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Mechanical properties of garlic scape

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Jing Yang¹

¹Tianshui Normal University

Yj



Jing Yang

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We use this protocol and it's working

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Keywords: mechanical properties of garlic scape, mechanized garlic scape harvesting, key parameters for the garlic scape, garlic scape, garlic plant, systematic mechanical testing, cultivar variations on mechanical property, testing methods for the mechanical property, agricultural engineering, mechanical property, shear loading, axial tension, mechanism analysis, cultivar variation

Abstract

This protocol details the testing methods for the mechanical properties of garlic plants and their components (garlic scapes and pseudo-stems) under axial tension, radial compression, and shear loading. The experiment aims to provide key parameters for the garlic scape and pseudo-stem separation mechanism in mechanized garlic scape harvesting through systematic mechanical testing. This protocol is intended for researchers in the field of agricultural engineering. It should be noted that this protocol does not account for the effects of moisture content or cultivar variations on mechanical properties, and the conclusion is mainly used for mechanism analysis. The tests are conducted on a universal testing machine, with expected outputs including force-displacement curves. All raw and processed data were output in EXCEL table format.

Guidelines

Determination of Physical Parameters: (1) Moisture Content: The moisture content of garlic scapes and pseudo-stems was determined using the 105°C oven-drying method. (2) Density Measurement: The density of samples was measured via the drainage method.

Specimen Preparation and Grouping:(1) The geometric dimensions of specimens (including diameter, pseudo-stems thickness, and plant length) were precisely measured using a vernier caliper and recorded. (2) Specimens were grouped based on dimensional data and prepared according to the specific requirements for tensile, compression, and shear tests.

Mechanical Testing Procedure:(1) The universal testing machine was activated, calibrated, and set with predetermined parameters, including loading speed and termination conditions. (2) Tensile, compression, and shear tests were conducted sequentially. The force-displacement curves were monitored in real-time during the tests.

Data management and equipment maintenance: After the tests were completed, raw data files were saved immediately and labeled with corresponding sample numbers for traceability. Residual plant sap and tissue debris were thoroughly cleaned from the fixtures to prevent corrosion and ensure the accuracy of subsequent tests.

Materials

1. Test samples

White garlic plants: Mature, intact and unbroken, harvested from Sanyangchuan Garlic Planting Base, Tianshui City, Gansu Province, China (May 2025 harvest), stored in sealed and refrigerated conditions to prevent moisture loss.

2. Major Instruments

(1) Universal Testing Machine: Manufactured by Wance Company (Shenzhen, China), with a capacity of 10000N and accuracy of 0.18%, equipped with special fixtures for tension, compression, and shear tests.

(2) Scaled-down clamping wheels: Thickness 10mm, diameter 50mm, used to simulate clamping scenarios in radial compression tests.

(3) Single-sided blade: Used as the loading component for shear tests, installed on the upper chuck of the universal testing machine.

(4) Vernier caliper: Accuracy 0.01mm, used to measure plant diameter, garlic scape diameter (root, middle, and upper sections separately), and pseudo-stem thickness/width.

(5) Electronic balance: Used to weigh the mass of garlic scapes and pseudo-stems in order to calculate the density and volume ratio of the garlic scapes to the pseudo-stems.

(6) Oven: Used for the determination of sample moisture content by the drying method.

3. Consumables

(1) Gauze: Wrapped around the clamping ends of samples in tensile tests to prevent sample slippage during the test process.

(2) Cutting tools: Used to prepare samples of specified sizes

(3) Beakers and Graduated Cylinders: Used for volume measurement (Beaker specification: 500mL; Graduated cylinder specification: 100mL).

(4) Disposable gloves: Used for sample handling to avoid contamination or hand injury.

Safety warnings

! Risk of Mechanical Pinching: It is strictly prohibited to insert hands or any part of the body into the test area while the testing machine is in operation. Loading and unloading operations must only be performed after the equipment has completely stopped and the load has been released.

Electrical Safety: Ensure the equipment is properly grounded. Do not operate the control panel with wet hands.

Ethics statement

This study takes garlic plants as the research objects and do not involve animal experiments, thus no special ethical approval is required. All experimental samples were collected from formal cultivation bases, and the sample collection process strictly complied with the relevant norms for agricultural scientific research.



Before start

- (1) Verify the accuracy of the test plan.
- (2) Maintain the freshness of the samples (garlic plants, garlic scapes, pseudo-stems) to prevent water loss, which could alter their mechanical properties.
- (3) Ensure that the laboratory is clean and organized, devoid of any potential safety hazards. (4) Inspect the connections and operational status of the universal testing machine to ensure it is functioning properly.

1. Equipment preparation

- 1 This experiment will be carried out in three main steps as follows: Equipment Preparation; Materials and Methods; Experimental Results and Analysis. This procedure is designed to ensure the reliability of experimental conditions and clarity of experimental methods, as well as to systematically present experimental data and corresponding conclusions.

- 2 **Equipment preparation**

- 2.1 **§ Universal Testing Machine**

Specification: 10,000 N capacity, $\pm 0.18\%$ accuracy

Manufacturer: Wance Company (Shenzhen, China)

Purpose: Axial tension, radial compression, and shear tests.

- § Vernier Caliper**

Specification: 0.01 mm accuracy

Purpose: Measurement of sample dimensions.

- § Electronic Balance**

Specification: ± 0.01 g accuracy

Manufacturer: Shanghai Puchun Metrology Instruments Co., Ltd. (China)

Purpose: Sample mass measurement.

- § Oven**

Model: DG450B

Temperature range: 5 °C to 250 °C

Manufacturer: Guangzhou Degong Machinery Equipment Co., Ltd. (China)

Purpose: Determination of moisture content.

- § Custom Clamping Fixture**

Specification: Clamping wheels with 10 mm thickness and 50 mm diameter (self-made)

Purpose: Radial compression tests.

- § Single-Sided Blade**

Purpose: Shear tests.

(Specification and manufacturer not specified.)

- § Gauze**

Purpose: Prevent sample slipping during tests.

(Specification and manufacturer not specified.)

- § Additional equipment**

Includes: Beaker and graduated cylinder

Purpose: Measurement of density and moisture content.

(Manufacturer not specified.)

- 3 **Materials and Methods**

- 3.1 Test Materials** The test materials of the white garlic variety used in the experiments were purchased from local farmers at the Sanyangchuan Garlic Planting Base, Tianshui City, Gansu Province, China in May 2025. A total of 80 plants were randomly selected. Among them, 64 intact and undamaged samples were chosen for mechanical property tests, and the remaining of them were reserved as backups. The garlic plant diameter (measured at 80–100 mm above the ground), the average diameter of garlic scape (calculated as the mean of the root, middle, and top section diameters), and the pseudo-stem thickness were repeatedly measured 20 times using a digital vernier caliper with an accuracy of 0.01 mm.



Picked experimental samples.



Measurement of diameters and lengths.

3.2 **Moisture content and density**

Moisture content determination: Measured by the 105°C drying method, the moisture content of fresh garlic scapes is $85.88 \pm 2.41\%$. Density determination: Measured by the drainage method, the density of garlic scapes is 970 kg/m^3 , and the density of pseudo-stems is 620 kg/m^3 .



Weighing of garlic scapes for density and moisture content measurement.



Weighing of pseudo-stems for density and moisture content measurement.

3.3 Test methods

Axial tensile test: The whole garlic scapes were extracted from garlic plants and samples with a gauge length of 350–500 mm were intercepted to perform axial tensile tests. To implement pseudo-stem tensile tests, pseudo-stems were made into rectangles with a length of 100 mm, a width of the maximum width of the material itself, and a thickness of the thickness of the material itself. In order to prevent slipping during tests, the samples were wrapped with gauze at the clamped part. The universal testing machine carried out tensile tests at the speed of 5mm/min. The samples were gradually broken with the increase of load, and the tests were successful if the fractures were not at the holding ends. Each test was repeated eight times.



Garlic scape tensile test samples.



The tensile test of garlic scapes.



The garlic scape fractures under tensile loading.



Process of pseudo-stem tensile tests.

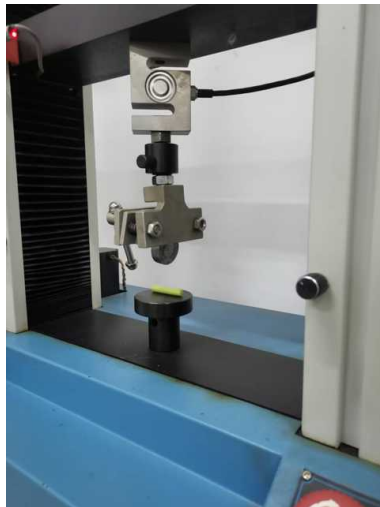
Radial compression test: Based on the method of clamping garlic scape, and scaled-down model of clamping wheels (thickness of 10 mm, diameter of 50mm) were installed on the universal testing machine to implement the radial compression tests. The upper chuck of the universal testing machine moved downward with the upper clamping wheel, and the lower clamping wheel was fixed at the lower chuck. The clamped position of garlic plants is 80mm~100mm above from the root of garlic plants (consistent with the position of manual clamping). Garlic scapes were prepared by sectioning 20 mm segments along its axial direction, and then placed between the upper wheel and the compression plate of the universal testing machine. The universal testing machine carried out compression tests at the speed of 5mm/min. Each test was repeated eight times.



Samples of compression tests.



The compression tests of garlic plants.



The compression tests of garlic scapes.

Shear test: 100mm gauge length sections were cut from plants at 50 mm above the root of garlic plants, and their diameters were measured using a vernier caliper. 50mm-long samples were cut from the middle part of garlic scape, with their diameters determined using the same measuring instrument. Pseudo-stems were made into rectangles about 30 mm long and 30-40 mm wide along the venation direction, with thicknesses of their own. The upper chuck on the universal testing machine clamped the single-sided blade and moved downward with 5mm/min. Each test was repeated eight times.



Garlic scape samples for shear tests.



Pseudo-stem samples for shear tests.



The shear tests of garlic scapes.

4 Test results

4.1 Tensile test results:

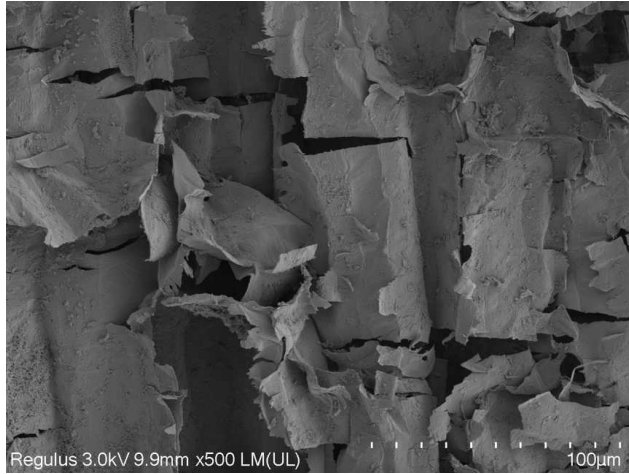
For garlic scapes, the average tensile elastic modulus was 17.08 MPa, the average tensile strength reached 0.98 MPa, and the average peak strain was 0.12 mm. For pseudo-stems, the average tensile elastic modulus was 57.03 MPa, the average tensile strength was 2.04 MPa, and the average peak strain was 0.06 mm. Based on the mixing rule of composite materials: $E_z = E_{zj}V_j + E_{zt}V_t$, the tensile modulus of the garlic plant was calculated to be 45.62 MPa.

4.2 Compression test results

For garlic scapes, the average compressive elastic modulus was 5.78 MPa, the average compressive strength was 1.97 MPa, and the average peak strain was 0.22 mm. For garlic plants, the average compressive elastic modulus was 2.85 MPa, the average compressive strength was 2.51 MPa, and the average peak strain was 0.80 mm. Based on the mixing rule of composite materials: $E_x = E_{xj}V_j + E_{xt}V_t$, the compressive modulus of the pseudo-stems was calculated to be 1.68 MPa.

4.3 Shear test results

For garlic scapes, the average shear elastic modulus was 1.53 MPa, the average shear strength was 0.80 MPa, and the average peak strain was 0.54 mm. For pseudo-stems, the average shear elastic modulus was 5.21 MPa, the average shear strength was 12.48 MPa, and the average peak strain was 1.48 mm. For garlic plants, the average shear elastic modulus was 1.45 MPa, the average shear strength was 0.87 MPa, and the average peak strain was 0.85 mm. The shear test was validated based on the mixing rule of composite materials. The theoretical shear modulus of garlic plants was calculated as 1.92 MPa. However, the average measured shear modulus was 1.45 MPa, which lies outside the 95% confidence interval [1.26, 1.65] MPa obtained from the actual tests, corresponding to a relative error of 25.5% compared to the experimental results. This discrepancy is mainly attributed to the occurrence of microscopic slippage, interface separation, and uneven stress transmission when the shear stress borne between cells exceeds their bonding strength under shear loading. These phenomena reduce the overall structural stiffness, which consequently leads to the theoretical values using the mixing rule of composite materials to be higher than the experimental values.



SEM image of the shear longitudinal section of garlic scapes at 200× magnification.

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