**Physical Properties of fenugreek leaves**

1. **Abstract:**

Understanding the physical properties of agricultural crops is fundamental for the design and development of efficient and effective machinery used in farming practices. The College of Agricultural Engineering at JNKVV, Jabalpur, recognized the significance of acquiring detailed information on the physical properties of fenugreek plants to enhance the design and performance of machines such as sowing machines, weeders, agricultural machinery, and post-harvesting equipment. The study conducted by the college focused on various parameters related to fenugreek crops. The data revealed a spectrum of physical characteristics, providing valuable insights for engineering applications. Fenugreek plant heights ranged from 25 to 35 cm, reflecting the variability in crop structure. Stem diameters exhibited diversity, ranging between 1.20 cm and 2.40 cm, influencing the engineering specifications of machinery interacting with the plant. The crop's branching pattern, with 3 to 5 branches per plant, contributes to the overall design considerations for equipment like agricultural machinery. Crop stand density, ranging from 288 to 366 plants per square meter, is a critical parameter influencing the efficiency and capacity of agricultural machinery in handling different planting densities. Plant material weight per square meter, varying from 0.45 to 0.57 kg/m², is crucial for understanding the load-bearing capacity of machines during harvesting and processing. The average bulk density of 183 kg/m³ is an essential parameter for the engineering of storage and transportation systems. Moisture content, a significant factor in post-harvest operations, varied across different parts of the fenugreek plant. The whole plant exhibited a moisture content of 84.2%, leaves at 25.6%, and stems at 8.5%. This information is vital for the design and optimization of drying and storage equipment, ensuring the preservation of fenugreek crops while minimizing post-harvest losses.

1. **Introduction:**

Fenugreek (Trigonella foenumgraecum L.) stands as an annual herb within the sub-family Papilionaceae of the Leguminosae family. Recognizing and understanding the physical properties of fenugreek, such as size, shape, volume, density, porosity, color, and appearance, holds immense importance in the realm of agricultural engineering. This knowledge serves as a crucial foundation for designing specific equipment and determining the behaviour of the product during various handling processes. The oil bean seed, a key focus in engineering considerations, demands an in-depth exploration of its physical and mechanical properties. This essential engineering data becomes pivotal in the design of machinery, storage structures, processing systems, and quality control protocols, as highlighted by (Supram et al., 2019). A comprehensive understanding of these properties ensures the development of machinery that optimally handles oil bean seeds, leading to enhanced efficiency in processing and storage. Moreover, the importance of considering the variation in physical properties as a function of moisture content cannot be overstated, particularly when designing equipment for aeration and storage. The work by (Srivastava et al, 1990) underscores the necessity of knowing how physical properties change under different moisture conditions, guiding the design of equipment that accommodates such variations. This is critical for maintaining the quality and integrity of the fenugreek crop during storage and processing. The significance of size and shape becomes particularly apparent in the design of machinery such as separating, harvesting, threshing, and grinding machines, as emphasized by (Rathod et al, 2020). Tailoring equipment to the specific size and shape characteristics of fenugreek ensures optimal performance, efficiency, and minimal loss during various agricultural processes.

1. **Materials and methods**

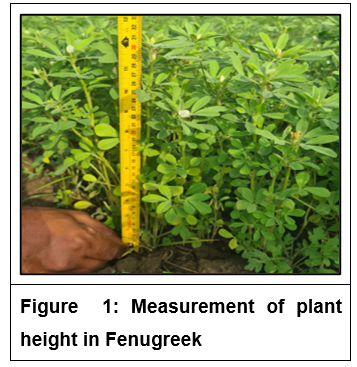
The prelude to designing any agricultural machinery, such as sowing machines, weeders, agricultural machinery s, and post-harvesting equipment, involves a meticulous study of the physical properties of leafy vegetables in field conditions. This comprehensive examination extends to encompass the soil parameters, considering the diverse cultivation practices adopted by farmers, varying row-to-row and plant-to-plant spacing in flat or check basin methods. To facilitate this understanding, a survey was conducted at the Agricultural Farm of the Department of Agriculture, JNKVV, Jabalpur, focusing on leafy vegetable crops. The investigation aimed to gather vital information on the physical properties of these crops, recognizing the importance of tailoring machinery and equipment to the specific characteristics of the plants. In the field, physical characteristics of leafy vegetables were measured on standing crops using suitable devices and methods for various parameters. This involved the deployment of appropriate tools and techniques to gauge factors like size, shape, density, and other relevant properties. The study also considered the interaction between the leafy vegetables and the soil in which they were cultivated, emphasizing the importance of understanding both plant and soil parameters for effective machinery design. Crucially, all measurements and tests related to the physical properties of the leaves were conducted promptly, within 24 hours from the harvesting of leaves. This timeframe ensured that the observations were taken under conditions representative of the immediate post-harvest state, with leaves stored at room temperature (25°C to 28°C in the month of November). Observations were meticulously recorded on characteristic dimensions of the leafy vegetable plants, offering valuable insights into parameters relevant to the study. This data forms the basis for the subsequent design and optimization of agricultural machinery, ensuring that the equipment is tailored to the specific physical properties of the leafy vegetables in question.

**3.1 Physical properties of fenugreek**

The crop parametersof fenugreek influence the agricultural practice, as crops with varying dimensions require adaptable mechanisms for efficient collection. Moreover, the crop parameters affect not only the energy requirements for agricultural practices but also the transportation and packaging aspects, all of which contribute to the economic feasibility of leafy crop production. The crop parametersof various leafy vegetables, separating the difficult relationships between these attributes and their implications for effective leafy crop practices. By shedding light on the features of different leafy greens, aim to facilitate the development of cutting-edge agricultural machinery s that maximize efficiency, reduce waste, and uphold the nutritional integrity of the produce. The study of these crop parameters, including size, shape, weight, crop stand density plays a pivotal role in designing innovative agricultural technologies tailored to the unique needs of each crop type.

**3.1.1 Plant height**

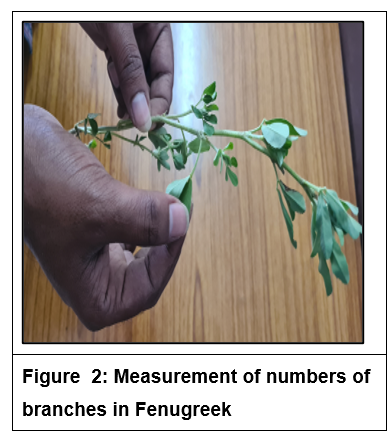
The top portion of the plant from the ground surface referred as plant height. The height of the crop is very important parameter while designing the agricultural machinery. To measure plant height, average height of the 50 randomly selected plants height was measured from each crop with the help of a measuring tape having least count of 1 mm. Figure 1 depicts a view for measuring the height of selected leafy vegetables.

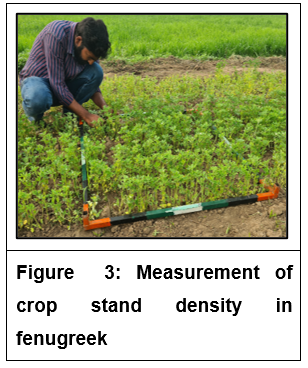


* + 1. **Numbers of branches**

The number of branches directly impacts the machinery speed and efficiency. Additionally, agricultural machinery designed for plants with fewer branches might be less effective when used on plants with more branches. The density of branches can vary from one leafy vegetable type to another and even within the same crop. Figure 2 depicts a view for measuring the number of branches of selected leafy vegetables. The branches were divided into primary and secondary according to its position. The branches near to the main stem are called as primary whereas the branches appeared from the primary are termed as secondary branches. Both primary and secondary branches were counted together to determine the total number of branches in a plant.

* + 1. **Crop stand density**

Crop stand density is defined as the plant population per unit square area. The power and speed of the agricultural machinery can also be influenced by crop stand density. The numbers of plants were counted in 1 m2 area at ten randomly selected locations in each treatment and mean value was determined. The 1 m2 frame was placed diagonally along the line of planting to count number of plants per unit area. Figure 3 depicts a view for measuring the crop stand density of selected leafy vegetables. Also, it is relevant in determination of conveying speed, length of conveyor and plant holding capacity of the conveying unit.



### Stem diameter

Different leafy vegetables have varying stem diameters and the cutting blades or tools must be designed to accommodate this variation. The power and energy requirements of the agricultural machinery may be affected by the stem diameter. Stem diameter of selected plants was measured by measuring average diameter of 50 randomly selected plants in each treatment for each crop of the field. Stem diameter was measured by using digital vernier caliper having a least count of 0.01 mm shown by Figure 4. The stem diameter is an important parameter for understanding its structural integrity and resistance to external forces.

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| **Figure 4: Measurement of stem diameter in Fenugreek** |

* + 1. **Weight of plants material per unit area**

### The weight of plant will be helpful in determining the material handling capacity of the conveying unit. The weight of plants is a variable used in determining the quantity of the crop entering into the machine per time at different speeds. This parameter along with the forward speed of machine was used for calculating feed rate of crop which the machine has to handle. Plants were weighted by using of electronic weighing balance (least count 0.01mm) method at the time of harvesting from ten randomly selected 1 m2 areas and the mean value was determined (Figure 5).

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| **Figure 5: Mesurement of weight of plants material per square meter in fenugreek crops** |

* + 1. **Bulk density**

The bulk density was calculated as the mass of leaves divided by the container volume (Singh and Goswami, 1996; Baryeh, 2002). It would be useful in designing the conveying system and collecting bag of leafy vegetable agricultural machinery. The bulk density of leafy vegetables can vary depending on factors such as moisture content, leaf size and crop type. A closely packed sample of a material would have a higher bulk density than a normally poured sample. A cube box of known dimension was used to measure the bulk density of leafy crops (Figure 6). The box was completely filled by leafy vegetables up to the top followed by three times tapping and weight was taken with an electronic balance having least count of 1 g. The bulk density was calculated by using the equation 3.1 (Kushwaha et al. 2015).

Bulk density, (kg/m3) .………eq. (3.1)

Where

M = Mass of leaves, kg; and

V = Volume of box, m3.

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| **Figure 6: Measurement of bulk density of fenugreek** |

**3.1.7 Determination of moisture content**

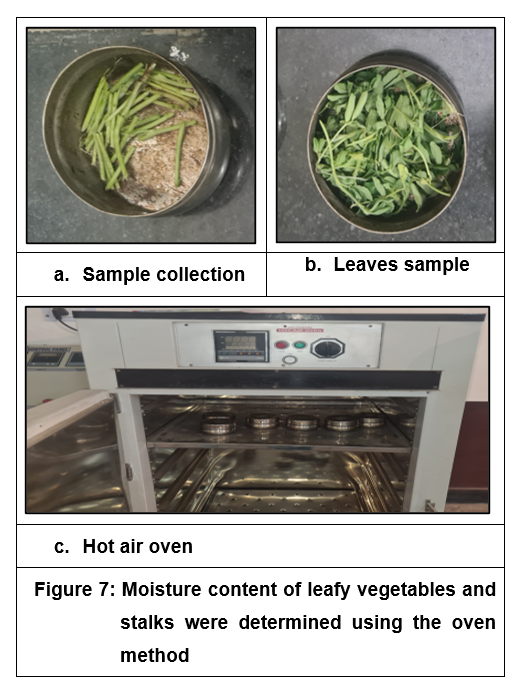
The moisture content of leaves and stalks were determined using the oven method (Figure 7). The initial weights of samples were determined using the electric weighing balance. Triplicate samples were dried in air convection oven set at temperature of 105°C ± 2 (ASAE, 1994) and monitored over a period of 24 hours at 8-hour intervals until the weights of the samples were found to be constant. The moisture content was calculated by using following relationship. Their results showed that the cross-sectional area and moisture content of the crop had significant effect on cutting energy and maximum cutting force.

Moisture content (db) .………eq. (3.2)

Where,

W1 = Weight of the wet sample, g; and

W2 = Weight of the dry sample, g



1. **Determination of physical properties properties of fenugreek**

The physical properties of most common variety of fenugreek **(Bombay bold)** variety such as plant height, stem diameter, moisture content, bulk density, angle of repose and coefficient of friction were determined. These values are helpful for designing and fabricating the agricultural machinery. Physical properties of plants were determined for matured crop in the research farm JNKVV, Jabalpur. These include number of branches per plant, crop stand density, and plant weight. The mean, standard deviation and coefficient of variation values are presented in the following sections.

**4.1 Height of fenugreek plants**

The given Fig. 8 provides following information about the height of randomly selected fifty plants in fenugreek treatments, with specific statistical measures to describe the distribution of the heights. The range of plant heights is 25 – 35 cm. This indicates that the heights of the selected plants vary between 25 cm and 35 cm. After 30 days of sowing fenugreek, similar trends in the plant height were observed, as reported by Srinivas et al. (1982). The mean height of the plants is 30.46 cm. The mean is the average height of all the fifty plants. The difference between the smallest plant height and the mean plant height of the treatment is 5.46 cm. This represents the spread of the heights below the mean. The difference between the largest plant height and the mean plant height of the treatment is 4.54 cm. This represents the spread of the heights above the mean. The standard deviation of the plant heights is 2.8650. It measures the amount of variation or dispersion in the set of heights. The variance of plant heights is given as 8.2084. It is another measure of the spread or dispersion of the heights. The standard error of the mean of plant heights is 0.4052. It provides an estimate of how much the sample mean is expected to vary from the true population mean. The coefficient of variation (CV) of the plants is 0.0941. This is a standardized measure of relative variability, calculated as the ratio of the standard deviation to the mean. The coefficient of variation (CV) expressed as a percentage was 9.41%. This provides a percentage representation of the relative variability in plant heights.

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| **Fig. 8: Height of randomly selected fifty plants in fenugreek** |

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**4.2 Stem diameter of Fenugreek plants**

The Fig. 9 provided the statistical characteristics of the stem diameter distribution for fifty randomly selected fenugreek plants. The range of stem diameters spans from 1.20 mm to 2.40 mm, indicating the observed variability in the sample. A similar trend of plant stem diameter has been reported for fenugreek Rathod et al. (2020). The mean stem diameter of the plants is reported as 1.79 mm, serving as the central measure representing the average stem diameter. The differences between the smallest and largest stem diameters in relation to the mean are specified as 0.59 cm and 0.61 mm, respectively, providing insights into the spread of stem diameters around the mean. From Table 1, the standard deviation, a measure of individual stem diameter deviation from the mean, is given as 0.37, while the variance, representing the squared standard deviation, is reported as 0.14. The standard error of the mean is provided as 0.0531, offering an estimate of how much the sample mean is expected to vary from the true population mean. The coefficient of variation (CV) is introduced as 0.2, representing a standardized measure of relative variability by expressing the standard deviation relative to the mean. When expressed as a percentage, the coefficient of variation is 20.92%, offering a percentage-based perspective on the relative variability in stem diameters.

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| **Fig. 9: Stem diameter of randomly selected fifty plants in fenugreek** |

**4.3 Numbers of branches of randomly selected fifty plants in Fenugreek**

In the examination of the number of branches in randomly selected fifty fenugreek plants, as illustrated in Fig. 10 and Table 1, the range spans from 3 to 5, providing an overview of the variation in the number of branches within the sample. Similar trends in the number of plant branches in fenugreek were observed by Gangopadhyay et al. (2012). The mean number of branches is determined to be 3.92, representing the central measure indicative of the average number of branches in the treatment. The smallest number of branches deviates by 0.92 from the mean, while the largest number of branches shows a difference of 1.08, indicating variability at both ends of the spectrum. The standard deviation for fenugreek plants is calculated to be 0.7167, reflecting the spread of individual branch numbers from the mean, with a variance of 0.51. The standard error of the mean is 0.1046, providing insight into the precision of the mean as an estimate of the population mean. The coefficient of variation (CV) and its percentage counterpart (18.28%) offer relative measures of variability, allowing for comparisons across datasets. The sum of squares, totaling 25.68, contributes to understanding the distribution of data points.

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| **Fig. 10: Number of branches of randomly selected fifty plants in fenugreek** |

**4.4 Crop stand density of fenugreek**

From the Fig.11, the observed crop stand density in fenugreek treatment, varied between 288 and 366 plants per square meter across ten randomly selected locations. A higher crop stand density in fenugreek was observed compared to the results of Diwan et al. (2021) due to the use of a broadcasting method and a higher seed rate for sowing. The mean density, a central measure of this distribution, was calculated to be 327.30 plants per square meter. The range, which is the difference between the highest and lowest density values, was found to be 78 plants per square meter. Notably, the difference between the smallest crop stand density and the mean was 39.3, while the difference between the higher crop stand density and the mean was 38.7. These differences provide insights into the dispersion of data points around the mean, highlighting the variability in crop stand density within the fenugreek treatment. The standard deviation, a measure of the amount of variation or dispersion, was 26.62 plants per square meter, indicating the degree to which individual data points deviate from the mean. The variance, calculated from the standard deviation, was 709.01, further quantifying the spread of data. The standard error of the mean, at 8.42 plants per square meter, estimates the likely variability of the mean in repeated sampling. The coefficient of variation (CV), expressing the standard deviation as a proportion of the mean, was 0.08, or 8.14% when expressed as a percentage. This coefficient offers a relative measure of variability that is independent of the scale of measurement. Additionally, the sum of squares, a measure of the dispersion of data points around the mean, was calculated to be 709.1.

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| **Fig. 11: Crop stand density of randomly selected ten locations in fenugreek** |

* 1. **Weight of plant material per square meter of randomly selected ten locations in fenugreek**

Table 1 investigation into the variations of plant material weight per square meter in fenugreek across ten randomly selected locations provides valuable insights into the heterogeneity of the data. The observed range, spanning from 0.45 to 0.57 kg/m², underscores the diverse weights recorded at these specific sites. This range signifies the extent of variability in the fenugreek plant material, indicating that different locations exhibit distinct levels of productivity. The statistical analysis of these variations further enhances our understanding. The mean weight of plant material per square meter, calculated at 0.5020 kg/m², serves as a central point around which the data fluctuates. Notably, the differences between the smallest observed weight and the mean, as well as the higher observed weight and the mean, are quantified at 0.052 kg/m² and 0.12 kg/m², respectively. These differences highlight the dispersion of data points around the mean and provide a nuanced perspective on the distribution of plant material weights in the fenugreek treatment.

Fig. 12 complements this analysis by visually representing the weight of plant material per square meter across various treatments. This graphical depiction allows for a more intuitive understanding of how different treatments contribute to the observed variations. It enables researchers to discern patterns, trends in the data, facilitating a comprehensive interpretation of the overall results.

Additionally, key statistical parameters, such as the standard deviation was 0.0361, variance was 0.0013, standard error of the mean was 0.0114 and coefficient of variation was 0.0724 or 7.24%, provide essential context to the data's reliability and consistency. These metrics offer a robust framework for evaluating the precision and stability of the measurements taken across the ten locations.

Furthermore, the sum of squares, quantified at 0.01, adds another layer to the statistical assessment, providing a measure of the spread of data points and contributing to a comprehensive understanding of the variability in plant material weights.

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| **Fig. 12: Weight of plant material per square meter in fenugreek** |

* + - 1. **Bulk density of selected treatments**

Fig. 13 explain about the examination of bulk density across three random locations of the cultivation of fenugreek. Fig. 13 provides a visual representation of the variations in bulk density within these fenugreek. Starting with fenugreek, the average bulk density was determined to be 183 kg/m³. This value signifies the mean density observed across the selected treatments for fenugreek cultivation. Analysing this Fig.13 allows for an understanding of how fenugreek cultivation influences soil compaction and structure in the specific locations under investigation. Variations in fenugreek bulk density could indicate differences in root development, nutrient distribution, and overall soil health.The lower crop bulk density in all fenugreek were attributed to the use of a broadcasting method and a lower seed rate for sowing, in contrast to the findings of Jammy et al. (2015) in their study on tea leaves. The variation in leaves' bulk density is influenced by factors such as differences in leaf anatomy, species characteristics, water content, and prevailing environmental conditions.

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| **Fig. 13: Bulk density of selected treatments** |

* + - 1. **Moisture content of entire plant, leaves and stems of selected treatments**

The analysis of moisture content in whole plant, leaves and stems of fenugreek, , as presented in Fig. 14 and Table 1, reveals nuanced variations that offer deeper insights into the water dynamics of these plant parts. Fenugreek whole plant was showing a lower moisture content of 84.2%, leaves display a moderate moisture content of 25.6%, indicating a balanced water composition, while the stems were showing a lower moisture content of 8.5%, suggesting a more fibrous and potentially drier nature. Rathod et al. (2020) reported a consistent trend in moisture content for fenugreek stems, and Alane et al. (2021) documented a parallel trend in moisture content for fenugreek leaves. This comprehensive understanding of moisture content in different plant parts not only informs agricultural practices, guiding optimal harvesting times and storage conditions, but also holds implications for the nutritional quality and culinary applications of these herbs. Such insights contribute to a holistic assessment of the overall quality and characteristics of fenugreek aiding in agricultural management decisions and culinary choices.

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| **Fig. 14: Moisture content in leaves and stems of selected treatments** |

**Table 1: Crop parameters and engineering properties of selected leafy vegetables**

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| **Parameter** | **Particulars** | **Fenugreek** |
| **Plant Height, (cm)** | Range | 25 – 35 |
| Average | 30.46 |
| SD | 2.86 |
| CV, % | 9.41 |
| **Stem diameter, (mm)** | Range | 1.20 - 2.40 |
| Average | 1.7960 |
| SD | 0.3757 |
| CV, % | 20.92% |
| **Numbers of branches** | Range | 3-5 |
| Average | 3.92 |
| SD | 0.7167 |
| CV, % | 18.28 |
| **Crop stand density** | Range | 288 - 366 |
| Average | 327.30 |
| SD | 26.6272 |
| CV, % | 8.14 |
| **Weight of plant material per square meter, (kg/m2)** | Range | 0.45 - 0.57 |
| Average | 0.5020 |
| SD | 0.0361 |
| CV, % | 7.24 |
| **Moisture content of plant, (%)** | | 25.6% |
| **Moisture content of stems, (%)** | | 8.5% |
| **Moisture content of leaves, (%)** | | 84.2 |

**Conclusion:**

In summary, the physical attributes of fenugreek encompass a spectrum of crop parameters, encompassing plant height, stem diameter, branching pattern, crop stand density, plant material weight, bulk density, and moisture content. The variability in these factors underscores fenugreek's adaptability to diverse environmental conditions. A comprehensive understanding of these physical characteristics is imperative for refining cultivation practices and tailoring machinery for the optimal cultivation of fenugreek, making it a valuable asset in both agriculture and various industries.

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