Effects of Different Maturity Stages and Varieties on Nutrient Composition and Rumen Degradation Characteristics of Whole-Plant Wheat Postprint

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Abstract

This study aimed to investigate the effects of different maturity stages and varieties on the nutritional components and rumen degradation characteristics of whole-plant wheat, thereby providing reference data for its application in dairy cow diets. Two wheat varieties, Shannong 22026 (SN22026) and Shannong 82567 (SN82567), were used, with samples collected from late March to mid-June 2015. The experiment determined the contents of dry matter (DM), crude protein (CP), starch, crude ash, organic matter, neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), and relative feed value of whole-plant wheat at different maturity stages, and measured the rumen degradation rate using three Holstein dairy cows (approximately 500 kg) fitted with rumen fistulas. The results showed: 1) The DM content of whole-plant wheat at the wax ripe stage was significantly higher than at other stages ($P<0.05$); the CP content gradually decreased during maturation and remained stable after the flowering stage; the NDF, ADF, and ADL contents exhibited a trend of first increasing then decreasing with wheat maturation. 2) The gross energy per unit DM of whole-plant wheat showed a decreasing trend during maturation, while net energy for lactation exhibited a trend of first decreasing then increasing. 3) The effective degradation rates of DM, CP, and NDF were highest at the jointing stage, significantly decreased at the heading and flowering stages ($P<0.05$), and significantly increased again at the milk ripe and wax ripe stages ($P<0.05$). 4) The rumen degradable protein (RDP) content was highest at the jointing stage, significantly higher than at other stages ($P<0.05$); it significantly decreased at the heading stage ($P<0.05$), reached the minimum at the flowering stage ($P<0.05$), and gradually increased after the flowering stage ($P>0.10$); whereas the rumen undegradable protein content gradually decreased

during wheat maturation, being lowest at the wax ripe stage and significantly lower than at other stages (P<0.05). Thus, comparison of the two whole-plant wheat lines in this experiment showed significant differences only in a few indicators. Whole-plant wheat at each maturity stage had high feeding value, but significant differences existed in nutritional value, yield, and rumen degradation characteristics among different maturity stages.

Full Text

Effects of Different Maturity Stages and Varieties on Nutritional Components and Rumen Degradation Characteristics of Whole Crop Wheat

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Abstract

This study investigated the effects of different maturity stages and varieties on the nutritional components and rumen degradation characteristics of whole crop wheat to provide data reference for its application in dairy cow diets. Two wheat varieties, ShanNong 22026 (SN22026) and ShanNong 82567 (SN82567), were used, with samples collected from late March to mid-June 2015. The experiment measured dry matter (DM), crude protein (CP), starch, crude ash, organic matter, neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL) contents, and relative feed value of whole crop wheat at different maturity stages. Rumen degradability was determined using three Holstein dairy cows (approximately 500 kg body weight) fitted with rumen fistulas. The results showed that: (1) DM content in the dough stage was significantly higher than in other stages (P<0.05). CP content gradually decreased during maturation and remained stable after the flowering stage. NDF, ADF, and ADL contents showed a trend of initially increasing then decreasing with wheat maturity. (2) Gross energy per unit DM decreased during maturation, while net energy for lactation first decreased then increased. (3) Effective degradability of DM, CP, and NDF was highest in the jointing stage, significantly decreased in the heading and flowering stages (P<0.05), and significantly increased again in the milk and dough stages (P<0.05). (4) Rumen degradable protein (RDP) content was highest in the jointing stage, significantly higher than other stages (P<0.05), decreased significantly in the heading stage (P<0.05), reached its lowest in the flowering stage (P<0.05), and gradually increased after flowering (P>0.10). Rumen undegradable protein content gradually decreased during maturation, with the lowest value in the dough stage, significantly lower than other stages (P<0.05). In conclusion, comparison between the two wheat varieties showed significant differences only in a few indices. While each maturity stage of whole crop wheat had high feeding value, significant differences existed in nutritional value, yield, and rumen degradation characteristics among different maturity stages.

Keywords: whole crop wheat; dairy cow; nutritional components; rumen degradation rate

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Introduction

Wheat is one of the most widely cultivated crops worldwide. Due to its high digestible fiber and energy content, whole crop wheat is suitable as a high-quality forage crop for high-yielding dairy or beef cattle, with feeding value comparable to corn silage. Whole crop wheat has high nutritional value and is widely used in dairy feed in Israel, Turkey, and some regions of the United States. China' s 2016 Central No. 1 Document proposed expanding the grain-to-forage pilot program and accelerating the construction of a modern forage and feed system. In recent years, with the development of China' s dairy industry, domestic high-quality roughage has struggled to meet the needs of dairy farms. Therefore, fully developing and utilizing local roughage resources is the general trend, and the application of wheat in dairy production has gradually attracted attention.

Applying whole crop wheat in dairy feed requires understanding the characteristics and changing patterns of its nutritional value during growth to determine the optimal harvesting period. However, many research results on wheat show inconsistencies. Currently, research on whole crop wheat in China is scarce, and studies on its rumen degradation rate have not been reported. Therefore, this experiment aimed to study the changing patterns of nutritional components and rumen degradation characteristics during the growth of whole crop wheat, providing data reference for its application in dairy diets. It is hoped that this research can serve as a reference for developing local roughage resources and reducing imported roughage.

Materials and Methods

1.1 Sample Collection

The wheat used in this experiment was sown on October 10, 2014, in two plots at the experimental field of the College of Agronomy, Shandong Agricultural University. The wheat varieties in the two plots were ShanNong 22026 (SN22026) and ShanNong 82567 (SN82567), with a seeding rate of 150,000 plants per mu (1 mu 666.67 m^2) in Tai' an, Shandong.

Samples were collected from late March 2015 (jointing stage) to mid-June (maturity harvest), spanning 11 weeks: jointing stage (weeks 1-2), heading stage (weeks 3-4), flowering stage (weeks 5-6), milk stage (weeks 7-9), and dough stage (weeks 10-11). Sampling occurred once weekly on Thursdays, starting 2 m from the field edge and proceeding longitudinally. Random plants were collected while avoiding adjacent plants. One hundred plants were collected from each plot per sampling, with wheat samples from each plot divided into two portions for determining nutritional component content and rumen degradation parameters.

After collection, samples were immediately dried to constant weight in a 65°C electric thermostatic oven, then rehydrated for 24 h to determine initial moisture content. The air-dried samples were ground using a plant sample grinder to 40-mesh and 7-mesh sizes for determining conventional nutritional components and rumen degradation parameters, respectively.

1.2 Determination of Rumen Degradability

Rumen degradability was determined using the nylon bag method. Wheat from two varieties was sown in two plots, with samples from each plot divided into two portions. An electronic analytical balance was used to accurately weigh whole crop wheat samples ground to 7-mesh (approximately 3 g) and nylon bags (pore size: 50 m, dimensions: 8 cm × 12 cm). Samples were placed in nylon bags, which were then fixed on rubber stoppers and placed in nylon mesh bags (approximately 50 cm long).

The experimental animals were three healthy mid-lactation multiparous Holstein dairy cows weighing approximately 500 kg, fitted with permanent rumen fistulas, with average milk yield of 25 kg/d. Cows were milked twice daily (06:30 and 18:30) and fed twice daily (08:30 and 15:30) with free access to feed and water. Diet composition is shown in Table 1 .

Nylon mesh bags were placed in the rumen 1 h before morning feeding, with the other end fixed to the rumen fistula. Each sample was divided into three portions and placed in the rumen of three cows. Based on the required sample residue amount, a certain number of nylon bags were removed at corresponding time intervals. Sample incubation times were 2, 4, 8, 12, 24, 48, and 72 h. Each time point had two replicates, with each sample in a nylon bag representing one replicate. After removal, nylon bags were immediately rinsed with clean water until the water ran clear, strictly preventing residue sample escape during washing. Cleaned nylon bags were dried in an electric thermostatic oven at 65°C to constant weight and then weighed. Nutritional components in residue samples were analyzed. Calculation indices for each variety used the average values across maturity stages.

1.3 Calculation of Degradation Parameters

Based on the real-time rumen degradation rate of target components in test samples at time t, the exponential curve of rumen degradation rate proposed by Feng Yanglian was calculated using the nonlinear regression procedure in SAS 8.2:

$P = a + b(1 - e^{-ct})$

Where: P is the rumen degradation rate (%) of protein at time point t (h); a is the rapidly degradable fraction (%); b is the slowly degradable fraction (%); c is the degradation rate of b (%/h).

1.4 Calculation of Effective Degradability

Using the values of a, b, and c from the above calculation, the effective degradability of target components in test samples was calculated as follows:

$ED = a + bc/(c + Kp)$

Where: ED is the effective degradability of protein (%); Kp is the rumen outflow rate (%/h).

The rumen outflow rate was predicted using the equation from NRC (2001):

$Kp = 3.362 + 0.479X1 - 0.007X2 - 0.017X3$

Where: Kp is the rumen outflow rate (%/h); X1 is the proportion of dry matter intake to body weight of experimental animals (%); X2 is the proportion of concentrate in the experimental diet (%); X3 is the proportion of neutral detergent fiber (NDF) in the diet dry matter (%).

The experimental cows used in this study were medium-weight Holstein cows with dry matter intake accounting for 3.4% of body weight, concentrate content of 50% in the diet, and NDF content of 25% in diet dry matter (DM). Based on the above formula, the calculated rumen outflow rate Kp was 4.2%/h.

1.5 Calculation of Relative Feed Value (RFV)

RFV is a widely accepted forage quality indicator that has become a common tool for determining hay quality in the U.S. hay market. Developed by the Hay Marketing Task Force of the American Forage and Grassland Council, RFV is estimated from acid detergent fiber (ADF) and NDF using the following formulas:

$DDM = 88.9 - 0.779 \times ADF$
$DMI = 120/NDF$
$RFV = (DDM \times DMI)/1.29$

Where: DMI (dry matter intake) is the dry matter intake of roughage, expressed as a percentage of body weight (BW); DDM (digestible dry matter) is expressed as a percentage of DM; 1.29 is the expected DDM for full-bloom alfalfa based on extensive animal trial data, expressed as a percentage of body weight. Division by 1.29 aims to make the RFV value of full-bloom alfalfa equal to 100.

1.6 Calculation of Rumen and Small Intestine Indices

Calculations of rumen and small intestine indices referenced "Nutrient Requirements and Feed Composition of Dairy Cows" edited by Feng Yanglian. Energy produced by feed rumen fermentation was expressed as rumen fermentable organic matter (FOM), digestible organic matter (DOM), etc., and affected rumen microbial protein (MCP) yield. In China' s small intestine protein system, each kilogram of FOM can support the synthesis of 136 g MCP (MCPE). The MCP yield supported by feed nitrogen sources was calculated from rumen degradable protein (RDP) yield and its conversion efficiency to MCP. The minimum of the two values represents the theoretical MCP yield (MCPN).

Rumen energy-nitrogen balance (RENB) = MCPE - MCPN. MCP(FOM) is the MCP yield calculated based on FOM. MCP(RDP) is the MCP yield calculated based on RDP. The conversion efficiency of RDP to MCP for both single feeds and diets was calculated at 90%, i.e., MCP = RDP $\times$ 0.9.

MCP synthesis supported by feed energy:
$\text{MCPE(g)} = 136 \times \text{FOM(kg)}$

MCP synthesis supported by feed RDP:
The efficiency of conversion of rumen degradable feed nitrogen (RDN) to rumen microbial nitrogen (MN) can be predicted from the ratio of RDN(g) to feed FOM(kg) using the regression formula:

$\text{MN/RDN} = 3.6259 - 0.8457\ln(\text{RDN/FOM})$
$\text{MCPN} = \text{RDN} \times (\text{MN/RDN})$

Small intestine protein = feed rumen undegraded protein + rumen MCP
Small intestine digestible protein = feed rumen undegraded protein $\times$ small intestine digestibility + rumen MCP $\times$ small intestine digestibility

Small intestine protein digestibility: MCP digestibility was 0.7, feed undegraded protein digestibility was 0.65. Conversion efficiency of small intestine digestible protein: 0.6 for growing dairy cows and 0.7 for lactating dairy cows.

1.7 Determination of Whole Crop Wheat Samples and Rumen Degradation Residues

DM content was determined according to GB 6435—1986. CP content was determined according to GB/T 6432—1994. Crude ash content was determined according to GB/T 6438—1986. Ether extract (EE) content was determined according to GB/T 6433—2006. NDF, ADF, and ADL contents were determined according to the method proposed by Van Soest (1991). Starch content in whole crop wheat samples was determined using the anthrone colorimetric method, referencing "Biochemical Experiments" compiled by Chen Junhui. Non-fibrous carbohydrate (NFC) content was calculated as:

$\text{NFC(\%)} = 100 - (\text{CP} + \text{NDF} + \text{EE} + \text{Ash})$

Based on measured CP, Ash, EE, NDF, and ADF contents, gross energy (GE) and net energy for lactation (NEL) were calculated using formulas from the French National Institute for Agricultural Research (INRA) (1978, 1988, 2000):

$$GE = 17.3 + 0.0617CP + 0.2193EE + 0.0387CF - 0.1867Ash + 0.19$$
$$NEL = ME \times Kl$$

$$Kl = 0.60 + 0.24 \times (ME/GE - 0.57)$$

Where: CF is crude fiber content; ME is metabolizable energy.

1.8 Statistical Analysis

Measurement results were preprocessed using Excel 2016, then analyzed using SAS 8.2 software for linear model analysis of variance and multiple comparisons. $P<0.05$ indicated significant difference, $P>0.10$ indicated no significant difference, and 0.05 P 0.10 indicated a significant trend.

Results

2.1 Effects of Different Maturity Stages and Varieties on Nutritional Components of Whole Crop Wheat

As shown in Table 2 , DM content of whole crop wheat gradually increased with maturity, with the rate of increase accelerating, particularly in the dough stage where DM content increased significantly ($P<0.05$). CP content gradually decreased during maturation, being highest in the jointing stage and significantly decreasing in the heading and flowering stages ($P<0.05$), then remaining stable after flowering. NDF, ADF, and ADL contents showed a trend of initially increasing then decreasing with wheat maturity; NDF content peaked in the heading stage, while ADF and ADL contents peaked in the flowering stage. NFC content showed a trend of initially decreasing then increasing, while starch content remained stable until the flowering stage and significantly increased thereafter ($P<0.05$). No significant differences in nutritional components were observed between varieties ($P>0.10$).

2.2 Effects of Different Maturity Stages and Varieties on Energy, Yield, and RFV of Whole Crop Wheat

As shown in Table 3 , gross energy per unit DM of whole crop wheat decreased with maturity. Net energy for lactation showed a trend of first decreasing then increasing, being lowest in the heading and flowering stages, significantly lower than other stages ($P<0.05$), and highest in the milk and dough stages, significantly higher than other stages ($P<0.05$). DM yield per plant increased with maturity, being lowest in the jointing stage, significantly lower than other stages ($P<0.05$), and highest in the milk and dough stages, significantly higher than other stages ($P<0.05$). Whole crop wheat had the highest RFV in the jointing stage, which significantly decreased in the heading and flowering stages ($P<0.05$)

and gradually increased in the milk and dough stages (P>0.10). No significant differences in energy, yield, or RFV were observed between varieties (P>0.10).

2.3 Effects of Different Maturity Stages and Varieties on Rumen Degradation Characteristics of Whole Crop Wheat

As shown in Table 4 , different maturity stages significantly affected rumen degradation rate of whole crop wheat (P<0.05). Effective degradability of DM, CP, and NDF was highest in the jointing stage, significantly decreasing in the heading and flowering stages (P<0.05) and significantly increasing again in the milk and dough stages (P<0.05). Effective degradability of gross energy showed irregular patterns, being highest in the jointing stage, significantly higher than other stages (P<0.05), and lowest in the heading and dough stages, significantly lower than other stages (P<0.05). Whole crop wheat had higher organic matter degradability in the jointing stage, which significantly decreased in the heading and flowering stages (P<0.05) and significantly increased again in the milk and dough stages (P<0.05).

2.4 Effects of Different Maturity Stages and Varieties on RDP and Small Intestinal Protein Contents of Whole Crop Wheat

As shown in Table 5 , RDP content of whole crop wheat was highest in the jointing stage, significantly higher than other stages (P<0.05), significantly decreased in the heading stage (P<0.05), reached its lowest in the flowering stage (P<0.05), and gradually increased after flowering (P>0.10). Rumen undegradable protein (RUP) content gradually decreased with wheat maturity, being lowest in the dough stage, significantly lower than other stages (P<0.05). MCP yield calculated based on FOM and MCP yield calculated based on RDP both showed a trend of first decreasing then increasing, but the former peaked in the dough stage while the latter peaked in the jointing stage. Rumen energy-nitrogen balance (RENB) was negative in the jointing and heading stages, positive after flowering, and closest to zero in the flowering stage. Small intestinal protein and small intestinal digestible protein contents of whole crop wheat gradually decreased with maturity, being highest in the jointing stage, significantly higher than other stages (P<0.05), and lowest in the dough stage.

Discussion

3.1 Effects of Different Maturity Stages and Varieties on Nutritional Components of Whole Crop Wheat

Based on wheat grain formation stages and grain weight gain characteristics during the filling period, wheat development from flowering to maturity can be roughly divided into three stages: grain formation, grain filling and weight gain, and rapid dehydration. The grain formation process determines the number of endosperm cells in the grain, which is closely related to final grain weight. During grain formation, rapid grain volume expansion occurs with highest water content and slow DM accumulation. After grain formation, grain weight gain gradually accelerates, entering the grain filling and weight gain process that continues until maximum grain dry weight is reached, during which nutrients in the wheat plant rapidly transfer to the grain. During grain filling, volume continues to increase until peaking, then enters the rapid dehydration period, which is relatively short with rapid water loss. After entering the dough stage, wheat plant leaves and stems turn yellow and dry, and from late dough to full maturity, DM content of whole crop wheat gradually increases. Crovetto et al. conducted experiments using wheat at the booting, flowering, milk, and dough stages, finding that higher wheat maturity corresponded to higher DM content. Qin Mengzhen et al. also reported that as whole crop wheat matured, water content decreased (i.e., DM content increased), consistent with our findings.

With wheat maturity, CP content of whole crop wheat decreased, as later maturity stages showed weaker photosynthesis, inhibiting protein synthesis. Throop, Qin Mengzhen et al., Crovetto et al., and Xie et al. all reported that plant maturity decreased CP content of whole crop wheat, though Oltjen et al. reported that dough-stage whole crop wheat silage had higher CP content than milk-stage wheat.

Cellulose components (NDF, ADF, and ADL) varied across maturity stages. Numerous studies have shown that as plants mature, forage cell wall components increase, along with cellulose content. In this experiment, cellulose content initially increased then decreased, with lower fiber content in the milk and dough stages after flowering, possibly because after grain formation, continuous starch deposition in grains during the filling process relatively decreased cellulose content. Crovetto et al. reported that NDF and ADF contents of whole crop wheat remained relatively stable from heading to milk stage and decreased in the dough stage, while ADL content gradually increased. Xie et al. found that crude fiber, NDF, and ADF contents in the milk stage were significantly lower than in the flowering and dough stages.

NFC content showed a trend of first decreasing then increasing, while starch content remained stable until flowering and significantly increased thereafter. This indicates that before flowering, non-starch carbohydrates in NFC of whole crop wheat decreased, while after flowering, most plant carbohydrates transferred to grains in the form of starch. Beck et al. used whole crop wheat hay as roughage for beef calves and also found that dough-stage whole crop wheat had higher NFC content than booting-stage wheat. Additionally, hay made at booting stage had higher washing fiber content but lower NFC content than silage, possibly because water-soluble carbohydrates were consumed during curing, incorporated into NDF through Maillard reactions, or lost through exposure to air. Such losses would be smaller in the milk and dough stages because in later maturity, most NFC exists as more stable starch in wheat grains.

3.2 Effects of Different Maturity Stages and Varieties on Energy, Yield, and RFV of Whole Crop Wheat

Feed GE is the heat released from oxidation combustion of feed per unit DM, determined by the ratio of carbon, hydrogen, and oxygen which determines the oxidation degree of organic matter. GE magnitude is determined by organic matter content per unit DM and the carbon, hydrogen, and oxygen ratio of organic matter. During maturation, GE per unit DM of whole crop wheat decreased, but energy remained high at each stage. Crovetto et al. also reported high GE at all stages that gradually decreased with wheat maturity, consistent with our results. Notably, GE in Crovetto et al.' s experiment was higher than in our study and even higher than similar maturity stages reported by INRA, possibly due to regional differences or different measurement methods.

Energy digestion, absorption, and utilization in ruminants is much more complex than in monogastric animals, affected by rumen microbial fermentation, digestive tract absorption, and conversion efficiency of organs producing animal products. Moreover, dairy cows show large differences in utilization efficiency of various feeds. Therefore, dairy cow feed cannot be evaluated using only digestible or metabolizable energy, but must be corrected using net energy (NE). Evaluation methods for net energy for lactation are relatively complex, generally based on measured data from representative feeds to regress the relationship between net energy for lactation and digestible or metabolizable energy, then calculating net energy for lactation from regression formulas. In this experiment, net energy for lactation per unit DM of whole crop wheat was lowest in the heading and flowering stages and highest in the milk and dough stages, mainly because in later maturity stages, starch deposition increased non-fibrous nutrient content while cellulose content decreased, as high-NDF feed has lower net energy content than low-NDF feed.

DM yield per plant increased with plant maturity, particularly increasing rapidly in the milk and dough stages, mainly from increased biological yield and nutrient deposition. Calculated yield per mu was very high, which would be unattainable in actual whole crop wheat harvesting because wheat seed germination rate, stubble height during harvest, and losses during processing would affect actual yield. Our results are consistent with many studies. Edmisten et al. reported that grain contributed 56% of wheat DM yield in the dough stage. Coblentz et al. reported that wheat spikes contributed 58% and 60% of DM in the dough and grain maturity stages, respectively. Ashbell et al. studied whole wheat yield changes in Israel, finding that DM yield increased by approximately 40% from milk to dough stage. This also indicates that after spike emergence, wheat grains make considerable contributions to overall forage nutritional quality during grain filling.

Whole crop wheat had the highest RFV in the jointing stage, which decreased in the heading and flowering stages and increased in the milk and dough stages. Xie et al. used whole crop wheat at flowering, milk, and dough stages to make silage, obtaining the highest RFV in the milk stage, followed by dough and flowering stages. In our experiment, RFV in the dough stage was higher than in the milk stage, inconsistent with Xie et al.' s results, possibly due to different processing methods of whole crop wheat. When whole crop wheat is processed into hay, some water-soluble compounds are lost during curing or incorporated into NDF through Maillard reactions. During silage, lactic acid fermentation converts carbohydrates to lactic acid, causing nutrient loss and dissolution of potential nutrients into silage, all of which change feed nutritional value.

In this experiment, variety had no effect on nutritional components of whole crop wheat, possibly because the two wheat varieties used had similar genetic characteristics.

3.3 Effects of Different Maturity Stages and Varieties on Rumen Degradation Characteristics of Whole Crop Wheat

DM degradability is an important factor affecting DM intake in ruminants. Roughage DM degradability in the rumen increases to varying degrees with extended degradation time, but the increase magnitude differs among roughages of different quality. Fiber content (cellulose content and lignification degree, etc.) in roughage affects feed degradation characteristics. Generally, cellulose degrades slower than NFC, while lignin is difficult to digest in the rumen. Lignin in different forages can also bind with other nutritional components, reducing their degradability. As wheat grows, the ratio of stems and leaves to the whole plant gradually increases, leaves and stems age, cell wall components increase, and cellulose content in the plant increases, reducing degradation speed of various nutrients and DM degradability. After wheat begins grain filling, starch deposition in grains transfers more nutrients to easily degradable grains. Increased starch content and decreased proportion of cellulose components in later maturity stages greatly improve rumen degradability of whole crop wheat.

Protein in forage is utilized by rumen microorganisms to produce MCP, which is then digested and absorbed in the small intestine. The fermentation difficulty and rumen retention time of feed protein determine its rumen degradability. Forage protein mainly exists as nitrogen-containing compounds in cell contents, while cellulose structure in cell walls affects protein degradation speed. As plants mature and age, increased lignification also affects nitrogen release and decomposition. Feed protein can be divided into rapidly degradable, slowly degradable, and non-degradable portions, with different proportions in different feeds. Values a, b, and c in regression formulas represent contents of these three portions. Whole crop wheat at different maturity stages had very little non-degradable portion, indicating that most protein in whole crop wheat can be degraded in the rumen. Results show that effective rumen degradability of CP in whole crop wheat was greatly affected by maturity stage. Leng Jing et al. and Liu Dalin et al. reported that high forage CP content was beneficial for CP degradation. In our experiment, CP content of whole crop wheat gradually decreased during maturation, while effective degradability of CP first decreased then increased.

That is, effective degradability of CP before flowering was consistent with results from Leng Jing et al. and Liu Dalin et al., but opposite after flowering. This is mainly because after flowering, most protein components transferred to wheat grains, which have very low fiber content and lignification degree, making them more easily degradable.

Rumen degradability of NDF in roughage is one of the important indicators for evaluating roughage quality. Dietary NDF plays an important role in maintaining normal rumination and rumen health in ruminants. Different NDF compositions affect NDF rumen degradability, so NDF degradability differs among feed materials. As plants mature, the leaf-to-stem ratio and stem lignification degree (affecting fiber digestibility) change, thereby affecting fiber digestibility and protein components of hay. Lignin affects the degree and speed of forage fiber digestion, depending on lignin content and composition, tissue distribution, and phenolic function. Lignin, due to its unique phenolic components, cannot be digested under anaerobic conditions and can reduce the proportion of potentially digestible fiber in forage. Therefore, effective degradability of NDF in whole crop wheat was highest in the jointing stage, decreasing with wheat maturity. Although effective degradability of NDF in the milk stage was significantly lower than in the jointing and heading stages, it was significantly higher than in the dough stage. This may be because wheat in the dough stage had become withered and yellow with increased lignification, and grains began to turn yellow and harden, potentially reducing effective NDF degradability.

Effective degradability of GE in whole crop wheat changed with maturity similarly to NDF content, indicating that NDF content affects energy degradation of feed in the rumen.

Fermentation products of feed in the rumen and digestion products in the small intestine are different. Many studies have shown that rumen FOM yield is proportional to volatile fatty acid (VFA) and MCP production from rumen fermentation. Therefore, degradability of organic matter in the rumen (FOM/OM) is an important parameter for evaluating feed quality. In this experiment, whole crop wheat had higher organic matter degradability in the jointing stage, which decreased in the heading and flowering stages and significantly increased again in the milk and dough stages. This indicates that organic matter in whole crop wheat became more easily degradable after grain filling, possibly because after flowering, nutrients in the plant gradually transferred to wheat grains, and the proportion of grains and their nutrients, especially non-fibrous nutrients, in whole plant DM gradually increased. This corroborates research by Jiang Jun et al. and Xu Ping et al., who reported that apparent rumen organic matter degradation increased with increasing dietary concentrate content, and whole digestive tract apparent organic matter digestibility also increased with more concentrate. However, some studies have shown that apparent digestibility of rumen organic matter and whole digestive tract organic matter is not affected by dietary organic matter content. The increased degradability of organic matter in whole crop wheat after grain filling may also be because easily degradable nutrients like starch in grains can be degraded in the rumen, providing energy for rumen microbial growth. Russell et al. reported that rumen microbial growth accelerated with increased carbohydrate fermentation speed, and large amounts of growing rumen microorganisms could in turn decompose more organic matter.

3.4 Effects of Different Maturity Stages and Varieties on RDP and Small Intestinal Protein Contents of Whole Crop Wheat

With in-depth research on protein nutrition in ruminants, traditional protein systems cannot fully explain protein digestion and metabolism in ruminants. Dietary protein enters the small intestine after rumen degradation, when its structure and quantity have changed. Protein entering the small intestine includes dietary undegraded protein and rumen MCP. Considering rumen microbial degradation and utilization of dietary protein requires evaluating dietary protein using the small intestine protein system.

Protein degradation in the rumen is one of the important factors affecting rumen fermentation in ruminants. Functionally, it can be divided into RDP and RUP. RDP provides necessary peptides, amino acids, and ammonia for rumen microbial growth and MCP synthesis, while RUP bypasses rumen degradation or is decomposed by rumen microorganisms but not utilized, directly entering the small intestine to be digested and absorbed with MCP, representing one of the important pathways for ruminants to absorb and utilize protein nutrients. Research shows that 60% of dairy cows' protein nutritional requirements are provided by RDP and 40% by RUP. Controlling a reasonable RDP to RUP ratio in ruminant diets can both meet rumen microbial degradation needs and provide sufficient small intestine amino acids for the host (RUP can provide amino acids for small intestine utilization, representing the second major source of small intestine amino acids). Whole crop wheat in the jointing stage had high contents of both RDP and RUP, indicating high protein content at this growth stage, with both high utilizable protein for rumen microorganisms and high non-utilizable protein. In later maturity stages, RDP content increased while RUP content decreased, indicating that in whole crop wheat protein components, the portion degradable and utilizable by rumen microorganisms increased while the portion not utilized by rumen microorganisms and directly entering the small intestine decreased.

Different feeds have different RDP contents, causing differences in rumen MCP synthesis amounts. High-protein feeds have higher RDP content than high-energy feeds, resulting in higher calculated rumen MCP synthesis from RDP, but high-energy feeds also show high MCP synthesis calculated from FOM. Therefore, using the RENB principle to evaluate diets can simultaneously meet rumen microbial needs for RDP and FOM, making diet formulation more reasonable. If dietary RENB equals 0, balance is good; if negative, rumen RDP is excessive and energy (FOM) is insufficient, requiring increased rumen RDP; if positive, rumen RDP is insufficient and energy (FOM) is excessive, requiring increased rumen energy (FOM). Our results show that before flowering, whole crop wheat had sufficient RDP but insufficient FOM, while after flowering the opposite was true, with RENB value closest to zero in the flowering stage, indicating good energy-nitrogen balance. Correspondingly, in maturity stages with excessive RDP (jointing and heading stages, RENB<0), small intestinal protein and small intestinal digestible protein contents were very high, while in stages with excessive FOM (flowering, milk, and dough stages, RENB>0), small intestinal protein and small intestinal digestible protein contents decreased, though degradable energy was high with energy excess.

Conclusion

1. Differences between the two varieties of whole crop wheat were small, with significant differences observed only in a few indices. While each maturity stage of whole crop wheat had high feeding value, significant differences existed in nutritional value, yield, and rumen degradation characteristics among different maturity stages.

2. From the perspective of nutritional value and rumen degradation characteristics, the jointing, milk, and dough stages were superior to the heading and flowering stages, with the milk and dough stages having higher DM yield. In North China, early harvesting of wheat can reduce risks from diseases, pests, and adverse weather, and is beneficial for planting and yield of the next corn season.

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