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Evaluating Harvesting Methods and Moisture Content for Effective Mung Bean Production

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ABSTRACT

This study investigates the impact of various harvesting techniques and seed moisture levels on the yield and quality of mung beans, aiming to optimize production efficiency through a better understanding of mechanical and physiological interactions. The research identified that manual harvesting at 20% seed moisture achieved the highest yield of 1012.20 kg ha^{-1}, a result primarily driven by the synergy between gentler manual handling and decreased mechanical friction at higher moisture levels, which effectively prevented pod shattering and minimized grain loss during collection. Conversely, the lowest yield of 946.80 kg ha^{-1} was recorded during direct combine harvesting at 12% moisture; this significant decline is attributed to the increased brittleness of drier seeds, making them highly susceptible to mechanical impact and breakage under high-speed machine operation, which consequently elevated both shattering losses and product impurities. These findings demonstrate that the interaction between harvesting methods and moisture content significantly influences grain integrity, highlighting that aligning mechanical intervention with seed physiology is crucial for maximizing output. Consequently, adopting evidence-based harvesting practices that account for these underlying biological and mechanical mechanisms is essential for enhancing the overall productivity and sustainability of mung bean cultivation.

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1. Introduction

Mung bean is cultivated as a second crop after autumn cereals or in order to strengthen the land, prevent soil erosion and green manure (Tani et al., 2017). The basic problem in leguminous farming is the mechanization of harvesting so that the cultivation levels in these products are influenced by the harvesting facilities. The harvesting method has a great effect on the yield and quality of the product. In legumes, on average, 20% of the crop is lost at the harvest stage (Johansen et al., 2012). Processing of seeds is done in a period of time and this issue results in problems in harvesting and product losses. Various harvesting methods have been suggested, each of which has advantages and disadvantages in different situations (Kumar and Kalita, 2017). The traditional method of harvesting by hand is not effective at high levels and this affects the spread of planting. Mechanized methods result in quantitative and qualitative losses. In this case, the role of seed moisture in these losses is very important (Chandel and Sharma, 2022). Given the critical role of moisture in grain loss and the rise in harvest losses, harvesting time is a key factor. Mechanized harvesting, which reduces harvest time, can lower losses and free up additional land for cultivation. A chickpea mechanized harvesting platform was evaluated against traditional manual harvesting, and results showed that using a combine equipped with a conventional platform offers advantages over the manual method (Marchetto et al., 2012). Mechanization of chickpea farming operations by changing tillage operations can provide the possibility of mechanized harvesting. He found that using a pen plow increases the height of pods from the ground and improves the possibility of mechanized harvesting (Johansen et al., 2012). One method of harvesting legumes is to cut the stems and line the plants. This method increases the quality and reduces grain losses. In semi-mechanized harvesting, the crop is cut and banded, and after reducing the moisture content of the plants: the crop is harvested by a combine and the seeds are separated. In addition, banding the plants helps in better drying of the seeds and preventing them from crushing. In this method, weeds and immature plants are also dried and do not prevent the increase in waste materials in the seeds from being crushed (Chibarabada et al., 2017). Uzbekistan's mung bean cultivation and exports are rising. Planted as a post-wheat crop in June–July and harvested in Oct–Nov, it boosts farm income and soil fertility. Harvest methods include mowing/plucking 5–10 cm above ground or cutting 5–10 cm below. Research aims to adapt Dominator-130 threshing without breakage (Astanakulov et al., 2022).

Iranian mung bean is pivotal for nutrition and livelihoods, yet its energy–water–food security (EWFs) links within an agri-food systems view are understudied. The study uses a cradle-to-fork approach with multiple functional units (1 kg beans, 1 kg protein, 1000 kcal) and load allocations to assess EWFs and environmental impacts, plus farm economics. Key findings: on-farm stages drive 40–96% of environmental impacts (including water and

energy), while cooking adds >50% to the carbon footprint. NR CED and TWF are 27.4 MJ and 1.55 m³ per kg beans; farm net margin is 3,677 $ ha-1. Further work is needed to boost environmental efficiency and diet sustainability (Abad-González et al., 2024). Incorporating or retaining wheat residue (T3/T2) improved mung bean yield vs removal (T1) across I1–I3 irrigation regimes; I3 yielded highest grain (0.70–0.79 t ha-1) with better CWP, IWP varied by regime. Residue use reduced water use and enhanced productivity; T2I2 and T3I2 were top performers (Tripathi et al., 2024).

The primary novelty of this research lies in determining the optimal intersection between crop physiological characteristics, specifically grain moisture content, and technical machinery parameters, including combine settings and harvesting methods, under the unique climatic conditions of Khuzestan province. Unlike previous studies that predominantly focused on single-variable performance analyses, this investigation simultaneously examines the interaction effects of various harvesting methods encompassing both direct and indirect approaches across different moisture levels on grain loss and quality indicators. Considering the significant mechanization challenges associated with pulse harvesting, particularly for mung beans, this study introduces a technical decision-making model for the first time to identify the most appropriate timing and methodology for minimizing losses and preserving grain vigor in this strategic region. Ultimately, by localizing operational variables for common combine harvesters in the area, this research bridges the gap between theoretical knowledge and field operations, providing a practical framework for enhancing productivity in sustainable pulse production.

2. Materials and Methods

2.1. Location of the studied area

The experiment was conducted Shushtar, Khuzestan province, at a geographical latitude of 58.31° N and longitude of 49.48° E. According to data from the Ahvaz Meteorological Department, the highest annual temperature reaches 46.2 degrees Celsius in July, while the lowest drops to 8.4 degrees Celsius in December. Historical records spanning 50 years indicate that the region receives an average annual rainfall of 212 mm, with a daily average relative humidity of 44%. Additionally, the area experiences an annual evaporation rate of 3497 mm and enjoys approximately 2940 hours of sunshine each year (Kaab et al., 2019).

Fig 1. Location map of the researched area.

The annual evaporation rate stands at 44%, with a precipitation measurement of 3497 mm and a total of 2940 sunny hours. In this harvesting method, laborers cut the crops by hand. The neglect in addressing issues related to mechanized harvesting has led to a predominance of manual labor in the production of legumes across the country. Harvesting occurs under high humidity conditions; after cutting, the crops remain in the field for two to four days to allow their moisture content to decrease before being moved to the threshing floor. Transportation to the threshing floor is done via tractor and trailer, where the crops are stored for 7-10 days until the leaves and pods are thoroughly dried. Threshing is then performed using a tractor, which separates mung beans from straw and stubble by wind exposure; this process is recognized as a sifting and cleaning operation (Pang et al., 2021). During the threshing period, periodically turning the crop helps reduce seed moisture content and facilitates the process of beating and separating seeds from pods. Grain cleaning and separation are conducted using fixed threshers designed to separate grain from straw. Typically, threshing occurs when the grain moisture content is between 12-16-20%. In certain regions, once the crop is sufficiently dried, threshing and grain separation are performed using a threshing machine (Chai et al., 2020). Key potential concerns during post-harvest drying include seed weight loss, as water weight loss lowers moisture content, but excessive loss of seed-moisture during drying could mechanically remove surface moisture without affecting dry weight. More relevant is seed dry matter loss due to respiration, desiccation, or mechanical damage causing seed shriveling, crack formation, or kernels breaking during threshing. Rapid or uneven drying can cause surface cracking, wrinkling, or textural changes, especially in seeds with fragile coats or high oil or protein content, and wrinkling can occur if moisture loss is uneven or if the seed coat collapses after endosperm shrinks. Aversion to wrinkling or micro-cracking is not just cosmetic; it can reflect damaged seed layers that reduce germination vigor, even if weight loss is minimal.

2.2. Manual Harvest

In this approach, the crop is harvested in two distinct phases to manage the challenges of indeterminate growth. Plants are initially cut at a seed moisture content of approximately 35%. It should be noted that at this moisture level, the mung bean seeds have already reached physiological maturity characterized by the pods transitioning to their mature color ensuring that the biological yield is fully accumulated. After cutting, the plants are banded in the field for natural sun-drying. This intentional delay allows the seeds to reach harvest maturity (below 20% moisture) uniformly. This controlled field-drying process is crucial as it prevents the wrinkling and mechanical crushing that typically occur when immature or high-moisture seeds are threshed directly. Furthermore, because the seeds remain attached to the plant during this drying phase, they complete their stabilization process without significant weight loss or quality

degradation (Bande et al., 2013). While effective in preserving seed integrity, this technique involves higher labor costs and requires precise timing to ensure the crop is not cut before the majority of pods have reached the necessary physiological stage (Afzal et al., 2019).

2.3. Mechanized Harvest

This method involves direct harvesting using a combine harvester. The moisture level of the crop at the time of harvest is a critical parameter; high moisture levels can lead to mechanical bruising and quality loss, whereas excessively low moisture increases the risk of pod shattering and seed loss. For crops with indeterminate growth like mung beans, where pods mature asynchronously, determining the optimal harvest window is particularly challenging. This asynchronous ripening, also observed in crops like soybeans, often results in a mixture of over-ripe and green pods, complicating the mechanization process (Chandrajith et al., 2016). To mitigate these issues, chemical desiccants or defoliants are often employed to promote leaf drop and accelerate the drying of late-maturing seeds. While these substances can help standardize seed moisture and maintain product quality to an extent, they pose environmental concerns and may limit the use of crop residues, such as straw and stubble, for livestock fodder due to chemical residues (Asghari and Aghdam, 2010).

The mechanized harvesting process was conducted using a John Deere model 955 combine harvester, manufactured in Iran in 2011. To minimize grain losses, the machine was meticulously adjusted according to the specific mung bean harvesting settings outlined in the technical manual. These operational parameters included a thresher cylinder speed of 550 rpm, with the clearance under the cylinder set at 16 mm for the front and 9.5 mm for the rear. Additionally, the cleaning system was configured with a 12 mm straw sieve and a 9 mm grain sieve, while the fan speed was maintained at 500 rpm. Throughout the operation, the harvester was operated in first gear at a constant forward speed of 1.2 km per hour to ensure optimal performance.

2.4.Harvester settings

The harvester used during the harvest was a four-wheel, self-driving model manufactured by Iran. It featured a cutting comb equipped with serrated blades. The blade adjustment was performed according to the manual before harvesting (Zareei and Abdollahpour, 2023). The operator adjusts the combine's forward speed based on the plant density, about 1.2 km/h (Rondelli et al., 2022).

2.4.1. Grain moisture

Humidity levels were determined using a field hygrometer, which measures seed moisture contain based on wet weight with an accuracy of 0.1% (Fig 2). Moisture readings were taken daily to assess the optimal harvest time based on varying moisture treatment levels (Zhan et

al., 2010). Moisture treatments in both direct and indirect harvesting methods were applied at three levels of 12, 16 and 20%. In order to apply the treatments, grains moisture was measured daily. Harvesting was done when the desired grains moisture content base on Variables levels was reached.

Fig 2. Specifications of the hygrometer.

2.4.2. Grain performance

To calculate loss percentages, production profit, and other metrics, grain yield in each plot was obtained through sampling. For this, a one-meter by one-meter surface area was marked at three different points within each plot, using a frame before the main harvest with the reaper and after separating the seeds (Ouyang, 2016).

2.4.3. Grain losses

Grain losses can be categorized into three primary types: pre-harvest losses, harvest losses, and losses from the harvester's separation system. Pre-harvest losses are determined by sampling seeds that spill from pods before harvest. This sampling is conducted at three locations within the plots using a box. Harvest losses occur with all harvesting methods and are quantified by evaluating breakage and cluster separation separately (Barbosa et al., 2020).

3. Results and Discussion

Table 1 presents a detailed variance analysis that examines how different harvesting techniques and varying grain moisture levels influence several factors critical to agricultural yield and quality. Firstly, the mean square (MS) values associated with replication indicate that there are no significant differences in pre-harvest loss, harvest loss, and various other quality measures, as denoted by the 'ns' (not significant) label. This suggests that these factors are consistent across different trials and do not introduce variability that could skew the results. In contrast, the mean square values for the harvest method exhibit highly significant differences, with star indicators denoting significance levels. For instance, there are substantial impacts observed in measures such as harvest loss, broken seed counts, impurity levels, yield, and even harvest cost. The seed moisture levels also show a mixture of significant and non-significant results. The first factor (harvest method) had significant effects on all measured traits at the 1% probability level. The second factor (grain moisture at harvest) had significant effects on the traits: grain loss during harvesting, grain yield, and harvest time at the 1% probability level. In the

trait of percentage of broken grains in the final product, grain moisture had a significant effect with a 5% probability. Grain moisture had no significant effects on grain loss before harvest and harvesting costs. While pre-harvest loss and some measures related to impurity shows meaningful differences (indicated with a single asterisk), the yield again stands out with a mean square value of 586.80, showcasing that variations in moisture can meaningfully impact yield outcomes. Furthermore, the interaction between seed and moisture levels presents an interesting aspect to consider, albeit with some results not reaching significance. The MS values here suggest there might be combined effects at play that are less pronounced but still warrant further investigation, particularly in terms of broken seed rates and yield implications. Finally, the error row indicates variations not explained by the factors investigated, which is essential for understanding the overall variability in the data. The presented coefficient of variation (C.V) allows readers to assess the consistency and reliability of the experimental results. With variance spread across different factors, it becomes clear that while harvesting techniques and grain moisture significantly influence yield and quality, there are overarching elements that contribute to the systematic variability observed. In conclusion, this analysis underlines the necessity to carefully select harvesting methods and monitor grain moisture levels to optimize both yield and quality, highlighting areas for potential improvement in agricultural practices. In the study to identify mung bean genotypes with yield stability and resistance to the mung bean yellow mosaic virus (MYMV). Sixteen genotypes were assessed over two years (2011 and 2012) using a randomized complete block design with two replications at three locations (Gazipur, Ishurdi, and Madaripur) under the Bangladesh Agricultural Research Institute. An analysis of variance revealed significant effects of genotype (G), environment (E), and their interaction (G×E) on grain yield. Of the eight agronomic traits evaluated, the first principal component (PC1) consistently exceeded the second (PC2). Taking G×E interaction into account, genotype BM6 performed best across all three locations and both years. In terms of grain yield and stability, BM6 was ranked first, while BM1 and G10 were the least effective. Gazipur was found to be the optimal environment based on discrimination and representation. Furthermore, there was a positive relationship between the Soil-Plant Analysis Development (SPAD) values and yield, but a negative correlation with MYMV severity. Genotypes BM6, G1, and G2 emerged as promising candidates for low disease scores and consistent performance across environments. The study highlighted the environmental influence on natural MYMV infection, noting a positive correlation between disease scores and temperature under typical growing conditions (Mahbubul Alam et al., 2014).

Table 1. Variance analysis of the impact of harvesting techniques and varying grain moisture levels

Variable sources	DF	profit	Harvest Cost	Harvest Time	Yield	Impurity	Broken Seed	MS of Harvest Loss	MS of Pre Harvest Loss
Replication	2	0.062^{ns}	0.074^{ns}	6.37^{ns}	14.63^{ns}	1.24^{*}	1.24^{*}	0.034^{ns}	0.843^{ns}
Harvest Method	2	2.84^{**}	14.93^{**}	9219.70^{*}	969.85^{**}	1.63^{*}	30.53^{**}	36.45^{**}	7.38^{**}
Seed Moisture	2	0.014^{ns}	0.034^{ns}	205.40^{**}	586.80^{**}	1.01^{ns}	1.78^{*}	2.28^{**}	0.43^{ns}
Seed ×Moisture	4	0.013^{ns}	0.05^{ns}	1.37^{ns}	105.60^{*}	0.17^{ns}	0.98^{*}	0.2	0.25^{ns}
Error	16	0.029	0.023	8.13	17.37	0.13	20.8	0.019	0.145
C.V.	-	13.30	12.10	12.50	17.30	16.10	15.8	15.40	12.30

The results demonstrate in the Table 2 that mung bean yield and quality are significantly affected by harvest timing, which was evaluated across three distinct moisture stages: 20%, 16%, and 12%. These stages represent the natural progression of field drying following the attainment of physiological maturity. The peak yield was recorded at 20% moisture (1018 kg ha^{-1}), marking the earliest optimal harvest window. At this level, the pods retained sufficient flexibility to withstand handling, while the seeds had achieved enough stability to resist the mechanical crushing typical of higher moisture contents (30%). Furthermore, seeds at this stage were less susceptible to the shattering that occurs as the crop continues to dry.

As harvest was delayed to reach the 16% and 12% moisture thresholds, a progressive decline in yield was observed, with the 12% treatment producing the lowest yield (931 kg ha^{-1}). This reduction is primarily attributed to the prolonged exposure of mature pods to environmental fluctuations, which exacerbated natural pod shattering in the field. Additionally, at 12% moisture, the seeds became increasingly brittle; the diminished moisture content compromised the seed's structural integrity, rendering it more vulnerable to internal fracturing and external breakage during both manual and mechanical handling.

The data reveal a critical interaction between the harvesting method and the moisture content at the time of operation. In manual and two-stage harvesting, cutting the crop at higher moisture levels (approaching 20% after the initial field-drying phase) effectively preserved the yield by minimizing the duration of exposure to natural shattering. Conversely, for mechanized harvesting, while the 20% moisture level reduced shattering losses compared to the 12% level, it necessitated precise combine adjustments to manage the denser, more humid biomass. The significant increase in impurities and grain loss at the 12% moisture stage across all methods most notably in direct combining—underscores that delaying harvest until the seeds are very

dry (12%) leads to excessive fragility. This fragility results in higher breakage rates and a subsequent loss of marketable weight, confirming that harvesting near the 20% moisture threshold, once physiological maturity is reached, is optimal for maintaining seed weight and physical integrity.

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Table 2. Comparison of the average effects of harvesting methods and different grain moisture levels.

	Profit ($)	Harvest Cost ($)	Harvest Time (hr/ha)	Yield (kg/ha)	Impurity (%)	Broken Seed (%)	Harvest Loss (%)	Pre Harvest Loss (%)
				Harvest Method				
Manual harvest	8.08[b]	3.23[c]	277.30[c]	1012.20[c]	2.20[a]	3.93[a]	6.95[a]	5.20[a]
Indirect harvest	9.18[c]	2.82[b]	207.60[c]	975.80[b]	3.17[b]	6.54[b]	9.70[b]	5.68[a]
Direct harvest	8.82[a]	0.8[a]	78.80[a]	946.80[a]	4.46[c]	7.48[b]	10.87[c]	6.95[b]
				Moisture Content				
20%	8.71[a]	2.31[a]	191.70[a]	985.80[a]	3.24[a]	5.44[a]	8.64[a]	5.80[a]
16%	8.73[a]	2.29[a]	188.80[a]	978.40[a]	3.28[a]	5.96[a]	9.24[b]	5.84[a]
12%	8.65[a]	2.25[a]	182.30[b]	969.80[b]	3.31[a]	6.55[b]	9.64[b]	6.20[a]

3.1.Seed fall during harvest operation

The results of the analysis of variance (Table 1) showed that seed loss due to harvesting was significantly (1%) influenced by the harvesting method and seed moisture at the time of harvesting. In addition to the significance of the effect of the factors, the mutual effects of the factors were also significant. The comparison of the averages of the main and mutual effects of the levels of the factors showed that the highest seed losses were caused by the direct harvesting method with a combine (10.87%) and the lowest losses were caused by the manual harvesting method (6.95%). Harvesting with a combine harvester seems to be the cause of seeds falling due to the need to dry the plant and pods and the impact of the carousel and the vibration of the harvester's cutting platform. In the method of indirect harvest, the product dries uniformly, for this reason, the drop of seeds in this method showed a significant decrease compared to direct harvest. The average comparison of the main effects of seed moisture factor levels showed that: moisture levels had a significant difference in terms of seed loss. Humidity of 20% showed the least loss of 8.64% and humidity of 12% showed the highest seed loss of 9.64% (Fig. 3). It seems that the decrease in humidity and the opening of the pods are the cause of the differences.

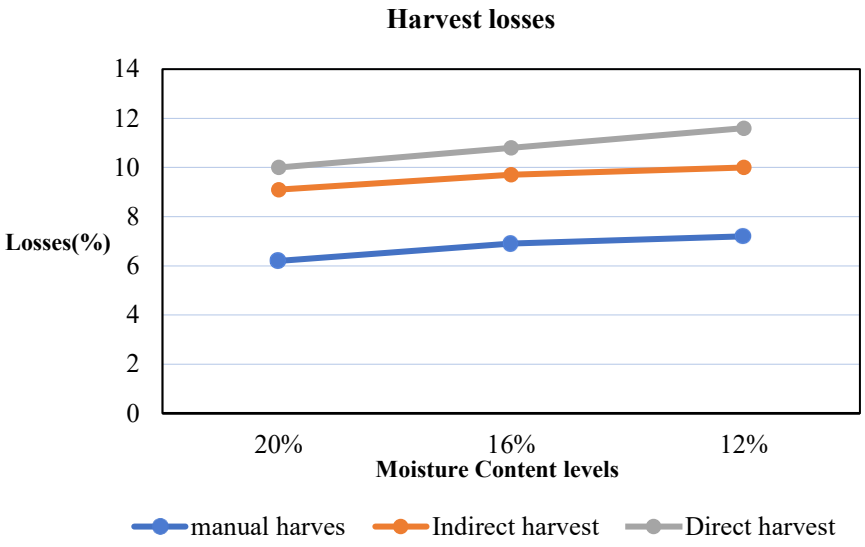

Fig 3. The effect of factor levels on seed loss in harvesting operations.

3.2. Grain breakage

The results of the analysis of variance showed that the characteristic of grain breakage in the harvested product was significantly influenced by the harvesting method (at the 1% level) and seed moisture at the time of harvesting (5%) (Table 2). The comparison of the averages of the main effects of the factor levels of the harvesting method showed that the lowest amount of broken seeds was observed in the manual harvesting method with 3.93%. The direct and two-step harvesting methods had less broken losses with a non-significant difference, and the most broken seeds were observed in the direct harvesting method (7.48%). Most of the fractures seem to have occurred in the threshing system of the combine. The comparison of the mutual effects of the test factors showed that the changes in grain moisture content had a significant correlation with the harvesting method in terms of grain breakage (Fig. 4). With the decrease of seed moisture, the breakage percentage decreased in all harvesting methods. This effect changed more steeply in two-stage and direct harvesting.

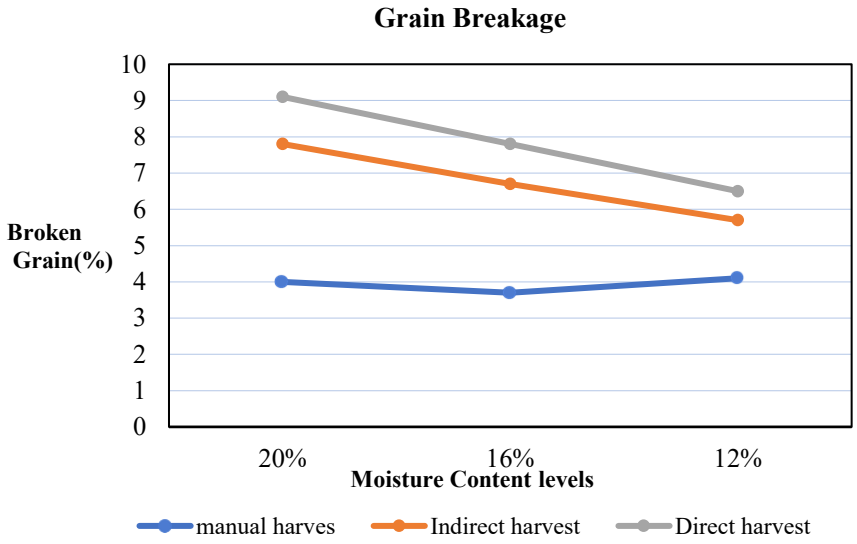

Fig 4. the effect of factor levels on fracture.

3.3. Final grain yield

Examining the final yield of the product is important because the loss of seed loss and loss of seed weight due to the harvesting of unripe seeds has an effect on the harvest amount. Analysis of the variance of the yield trait in (Table 1) showed that the harvesting method and grain moisture and their interaction have a significant effect on the yield of the product (1%). The comparison of the averages showed that they are different in the harvest methods in terms of their effect on performance. The highest yield of 1012 kg/ha was observed in the manual harvesting method and the minimum yield of 947 kg/ha was observed in the direct harvesting method. It seems that the decrease of 65 kg (6.4%) is caused by the fall in the harvest time and the delay in harvesting with the combine to handle the seeds. Comparison of the effects of different levels of grain moisture on yield (Fig. 5) showed that the highest yield in 20% moisture was 986 kg/ha and the lowest yield was 970 kg/ha in 12% moisture. It seems that the decrease in humidity led to a decrease in the weight of seeds and a decrease in yield.

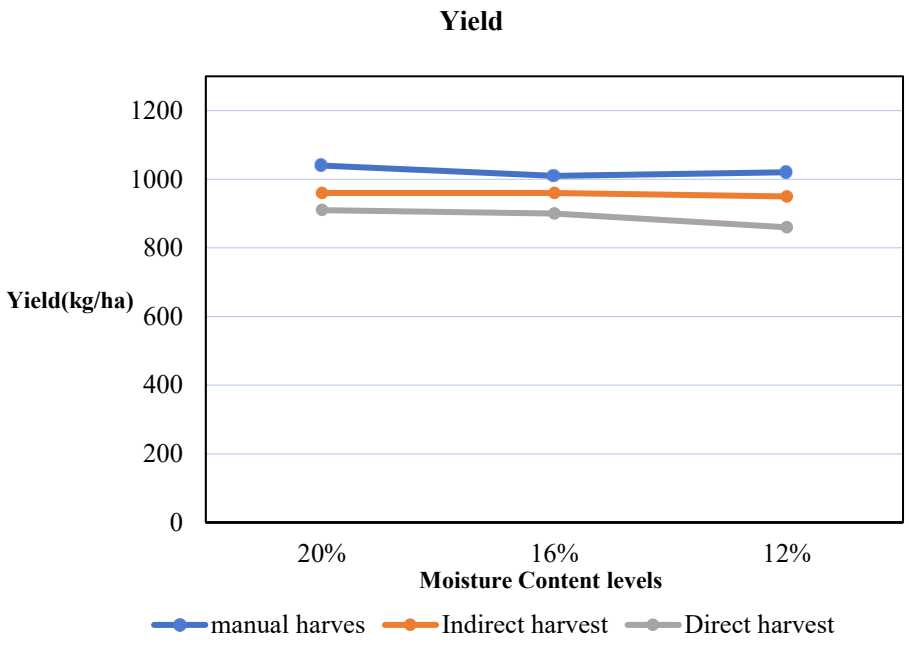

Fig 5. Interaction of factors on performance.

4. Conclusion

The variance analysis presented in the study highlights the significant impact of harvesting techniques and grain moisture levels on agricultural yield and quality. Key findings reveal that while there were no notable differences in pre harvest loss and other quality measures across trials, harvesting methods played a critical role in determining outcomes. Specifically, manual harvesting emerged as the most effective method, resulting in the lowest loss and highest yield, while direct harvesting methods yielded poorer results in both losses and final grain quality. Significant mean square values indicated that both the harvesting method and moisture levels significantly affected key performance metrics particularly yield and cost efficiency. The optimal moisture content for harvesting appears to be around 20%, as this moisture level balanced yield and minimized losses effectively. Conversely, lower moisture content resulted in increased seed losses and lower overall yield, emphasizing the importance of proper moisture management during the harvesting process. Furthermore, the analysis of mung bean genotypes under varying conditions demonstrated the profound effects of environmental factors on crop stability and disease resistance. This illustrates the necessity for thorough assessments of both genotype and environmental conditions to enhance agricultural resilience. In summary, the study underscores the importance of strategically selecting harvesting methods and maintaining optimal grain moisture levels to enhance yield and quality. Continuous improvement in harvesting practices, grounded in empirical analysis, is essential for optimizing agricultural

productivity and profitability, ultimately supporting sustainable farming practices.

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