Postprint: Correlation between Shear Force and Nutrient Content of Cotton Stalk

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Abstract

This study aimed to investigate the correlation between shear force and nutrient content in cotton stalks. Cotton stalks were sectioned into three parts: the lower 1/3 (bottom 1/3) near ground level, the middle 1/3, and the upper 1/3 (top 1/3). The mass and length of each section were measured to calculate linear density, and the shear force of stems and lateral branches, as well as the content of main nutrient components, were determined. The results showed that the linear density and diameter of cotton stalks gradually increased from top to bottom, with significant differences among the three sections ($P<0.05$); the crude protein content of whole-plant cotton stalks was 8.78%; neutral detergent fiber content was highest in the lower 1/3 of the stem (62.54%) and lowest in cotton leaves (35.51%); crude protein and crude ash contents in cotton stalk stems showed a negative correlation with shear force ($P<0.001$); dry matter, neutral detergent fiber, acid detergent fiber, and hemicellulose contents showed a positive correlation with shear force ($P<0.001$). In different parts of cotton stalks, shear force was mainly influenced by diameter and nutrient content, and there was a strong linear relationship between shear force and nutrient content in cotton stalks.

Full Text

Correlations between Shearing Force and Nutrient Contents of Cotton Stem

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Abstract

This experiment was conducted to study the correlations between shearing force and nutrient contents of cotton stem. Cotton stems were cut into three parts at 1/3 from bottom (bottom 1/3), 1/3 in the middle (middle 1/3) and 1/3 from top (top 1/3), respectively. The mass and length of different parts were tested, and the linear density was calculated; the shearing force and main nutrient contents of stem and lateral branch were determined. The results showed as follows: the linear density and diameter increased from top to bottom, and the differences among three parts were significant ($P<0.05$); crude protein content of whole cotton stem was 8.78%; neutral detergent fibre content in stem bottom 1/3 was the highest (62.54%), while that in cotton leaves was the lowest (35.51%); crude protein and ash contents had negative correlations with shearing force ($P<0.001$); dry matter, neutral detergent fibre, acid detergent fibre and hemicellulose had positively correlations with shearing force ($P<0.001$). In conclusion, in different parts of cotton stem, shearing force is mainly affected by diameter and nutrient contents, and strong linear relationships exist between shearing force and nutrient contents.

Keywords: cotton stem; shearing force; nutrition characteristic

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Xinjiang is China' s largest cotton production base, with abundant cotton stem resources. In 2013, Xinjiang' s total cotton output reached 3.4 million tons. Based on a grain-to-straw ratio of 2.18 for cotton, Xinjiang could produce 7.41 million tons of cotton stems in 2013 alone. However, the utilization of cotton stems in herbivorous animal production is limited due to their low edible portion, low protein content, and high cellulose and lignin contents. Therefore, comprehensive evaluation of the nutritional value of different cotton stem parts and efforts to achieve precise harvesting of cotton stems are of great significance for making full use of cotton stem resources and developing grain-saving animal husbandry.

Feed nutritional value evaluation is the foundation of feed resource utilization. Evaluation methods include chemical analysis, the Cornell Net Carbohydrate and Protein System (CNCPS), in vitro fermentation gas production, and nylon bag methods. Shearing force refers to the force required to cut vertically through a crop surface. Research indicates that shearing force technology has the potential to become a tool for breeding and improving forage quality. This measurement can reflect not only animal feeding preferences but also identify forage nutritional value. This study used Xinjiang' s abundant cotton stem resources as research objects, focusing on shearing force as an indicator to evaluate cotton stem nutritional value. Combined with chemical analysis, we investigated the relationship between shearing force and nutrient contents in different parts of cotton stems to provide theoretical basis for evaluating cotton stem nutritional value using shearing force and basic data for efficient utilization of cotton stem resources.

1.1 Experimental Materials

Cotton stalks from sea-island cotton manually harvested in the Alar reclamation area of Xinjiang were used as experimental materials. The physical traits (including shearing force) and nutrient contents of the main nutritional organs (stem, lateral branches, leaves, and cotton bolls) were determined.

1.2.1 Physical Trait Measurement

Sixty cotton stalks were randomly selected from the field. After air-drying in the laboratory, they were divided into five replicates with 12 stalks each. Plant height and weight were measured with the stalks placed horizontally on the ground. Lateral branches, cotton bolls, and leaves were removed and weighed separately. The stem was cut into three equal parts: bottom 1/3 (near ground), middle 1/3, and top 1/3. The mass and length of each segment were measured to calculate linear density [linear density (g/mm) = mass/length]. Diameter was measured at the midpoint of each segment using vernier calipers. At the same midpoint location, each stem segment was cut vertically to record shearing force. The average of the three segments was calculated, with each replicate of 12 stalks serving as the statistical unit. A digital muscle tenderness meter (measurement range 0–2) was used for shearing force determination.

1.2.2 Nutrient Content Measurement

After air-drying, cotton stem, cotton boll hull, lateral branch, and leaf samples were ground using a small grinder and passed through a 50-mesh sieve. Main nutrient contents were determined according to *Feed Analysis and Feed Quality Detection Technology* [5], including dry matter, crude protein, crude fat, crude ash, organic matter, neutral detergent fiber (NDF), and acid detergent fiber (ADF).

1.3 Data Processing

Experimental data were initially organized using Excel 2007, and statistical analysis was performed using SAS 9.1.3 software with ANOVA.

2.1 Morphological Parameters and Shearing Force of Cotton Stem

Morphological parameters and shearing forces are shown in Table 1 . When cotton stems were divided into three equal parts, mass increased gradually from top to bottom, with significant differences among segments ($P<0.05$). Linear density and diameter showed the same pattern ($P<0.05$). Regarding lateral branch mass from the top, middle, and bottom thirds, the top 1/3 segment had the highest lateral branch mass, which was not significantly different from the middle 1/3 segment ($P>0.05$) but was significantly higher than the bottom 1/3 segment ($P<0.05$). Shearing force analysis revealed that cutting the top, middle, and bottom stem sections required 157.77, 340.80, and 726.22 N, respectively, increasing significantly from top to bottom (P<0.05).

2.2 Nutrient Contents in Different Parts of Cotton Stem

Nutrient contents in different parts of cotton stem are presented in Table 2 . Dry matter content did not differ significantly among whole plant, cotton boll hull, leaves, lateral branches, or different stem parts (P>0.05). Crude protein content of whole cotton stem was 8.78%, second only to cotton leaves (11.94%), with significant difference between them (P<0.05). Crude protein contents in lateral branches and top 1/3 stem were not significantly different (P>0.05). Cotton boll hull and bottom 1/3 stem had similar crude protein contents (P>0.05), both significantly lower than other parts (P<0.05). Calcium content was highest in lateral branches, significantly higher than other parts (P<0.05). Phosphorus content in different parts ranged from 0.06% to 0.11%. NDF content was highest in bottom 1/3 stem (62.54%), significantly higher than cotton boll hull, leaves, top 1/3 lateral branch, and top 1/3 stem (P<0.05). Leaves had the lowest NDF content (35.51%), significantly different from all other parts (P<0.05). ADF content followed the pattern: bottom 1/3 stem > bottom 2/3 lateral branch, bottom 1/3 lateral branch, middle 1/3 stem > whole plant, top 1/3 stem, cotton boll hull > leaves. Crude ash content was highest in leaves, significantly higher than other parts (P<0.05).

2.3 Regression Relationships Between Nutrient Contents and Shearing Force of Cotton Stem

Regression relationships between main nutrient contents and shearing force are shown in Table 3 . Cotton stem shearing force can predict main nutrient contents (dry matter, crude protein, NDF, ADF, hemicellulose, crude ash). Crude protein and ash contents showed negative correlations with shearing force (P<0.001), while dry matter, NDF, ADF, and hemicellulose contents showed positive correlations (P<0.001).

2.4 Regression Relationships Between Shearing Force and Diameter in Different Parts of Cotton Stem

Regression relationships between shearing force and diameter in different parts are presented in Table 4 . Strong linear regression relationships exist between different parts and their diameters (r^2=0.653-0.709; P<0.001). Since shearing force requires specialized tools and is not easily obtained in practice, it can be calculated through its relationship with cotton stem diameter.

3.1 Nutritional Value of Different Cotton Stem Parts

Cotton stem is one of the main roughage sources for herbivorous livestock in Xinjiang, especially in southern Xinjiang. However, its high fiber content, low edible portion, low crude protein content, and presence of free gossypol restrict its effective utilization and limit the rapid development of herbivorous livestock farming in southern Xinjiang. Some scholars believe that roughage nutritional value depends on nutrient content and animal intake, with morphological characteristics and nutrients directly affecting forage utilization and animal feeding. Ren et al. analyzed nutrient contents in different cotton stem parts, reporting stem crude protein content of 5.7% and lateral branch content of 6.8%. In this experiment, dividing the stem into top, middle, and bottom thirds yielded crude protein contents of 7.85-5.88%. Top 1/3 lateral branch crude protein was 7.93%, while bottom 2/3 was 7.86%, with upper lateral branches slightly higher than lower parts. Overall, our results were somewhat higher than previous reports. These differences may be related to cotton variety, growing region, light conditions, soil fertility, and irrigation. Additionally, our results showed that when cotton stem was divided into three parts, crude protein content gradually increased from bottom to top, while NDF and ADF gradually decreased, with lateral branches showing the same pattern. From the growth pattern of cotton plants, upper stems are slender while lower stems are thick. Combined with shearing force measurements, we can preliminarily conclude that greater shearing force corresponds to lower crude protein content and higher NDF and ADF contents.

3.2 Feasibility Analysis of Using Shearing Force to Predict Nutrient Contents in Cotton Stem

Shearing force refers to the force required to cut vertically through a crop surface, which can objectively reflect forage edibility, chewing difficulty, and nutritional value, and serve as a basis for forage selection. Iwaasa et al. used shearing force technology to study stem fracture properties, finding that shearing force was closely related to diameter, mass, and linear density—factors more important than chemical composition of cell walls. Hughes et al. investigated relationships between leaf shearing force and nutrient contents in 12 Brachiaria ecotypes, reporting r^2 values of 0.74, 0.82, and 0.80 between shearing force and NDF, ADF, and lignin contents, respectively, suggesting shearing force is more accurate and efficient than nutrient content for forage selection. Shearing force is influenced by many factors including stem thickness, stem wall thickness, linear density, and nutrient content, with nutrient content and linear density being important influencing factors. Liu et al. studied relationships between ginger stem shearing force and morphological indicators, nutrient contents, and rumen degradability, concluding that shearing force could serve as an indicator for estimating crop straw nutritional value. The same researchers also studied relationships between morphology, nutrient content, and 48-hour rumen degradability with shearing force in alfalfa at full bloom stage and winter rye grass at grain-filling stage, finding that shearing force of both forages was affected by morphological indicators and nutrient contents. Regarding the relationship between shearing force and rumen degradability, shearing force could estimate rumen degradability of alfalfa stem nutrients, but the relationship was not significant for rye grass. In this experiment, r^2 values between cotton stem NDF, ADF, and hemicellulose contents and shearing force were 0.893, 0.675, and 0.836, respectively, similar to Hughes et al.' s results. Correlation analysis between main nutrient contents (dry matter, crude protein, NDF, ADF, etc.) and shearing force in cotton stem showed r^2 values ranging from 0.552 to 0.974, indicating strong linear relationships between cotton stem shearing force and main nutrient contents. However, whether shearing force can be used as a factor to predict nutrient contents requires further in-depth research.

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Note: Figure translations are in progress. See original paper for figures.