*International Journal of Physics, 2026, Vol. 14, No. 1, 1-5*
Available online at http://pubs.sciepub.com/ijp/14/1/1
Published by Science and Education Publishing
DOI:10.12691/ijp-14-1-1

# Effect of Gamma Radiation on Mechanical Properties of Wheat (*Triticum aestivum* L.)

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*Received November 28, 2025; Revised December 30, 2025; Accepted January 06, 2026*

**Abstract** Wheat is ranked second as the most consumed and produced food across the globe. Over the years, wheat production has been faced with biotic and abiotic factors, leading to low wheat production and quality. As a result, it has attracted many researchers aiming to improve productivity and quality through mutation breeding. Although there is significant literature on morphological, biological and chemical properties of wheat under the influence of gamma radiations as physical mutagens, a gap exists on how gamma radiations influences strength of the wheat stem, a mechanical property. *Njoro BW 11* wheat seeds were irradiated with dosages of 80, 100, 120, 150, 200, 250 and 300 Gy from a Cobalt 60 gamma source. Seeds were then sown, and at the maturity stage, samples of wheat straw from four randomly selected plants were cut from the second internode for the first and second mutant generations. Using the universal testing machine, the samples were subjected to tension force, where the stress-strain curves, stress, ultimate force, elongation percent and break distance were obtained automatically. S-shaped stress-strain curves were obtained. Analysis of variance showed statistical significance between ultimate force and treatments ($p = 0.00478$), and an interaction effect exists between treatment, mutant generations and ultimate force ($p = 0.01456$). Stress-strain curves showed wheat straws are elastic in nature with little or no plastic deformation. In conclusion, wheat straw mimics collagen fibers and structurally resembles biological tissues. Gamma radiations have significant effect on straw strength, where dosages of 150 and 200 Gy produced straws with high ultimate force and stress. Therefore, mutations by gamma radiation should maintain moderate dosages (150-200 Gy) to prevent the development of weak wheat stems in *Njoro BW11,* which may potentially predispose wheat plants to lodging.

***Keywords:*** *Gamma radiations, mechanical properties, wheat (Triticum aestivum L.), ultimate force, stress-strain curves*

**Cite This Article:** Njoroge Janet Wamuyu, Wamalwa Mercy Nasimiyu, and Muga Charles Ope, “Effect of Gamma Radiations on Mechanical Properties of Wheat (*Triticum aestivum* L.).” *International Journal of Physics*, vol. 14, no. 1 (2026): 1-5. doi: 10.12691/ijp-14-1-1.

## 1. Introduction

Wheat is ranked second as the most consumed and produced food across the globe [1,2]. It plays a crucial role in providing essential nutrients to human beings, such as proteins and calories [3,4]. Over the years, wheat production has been faced with biotic and abiotic factors, leading to low quantity and quality of wheat. For instance, [5] reported 21.5% of losses in wheat production are caused by diseases and specifically, stripe rust leads to a $1 billion loss annually. In Kenya and Ethiopia, a study by Wanyera and Wamalwa in 2022 [6] recounted a yield loss of 67-100% due to yellow rust. Lodging in severe cases recorded a loss of upto 80% [7]. As a result, low quality and production occurs leading to a gap between demand and supply.

Plant breeding has been embraced to create crop varieties with more desirable agronomic and economic traits [8,9]. Nuclear techniques, due to their high mutation frequency of exclusively new gene combinations, have quickly overtaken the conventional plant breeding methods such as hybridization and selection [10]. Ionizing radiation, such as gamma rays and X-rays are utilised as a physical mutagenic agents causing beneficial mutations, increasing the species’ variability and favoring their adaptation. Literature has significantly discussed morphological and biological changes such as plant height, number of spikes, spike length, germination, fresh and dry weight of stem and root due to gamma mutagens [11,12,13]. Hence, plant characteristics are subject to modification through varied types of mutations influencing a couple of wheat properties.

Mechanical properties, namely the strength of the stem, one of the factors affecting lodging, can also be affected by mutations. The strength of the straw is dictated by various traits. These include elasticity, stem rigidity, structural orientation, chemical and physical properties such as internode length, and stem thickness [7]. In terms of structural orientation, the polymer in the cell walls regulates the leaning of the straw, hence the rigidity and strength of the stem. Positive correlation between breaking strength and lignin content exists in several wheat varieties [7]. Tensile strength is primarily supplied by the cellulose microfibrils. This supports plant growth and promotes physical strength.

Gamma radiation affects wheat stems in various ways. Most studies revolve around the morphological, biological and physiological properties of wheat stem. For instance, increasing gamma radiation leads to a reduction in fresh weight and dry weight of the wheat stem [12]. Stem length decreases with increasing radiations where some researchers [12] obtained the highest length at 200 Gy and the lowest length at 400 Gy dosage. Increasing radiation results in high stem mortality [14]. Limited literature exists regarding mechanical properties and gamma radiation. Reference [15] study showed an increase in shear strength of the bread wheat stem for the $M_5$ and $M_6$ in two mutant lines. This occurred in only two mutant lines out of eight selected lines, hence a minor fraction. Therefore, there is a need to elucidate more on the changes in mechanical properties due to gamma radiation on wheat, which may help breeders in the selection of the best mutant lines. This study aims to discuss the influence of different gamma radiation dosages on wheat stem and its behavior under tension force.

## 2. Materials and Method

### 2.1. Treatment of Seeds with Gamma Radiations

One kilogram of wheat seeds, *Njoro BW 11* variety, obtained from Kenya Agricultural and Livestock Research Organization (KALRO) – Njoro, was sorted, and 8 samples were separately packed in medicine envelopes. Each sample represented 0, 80, 100, 120, 150, 200, 250, and 300 Gy treatments. At the Kenya Bureau of Standards (KEBs), the seed samples were exposed to gamma radiation from Cobalt 60, except for the control seeds (0 Gy).

### 2.2. Study Site

The seeds were planted in Field 7, a land in Egerton University whose elevation is about 2238 m above sea level (Figure 1). It lies at latitudes of 0.36379 and 35.92523 longitude. Temperatures throughout the year range between 5.0°C and 26.4°C and rainfalls between 1200 mm and 1400 mm [16]. The first mutant generation remained in the field from April to September 2024, and the second mutant generation from October 2024 to February 2025.


**Figure 1.** Field experiment location

### 2.3. Experimental Procedure

Land preparation was done by manual digging. In a randomized complete block design with three replications, control and treated seeds were sown. Sowing was done by dibbling at the rate of 25 seeds per row. First and second mutant generations were planted in rectangular plots of 1.25 $m^2$ and 1.44 $m^{2,}$ respectively, with inter-row spaces of 0.20 m, treatment-treatment spacing of 0.3 m and replication spacing of 0.5 m.

During planting, Di-ammonium phosphate (D.A.P, 18% N, 46% P, 0% K) was applied in both mutants at the recommended rate of 200Kg ha-1. Urea (20% C, 6.67% H, 46.67% N, 26.67% O) was applied at the tillering stage at the application rate of 200Kg ha-1 in $M_1$ and $M_2$. Weeds were physically controlled throughout the field experiment.

### 2.4. Data Collection

After maturation, wheat was harvested, and four specimens of randomly selected wheat straw were cut from the second internode across all treatments, replicates and mutants. They were wrapped in cling film and stored in a refrigerator to prevent them from drying. Figure 2 shows the Universal Testing Machine at the KEBS laboratory that was used to test the specimens' strength. Pulling speed was set at 50 mμ per minute, and a pressure of 45.0 Pa was applied. Stress-strain curves, stress, ultimate force and elongation percentages of the samples were obtained by Horizon software, a control and analysis software that was integrated in the machine.

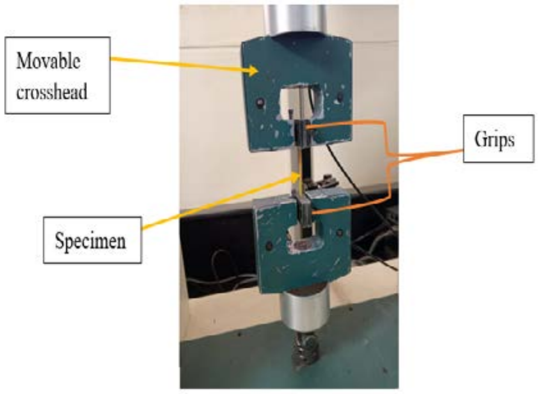


**Figure 2.** Sample mounted on the Universal Testing Machine

Using R software, the data were subjected to analysis of variance (ANOVA).

## 3. Results and Discussions

### 3.1. Stress-strain Curves

Figure 3 shows stress-strain curves that were obtained from the UTM.

Region A (0 to approximately 1.09% strain) was observed at the initial phase of the stress-strain curve, showing a non-linear relationship between stress and strain. The region is known as the toe region, where the sample easily stretches and suddenly becomes resistant to stretch [17]. The curve becomes linear in region B (from about 1.09 to 3.44% strain), revealing that stress increases with an increase in strain. It reflects the elastic nature of the wheat straw, where relief from the applied load, the sample returns to its original shape. At point D (2.82 % strain), the curve transits from linearity to nonlinearity up to point E (4.22 % strain), where the sample fractures. This shows the ability of the wheat stem to deform plastically, where irreversible change in shape and size occurs since the elastic limit is exceeded. At point C (2.66% strain), the sample fractures, exhibiting the inability of the sample to bear more stress. The sudden fracture at this point exposes the brittleness of the sample, unlike at point E, where it exhibits some ductility, hence its strength.

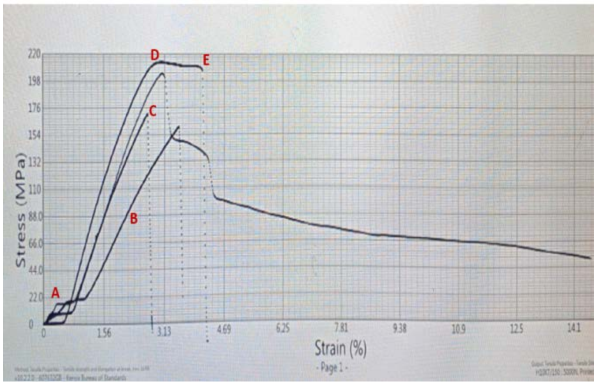


**Figure 3**. Stress-strain curves of wheat straw

This characteristic nature of the stress-strain curve has been observed in several biological materials in previous studies. In reference [17], Korhonen & Saarakkala obtained a similar graph for the mechanical properties of skeletal soft tissues. Reference [18] obtained an S-shaped stress-strain curve for both tensile and compression tests of an apple tissue. Mechanical studies in 2017 of rabbit skin and of collagen fibers and scaffolds in 2003 revealed a similar trend of stress-strain curves obtained in this study [19,20]. Reference [21] reported the ability of plant-based biopolymers to mimic the human skin's nonlinear mechanical properties. According to reference [22], the composition and the structural properties of plant tissues influence their mechanical properties significantly. Similarly presence of collagen fibers which are the structural composition of biological tissues are highly linked with the S-shaped stress-strain curve [19,20] [23,24,25]. Therefore, to discuss the stress-strain curves obtained in this study, the structural composition of wheat straw was considered.

Wheat straw is made up of cell walls comprising cellulose, lignin, and hemicellulose. Cellulose is the major component of cell walls, where microfibrils are formed by parallel cellulose chains linked by hydrogen bonds [26]. Wheat straw is a composite material, fibrous in nature, formed by cellulose microfibrils confined within an amorphous matrix of hemicellulose and lignin [26,27]. Mechanical strength of wheat straw is dependent on the characteristics of the cell wall components and structural arrangement [7]. The structural composition of wheat straw resembles that of biological tissues such as blood vessels, skin, skeletal tissues and lungs in that they contain micro-fibrils [21,28]. When the tension force is applied to the wheat straw, the micro-fibrils, which mimic the collagen fibers in animal cells, first stretch out to unfold from its extrafibrillar matrix, hence the toe region (Region A) in Figure 3. As stress continued to build up in the sample, the bonds and the physical interactions within the cellulose microfibrils were overcome, realigning the fibers in the direction of tension force. This is represented by the linear region (part B) where all the fibers bears the applied load. It reveals the elastic nature of the wheat straw due to the cellulose composition, hence its flexibility.

The wheat stem can bear stress up to a certain limit where it deforms plastically and /or fractures. At point C, the stem fractured, separating into two parts without plastic deformation. At this point, the matrix forces within the stem were exceeded by the tensional forces, hence the breakage. Region D to E exhibits plastic deformation with a change in the area under the curve. An increase in stress leads to a reduction in the cross-sectional area of the sample under the tension loading. As the material deforms, gradual necking occurs, hence the plastic deformation and ultimate fracture of the sample at the narrowest point. In this study, most of the samples at various treatments showed little or no plastic deformation, implying that wheat stems are brittle in nature. Therefore, both radiated and non-radiated wheat straws produce an S-shaped stress-strain curve under tension force.

## 3.2. Normality Tests and Analysis of Variance

Statistically, the P values for ultimate force in both generations were $P > 0.05$, implying normal distribution (Table 1). On the other hand, elongation and break distance failed the normality tests ($P < 0.05$), backing the visual normality tests presented in histograms (Figure 3).

**Table 1. Shapiro-Wilk test results for normality tests of stress, ultimate force, break distance and elongation of wheat straw under tensile force for $M_1$ and $M_2$**

| Trait | $M_1$ | | $M_2$ | |
|---|---|---|---|---|
| | W | P | W | P |
| U.F | 0.97493 | 0.78750 | 0.95845 | 0.40820 |
| S | 0.96518 | 0.55090 | 0.93204 | 0.10830 |
| B.D | 0.71657 | 1.681e-05 | 0.86861 | 0.004941 |
| E | 0.71619 | 1.661e-05 | 0.86870 | 0.004961 |

Normality tests for ultimate force tested positive for both $M_1$ and $M_2$, as visualized in Figure 4.

The ANOVA revealed a statistical significance between ultimate force and treatment ($P = 0.00478 < 0.05$). This implies gamma radiation dosages affect the strength of the wheat straw, hence the maximum load supported under external force. No interaction effect was found between treatment and generation, hence their effect on mechanical properties are independent. Likewise no statistical difference and interaction effect of treatment and mutant generation on break distance and elongation of straw when subjected to force.

Ultimate force, also known as ultimate tensile strength (U.F), is the maximum stress a material can withstand before fracturing and is given by ultimate stress multiplied by initial cross-sectional area [29]. Since cross section area remains constant, the higher the ultimate force, the higher the stress the sample can withstand. Consistent with this study, irradiated seeds (150 Gy and 200 Gy) produced straws with higher strength than control seeds in both $M_1$ and $M_2$, inferred from high ultimate force and stress. In $M_1$, the ultimate force at 150 Gy and 200 Gy were 244.67 N and 249.69 N, while stress was 13.14 MPa and 13.72 Mpa respectively. In $M_2$, the ultimate force at 150 Gy and 200 Gy were 260.67 N and 252.0 N, while stress was 11.54 MPa and 10.43 Mpa respectively. On the other hand, radiation dosages of 80 Gy produced straws supporting the least maximum force (169.33 N and 146.03 N) and hence the stress (10.74 MPa and 6.74 MPa) in $M_1$ and $M_2$, respectively. Therefore, gamma radiation, 150 Gy and 200 Gy, increases the strength of wheat stems in $M_1$ and $M_2$.

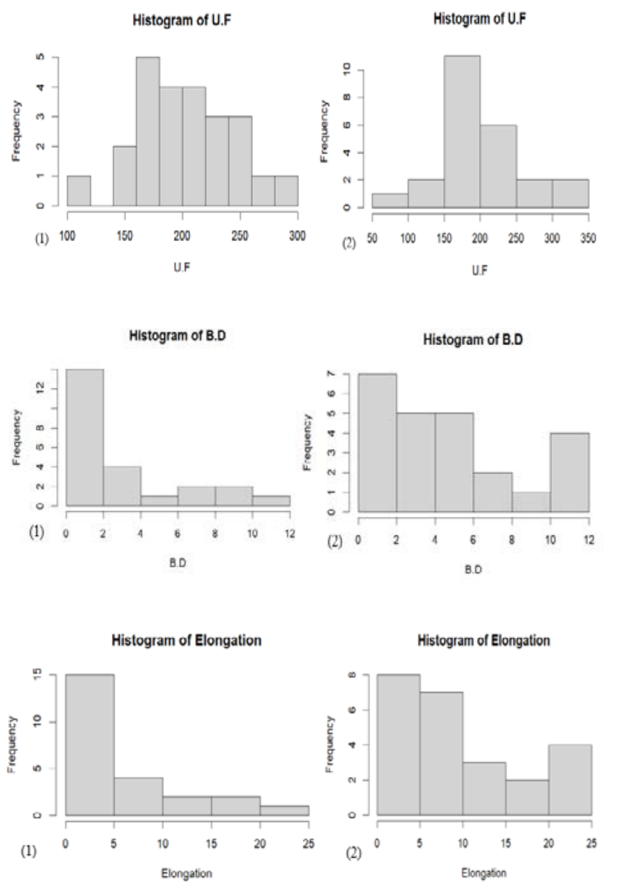


**Figure 4.** Normal distribution histogram for ultimate force (U.F), break distance (B.D) and Elongation in $M_1$ (1) and $M_2$ (2), respectively

**Table 2. Analysis of Variance of Irradiated Wheat for Mechanical Traits of Wheat Stem**

| Character Trait | df | U.F | B.D | E |
|---|---|---|---|---|
| Treatment | 7 | 0.00478** | 0.71160 | 0.71410 |
| Generation | 1 | 0.76247 | 0.09270. | 0.09430. |
| Treatment x Generation | 7 | 0.98114 | 0.0752. | 0.07600 |
| Error | 30 | 1738 | 8.65 | 34.67 |

Significant codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

# ACKNOWLEDGEMENTS

We gratefully acknowledge the IAEA – Marie Sklodowska-Curie Fellowship Programme for their support towards the tuition fees and upkeep during the period of this study.

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