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Mechanical properties of mung beans [*Vigna radiata* (L.) R. Wilczek] after drying and during hermetic storage

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Abstract

Mung beans, a grain legume of Asian origin primarily cultivated for human consumption, are rich in proteins, vitamins, and minerals. Handling these grains during harvest and post-harvest can significantly impact their mechanical properties, which are critical for designing machinery for pod shelling, processing, and grinding. This study aimed to assess the mechanical properties of mung bean grains after drying and during storage in a hermetic environment. The grains were manually harvested and threshed at approximately 15% moisture content (wb). They were then dried in an experimental fixed-bed convective dryer at temperatures of 40 and 50 °C with an air speed of 1.0 m s^{-1} until a final moisture content of 11.5 ± 0.3% (wb) was achieved. Post-drying, the grains were stored in 200 mL polyethylene terephthalate bottles covered with aluminum foil in a laboratory setting, with analyses conducted every 60 days over 180 days. Results showed that neither the drying temperatures of 40 and 50°C nor the storage duration of 180 days affected the rupture force, deformation, absorbed energy, modulus of toughness, or hardness of the mung bean grains.

Keywords: Moyashi; breaking; rupture force; deformation; toughness.

Practical Application: Mechanical properties during hermetic storage are essential for preserving quality.

1 INTRODUCTION

Currently, soy dominates as the primary protein source among legumes. However, diversifying protein sources is crucial to provide alternatives with varied functional properties that can substitute animal proteins (Wintersohle et al., 2023). Recently, the European Food Safety Authority (EFSA) has approved mung bean protein isolate as a novel food (Turck et al., 2021), highlighting its potential.

Mung beans [*Vigna radiata* (L.) Wilczek], noted for their high nutritional value (Huppertz et al., 2023), are adaptable for intercropping or crop rotation, facilitating the expansion of production in Brazil's Cerrado regions. This expansion aligns with increasing consumer demands for healthier diets, influenced by lifestyle changes (Favero et al., 2021).

At harvest, mung beans typically possess a moisture content too high for safe storage, necessitating a drying process (Siqueira et al., 2024). The conventional method involves hot air drying (Yao et al., 2020), which means the simultaneous transfer of heat and mass between the grains and heated air. Post-drying, the grains are stored to prevent deterioration and nutritional loss (Ma et al., 2022). Hermetic storage technologies (García-Lara et al., 2020), often utilizing recycled or reused containers like polyethylene terephthalate (PET) bottles, are popular among small-scale producers (Freitas et al., 2011). These containers not only facilitate batch separation (Quezada et al., 2006), but also preserve quality by reducing oxygen and increasing carbon dioxide levels due to grain respiration.

From pod shelling to grain grinding, understanding the mechanical properties such as breaking strength and elastic modulus is vital. These properties, influenced by drying and storage conditions (Babić et al., 2013), are crucial for maximizing processing efficiency. In this sense, this study aimed to analyze the mechanical properties of mung beans after drying at 40 and 50°C and 180 days of storage in a hermetic environment.

2 MATERIALS AND METHODS

The research was conducted at the Post-Harvest Processes Laboratory and the Pre-Processing and Storage of Agricultural Products Laboratory at the Faculty of Agricultural Sciences, Universidade Federal da Grande Dourados (UFGD).

Mung bean grains harvested from the experimental area of the Faculty of Agricultural Sciences at UFGD were used.

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Harvesting and threshing were performed manually when the grains had a moisture content of approximately 15% wet basis (wb). The grains were then placed in transparent polyethylene plastic bags and stored in a cold room at 5°C to standardize their moisture content. The moisture content of the grains was determined using the gravimetric method in a forced air circulation oven at 105 ± 3°C for 24 hours, following the Rules for Seed Analysis (Brasil, 2009).

An experimental fixed-bed convective dryer (Figure 1), equipped with a system that precisely controls the flow and temperature of the drying air, was used to study the drying kinetics of mung bean grains under different air conditions.

Six hundred grams of mung beans were used, evenly distributed as 200 grams in each of the three trays. Drying was carried out at two temperatures, 40 and 50°C, with an air speed of 1.0 m s^{-1}. The heated and homogenized air was blown upwards into the three trays. Air temperature and velocity were controlled and monitored using a temperature controller (Novus, N1040) and a digital thermo-anemometer (Instrutherm AM-100). The dryer was turned on 30 minutes before the experiment to stabilize the temperature in the trays. During drying, the moisture content was monitored using the gravimetric method, with a scale resolution of 0.01 g. The process was terminated when the product reached a moisture content of 11.5 ± 0.5% (wb).

After drying, the grains were stored in 200 mL PET bottles, covered with aluminum foil to prevent light passage, and subsequently placed in a laboratory environment. Analyses were carried out every 60 days over a period of 180 days. The average temperature and relative humidity values at the storage location were 24 ± 2°C and 66 ± 8%, respectively.

2.1 Mechanical properties

To evaluate the mechanical properties, 15 repetitions of each treatment were performed and subsequently subjected to a uniaxial compression test. The dimensions (major axis, medium axis, and minor axis) of each grain subjected to the compression test were measured using a digital caliper with a resolution of 0.01 mm. The average volume of the grains was determined considering the shape of the mung bean as a spheroid, using the equations proposed by Mohsenin (1986) (Equations 1 and 2).

$$d_e = \sqrt[3]{abc} \quad (1)$$

$$V_g = \frac{1}{6}\pi d_e^{\,3} \quad (2)$$

Where:

d_e: the equivalent diameter of mung bean grains (mm);

V_g: the volume of mung bean grains (mm^3);

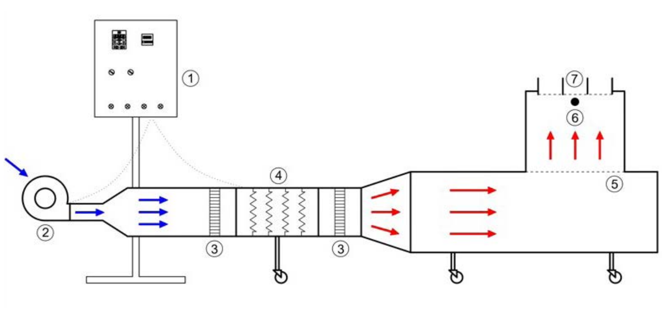
a, b, and c: the major, medium, and minor axes of mung bean grains (mm).

To obtain the deformation force curves as a function of deformation, the grains were subjected to a uniaxial compression test using a texture analyzer (model TA HD Plus) with a 500N load cell. Mung bean grains were tested in their normal resting position, with 2 mm adopted as the maximum deformation value. After determining the force curves as a function of deformation, the grain rupture point was identified, as illustrated in Figure 2.

The rupture point corresponds to a continuous reduction in the upward trend of force values, coinciding with a break or crack in kernels, which may or may not be visible (ASABE, 2008).

2.2 Absorbed energy

The absorbed energy (E) required for deformation corresponds to the area under the force-deformation curve during loading (Figure 2), as shown in Equation 3 (Tarighi et al., 2011).



1: Temperature and airflow control panel

2: Centrifugal fan

3: Air homogenizers

4: Set of electrical resistances

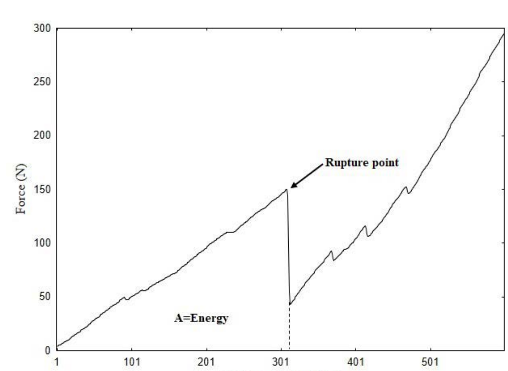
5: Perforated metal sheet for drying in thick layer

6: Temperature measurement point

7: Set of thin layer drying trays

Source: Siqueira et al. (2024).

Figure 1. Experimental fixed-bed convective dryer used for drying mung bean grains



Source: Mabasso et al. (2020).

Figure 2. Example of force curve variation as a function of deformation with rupture point.

$$E = \frac{F_r D}{2} \quad (3)$$

Where:

F_r: the rupture force (N);

D: the deformation at the kernel rupture point (mm).

2.3 Modulus of toughness

According to the methodology described by Abasi and Minaei (2014), the modulus of toughness is the energy needed for the product to break, or the energy absorbed by the product up to the rupture point per unit volume (Equation 4).

$$P = \frac{E}{V_e} \quad (4)$$

Where:

P: the modulus of toughness (mJ mm^{-3});

E: the absorbed energy (mJ);

V_e: the volume (mm^3).

2.4 Hardness

Hardness is the ratio of compressive force to deformation at the rupture point, as described by Equation 5 proposed by Olaniyan and Oje (2002).

$$Q = \frac{F_r}{D} \quad (5)$$

Where:

Q: the kernel hardness (N mm^{-1});

F_r: the rupture force (N);

D: the deformation at rupture point (mm).

The experiment was set up in a 2 × 4 factorial scheme (two temperatures and four storage times) in a completely randomized design, with 15 replications. The data underwent analysis of variance and regression. The models were adjusted based on the coefficient of determination and F-test significance. Means were compared using the t-test at 5% probability. Data distribution and variances were analyzed using the Shapiro-Wilk and Brown-Forsythe tests, respectively, at a 5% probability level.

3 RESULTS AND DISCUSSION

The moisture content of mung bean grains during storage was 11.94, 11.40, 11.85, and 11.70% for days 0, 60, 120, and 180 days, respectively, at 40°C; and 11.35, 11.02, 11.39, and 11.13% for days 0, 60, 120, and 180 days, respectively, at 50°C. The small variability in average values can be attributed to the behavior of grains in seeking hygroscopic balance.

Figure 3 shows the average force (N) required to rupture mung bean grains subjected to uniaxial compression in the natural resting position. There was no trend in the average values over the storage time, regardless of the drying temperature ($\overline{RF}$).

According to Corrêa et al. (2017), higher drying temperatures increase vapor pressure in the internal layers of the grain. This steam expansion creates internal tensions, leading to cracks and structural damage in agricultural products, as observed by Abasi and Minaei (2014) with corn grains. Due to the low elastic and plastic capacity of the grains, continuous exposure to heat, and constant reduction in moisture content, the grains can experience thermal and physical stress, resulting in cracks or other structural damage (Lima et al., 2016), and, consequently, changes in mechanical properties. However, the temperature of 50°C was not high enough to cause these changes. The average breaking strength was expected to increase throughout storage, as observed by Corrêa et al. (2019) for common beans (*Phaseolus vulgaris*) stored in cotton bags.

When grains are stored in hermetic environments, such as PET bottles, the level of oxygen decreases, and the level of carbon dioxide increases due to respiration. This condition reduces enzymatic activity that requires oxygen for substrate oxidation and promotes darkening and hardening of the integument (Lima et al., 2014). This condition contributed to maintaining the breaking strength.

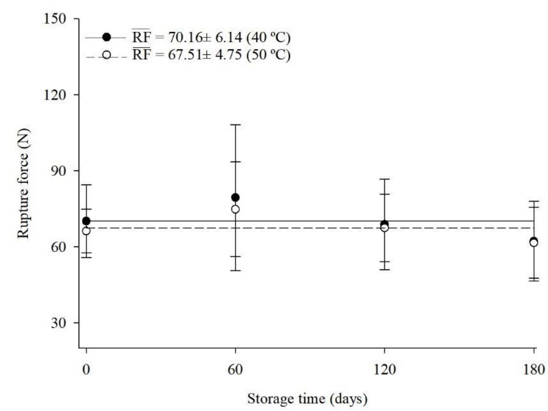


Figure 3. Example of force curve variation as a function of deformation with rupture point.

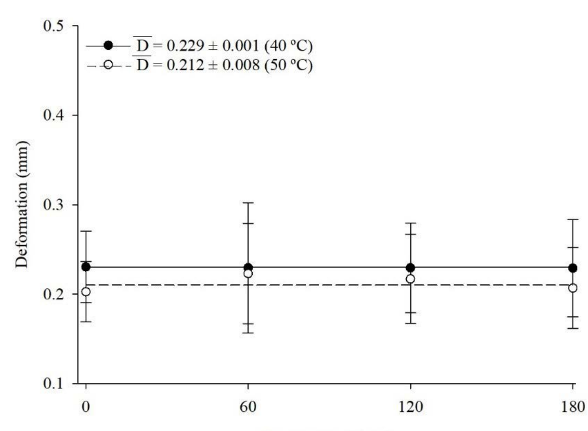


Figure 4. Average deformation of mung beans (at natural resting position) dried at different temperatures as a function of storage time

The storage of mung bean grains over 180 days did not influence average deformation values at both drying temperatures (Figure 4), with values remaining practically constant. These results are similar to those found by Mabasso et al. (2023).duma et al. (2016), in research on the physical and mechanical properties of African bean grains (*Pentaclethra macrophylla*), found that, as seeds continually deform, the force required for their rupture also increases correspondingly. This explains the behavior observed in Figures 3 and 4. The absorbed energy (Figure 5A) and toughness modulus (Figure 5B) showed constant behavior during the evaluation period, with average values showing no significant changes at the two drying temperatures used. This behavior is similar to that observed by Mabasso et al. (2023) in research with corn grains.

The absorbed energy (Figure 5A) depends on the deformation distance, which did not show a behavioral trend (Figure 5). The modulus of toughness is the ratio of absorbed energy to the volume of the grains, which has a high correlation with moisture content. Since the moisture content did not fluctuate significantly during storage, it also influences the "softness" of the grains. Therefore, the higher the moisture content, the "softer" the product and the lower the modulus of toughness (Bako & Aguda, 2023).

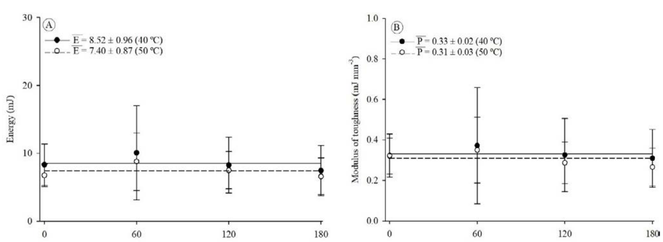


Figure 5. (A) Average energy required for rupture and (B) modulus of toughness of mung beans (at natural resting position) dried at different temperatures as a function of storage time.

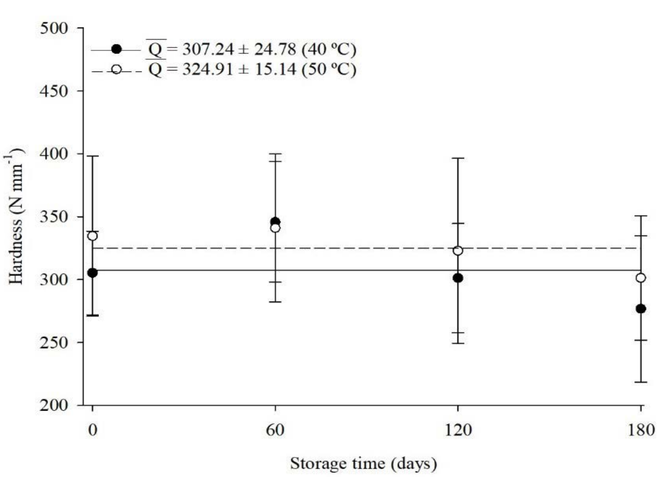


Figure 6. Average rupture force of mung bean grains (at natural resting position) dried at different temperatures as a function of storage time

The hardness of mung bean grains did not show a behavioral trend (Figure 6), similar to the other evaluations. The practically constant behavior can be explained by the fact that hardness tends to correlate with rupture force; thus, the greater the rupture force, the stiffer the grain (Mabasso et al., 2020).

Kljak et al. (2011) state that post-harvest factors such as drying and storage conditions affect hardness values. However, as shown in Figure 6, the results were not significantly affected by the treatments. This can be attributed to storing mung bean grains in hermetic containers, a behavior also observed by Freitas et al. (2011), who evaluated the hardness values of common bean grains (*Phaseolus vulgaris*) during storage in hermetic environments such as PET bottles.

The results obtained highlight the rusticity of mung bean grains. Data analysis showed consistent stability throughout the study period, indicating the resilient nature of these grains. This characteristic is extremely important in the agricultural production chain, as it gives mung beans a significant advantage in terms of durability, storage capacity, and pressure resistance.

4 CONCLUSION

Drying temperatures of 40 and 50°C and a storage time of 180 days in a hermetic environment did not influence the breaking strength, deformation, absorbed energy, modulus of toughness, and hardness of mung bean grains. Both temperatures are recommended for drying and hermetic storage up to 180 days, without significantly affecting physical integrity of the grain.

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