impact on the rumen and the dairy cow. Starch comprises the majority of the NSC in many feedstuffs. The rate and extent of starch digestibility is influenced whit several factors [37].

Rate of starch fermentation varies by type of grain and processing. Starch degradability can be ranked from fastest to slowest: oats> wheat> barley> corn> milo. Processing methods such as fine grinding, steam flaking, and ensiling can alter ruminal availability of starch. In a Penn State study, it was demonstrated that effective degradability of starch in situ for cracked corn, fine ground corn and steam flaked corn was 44%, 65%, and 75% respectively. Most grain processing methods increase both rate and extent of starch fermentation and ruminal digestibility. Decreasing the particle size of a starch source, i.e. ground corn, increases both rate of digestion and rate of passage. These can have counteractive effects on ruminal digestion [46, 72].

Animal characteristics and level of intake affect rate of passage. Fine grinding may have less effect on ruminal starch digestibility at higher levels of intake, such as early lactation cows, compared to animals in late lactation. In reviewing research studies estimating the effects of NSC in diets on animal performance, there is some variation in results.

Small factors influence the amount of forage NDF and total NDF that is formulated in rations. CHO nutrition requires more than meeting a certain NDF or NFC value. Other considerations include starch source, processing methods, particle size, physical and effective fiber, buffer inclusion levels, and feeding management practices [30, 61].

Carbohydrate deficiencies

Several indicators can be monitored which may mirror rations improperly balanced or implemented for CHO. These include milk fat percentage, rumination and cud-chewing, dry matter intakes, metabolic problems, laminitis, rumen pH, and fecal consistency [65].

Deficient NDF and Excess NFC

Ruminal and cow health is negatively affected whit low NDF and high NFC rations. Indicators which respond quickly to this feeding scenario are ruminal pH, milk fat percent, and chewing activity. Long-term effects include laminitis and an increased incidence of ketosis and abomasal displacement. A general term used to describe these problems and feeding conditions is ruminal acidosis [39].

The objective of balancing and managing CHO nutrition is to minimize deviations of ruminal pH throughout the day. Low NDF/high NFC rations lower rumen pH whit decreasing rumen motility that reduces the rate of volatile fatty acid absorption. This occurs because rumen mixing is reduced and the concentration of VFA near the ruminal papillae is reduced. Low rumen pH damages the papillae and causes adhesion of adjacent papillae, reducing the absorptive surface area. This results in a decrease in the rate of VFA removal. Based on a summary of published research studies, the effect of overall dietary NDF concentration is not correlated with ruminal pH. The concentration of NDF provided by forage as a percent of dry matter has a strong positive relationship with ruminal pH. However, it appears that fiber fermentability is more critical to the amount of VFA produced than either changing forage NDF as a percent of dry matter or total NDF [56, 70].

Difference in sources of NDF, forage particle size, NFC source and amount, and the interaction among those factors also have a large influence on rumen pH. Several indirect indicators can be used to determine if rumen acidosis is occurring. Typically, more than one measure should be used to determine if rumen acidosis is really the culprit [6].

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Corresponding Author

S.Masoud Davoudi

Department of Animal Science, Islamic Azad University of Shahrkord, Shahrkord, Iran.

E-mail: h.aminipor@gmail.com

Refernces

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