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Implications of biometric properties of chilli seedlings for mechanical transplantation

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Abstract

The biometric properties of chilli seedlings, including physical attributes such as height, weight, stem diameter, and size, as well as mechanical properties like stem compressive strength and the coefficient of friction, were studied for their relevance in the design and selection of components for chilli transplanters. The seedlings, aged 25, 30, and 35 days, were grown in pro-trays with truncated square pyramid cells (120 cells) and procured from a nursery. The maximum recorded values for seedling height, weight, stem diameter, and size were 20.52 cm, 11.4 g, 2.31 mm, and 12.52 cm, respectively. The physical properties increased with seedling age, with a notable acceleration after 30 days. Among the age groups, 35-day-old seedlings exhibited the highest average compressive strength of 16.36 N. However, the coefficient of friction showed minimal variation with age. The findings indicate that the biometric properties of chilli seedlings evolve significantly with age, highlighting their importance for optimizing mechanical transplantation systems.

Keywords: Chilli seedlings, physical and mechanical properties, seedling compressive strength, seedling age optimization, Transplanter design

1. Introduction

Chilli, a versatile and universally used spice, is cultivated across tropical and subtropical regions worldwide, accounting for 20–30% of Indian seasoning exports. The origin of chilli traces back to Latin America, specifically to the New Mexico and Guatemala regions, where it is believed to have grown wild as early as 7500 BCE (Madhushaker *et al.*, 2020) ^[1]. Today, over 400 distinct varieties of chilli are grown globally, with *Capsicum annuum* L. being one of the most widely cultivated species.

In India, chilli holds a unique position among the 50+ spices produced nationwide. *Capsicum annuum* is grown for two main fruit types: pungent varieties (commonly referred to as hot pepper, cayenne, or paprika) and non-pungent varieties (such as bell pepper, also known as Shimla mirchi). Both fresh and dried chillies offer significant nutritional benefits. Green chilli peppers are rich in protein and vitamins A, B, C, E, and P, while dried chillies are excellent sources of vitamins A and D. Red chilli peppers, in particular, contain more vitamin A than carrots, and green chillies surpass citrus fruits in vitamin C content (340 mg per 100 grams). India is the world's largest producer of chilli, contributing 43% of global production with an output of 1.98 million tonnes (ANGRAU, 2022) ^[1]. Andhra Pradesh led India's chilli production in 2022 with 700,000 tonnes, representing 37.35% of national output, while Gujarat contributed 22,360 tonnes, holding a 1.19% share (NHB, 2020) ^[14]. However, despite red chilli's prominence as a key spice in global markets, the crop faces production challenges due to factors such as an aging labour force, rising labour costs, specific growing conditions, and a labour shift toward industrial and household sectors.

Transplanting is a critical and labour-intensive stage in chilli production. It involves transferring uniform seedlings from nurseries to the field (Hwang *et al.*, 2020) ^[6]. Typically, seedlings are raised on nursery beds, where seeds are either broadcast or dibbled in rows. After 4–10 weeks, these seedlings are manually uprooted and transplanted into the field (Kaushik *et al.*, 2020) ^[8]. While many crops are directly sown, crops like chilli, tomato, and eggplant are often grown in nursery beds before being manually transplanted onto prepared seedbeds (Patil *et al.*, 2015) ^[16].

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Manual seeding and transplanting account for about 40% of the total working hours in cultivation, making it a costly operation that requires approximately 254 man-hours per hectare, with average labour wages of ₹300 per day (Bhambota *et al.*, 2018) [3]. Mechanizing transplanting operations can address these labour-related challenges, reduce physical strain, and improve productivity in chilli production. In India, small farms of less than 2 hectares dominate the agricultural landscape, and farmers typically allocate a smaller portion of their land to chilli cultivation.

Recognizing the challenges posed by labour shortages and the need for cost-effective machinery, the Chilli Task Force Committee (CTFC) established by the Spice Board of India has recommended two key initiatives: the development of locally made machinery and the application of mechanization across all stages of chilli production (Dwivedi, 2022) [4]. Introducing efficient transplanting technologies and improved cultivation practices could help reduce the yield gap between potential and actual crop yields, which currently ranges from 26% to 72% (Kumar and Raheman, 2008) [10]. As modern machinery becomes increasingly essential in agriculture, understanding the engineering properties of crops is critical for designing machines, processes, and handling methods that maximize efficiency and quality (Khadatkar *et al.*, 2020) [9]. For chilli seedlings, physical properties such as shape, size, height, weight, and stem diameter are vital parameters in developing effective transplanting machinery (Gaikwad, 2010; Turbathmath, 2010) [5, 19]. Accurate measurements of these physical and mechanical properties are essential engineering parameters in product development (Sharma *et al.*, 2023) [17].

2. Materials and Methods

The study was conducted on the Saniya (*Acsen Hyveg*) variety, which is commonly cultivated in the Saurashtra region of Gujarat. Fresh seedlings were procured from a nursery employing standard agronomic practices under the supervision of an experienced and verified nursery grower. The plug seedlings were raised in pro-trays following recommended seed rates and cultural practices. Pro-trays with 120 cells, having a plug depth of 30 mm and a 30 × 30 mm truncated pyramid shape, were used to determine the biometric properties. As per the nursery grower's recommendations, the seedlings are typically transplanted around four weeks after sowing, depending on the climatic conditions of chilli-growing regions in Saurashtra. Therefore, biometric properties relevant to the design of a chilli seedling transplanter were evaluated at 25, 30, and 35 days after sowing (one week before and after the recommended age).

The studies on the biometric properties of thirty randomly selected samples of 25-, 30-, and 35-day-old chilli seedlings were conducted in the laboratories of Farm Machinery and Power Engineering and Processing and Food Engineering Departments, CAET, JAU. The following engineering properties were studied.

2.1 Physical Properties

2.1.1 Weight

The weight of the seedling is a critical parameter in designing the seedling handling tray for the transplanter. Thirty samples from each age group were measured using an electronic weighing balance with a 5 kg capacity and a least count of 0.5 g (Fig. 1).



Fig 1: Measurement of weight using electronic weighing balance

2.1.2 Height

To determine the average seedling length, the seedlings were carefully removed from the plug. Thirty observations were recorded for each age group. Seedling height was measured using the ANSI Z60.1 (2014) [2] method, wherein the distance from the seedling tip to the end of its root was measured using a 300 mm scale with an accuracy of 1 mm (Sharma *et al.*, 2023) [17].



Fig 2: Measurement of seedling height using a steel ruler

As the size of the seedlings increases with age, determining the optimal height for transplantation is essential. Seedling height significantly influences the design parameters, such as the diameter of elastic wheels in the seedling metering mechanism and the inclination angle of seedlings after being planted in the soil (Fig. 2).

2.1.3 Seedling stem diameter

The stem diameter of thirty uprooted seedlings from each age group was measured using a digital Vernier caliper with a minimum count of 0.01 mm (Sharma *et al.*, 2023) [17]. To ensure uniformity, measurements were taken 20 mm above the bottom end of the stem (Mohsenin, 1986) [13]. Stem diameter is a critical factor in determining the clearance between elastic discs to securely grip the seedlings without causing damage (Fig. 3).



Fig 3: Measurement of stem diameter using a digital Vernier caliper

2.1.4 Size

The canopy size of plug seedlings was represented by the critical canopy diameter (spread diameter). This was defined as the minimum inner diameter of a circular pipe through which a healthy plug seedling could pass vertically without getting stuck (Gaikwad, 2010) ^[5]. Thirty seedlings from each age group were placed in their natural state, and the spread diameter was measured using a ruler with 1 mm accuracy as per ANSI Z60.1 (2014) ^[2] (Fig. 4).



Fig 4: Measurement of canopy size using measuring tape

2.2 Mechanical Properties

2.2.1 Compressive strength

Compressive force indicates the maximum strength that seedlings can withstand during various stages of the transplanting operation. The compressive strength of the plug and stem of the seedlings was measured using a texture analyzer by placing the seedlings horizontally under the probe (Fig. 5).



Fig 5: Texture analyzer used for measuring compressive strength

The following specifications were used:

- Load cell capacity: 25 kg
- Pre-test speed: 5 mm/sec
- Test speed: 0.5 mm/sec
- Post- test speed: 10 mm/sec
- Compression Distance: 30%
- Probe: ½” cylindrical ebonite

The seedlings were compressed to 30% of their stem thickness to assess the compressive force required to securely hold the seedlings with minimal damage. This compression distance was chosen as it resulted in minimal damage, reduced mortality, and provided optimal gripping force (Pandirwar *et al.*, 2015) ^[15]. Compressive strength is crucial in determining the force-bearing capacity of seedlings during transplanting operations.

2.2.2 Coefficient of static friction

Friction between surfaces is essential to prevent seedling slippage during handling. The angles of friction between the seedlings and commonly used plastic materials, such as polypropylene sheets and fibre-reinforced plastic (FRP) surfaces, were measured using a calibrated tilting table (Fig. 6).



Fig 6: Apparatus for measuring the coefficient of static friction

The seedling was placed on a horizontal plane sheet of the test surface, and the sheet's inclination was gradually increased until the seedling began to slip. The angle at which slippage occurred was recorded, and the coefficient of static friction was calculated as the tangent of the measured angle (Khadatkar *et al.*, 2020) ^[9]. The coefficient of static friction was computed using the formula:

$$\mu = \tan \delta \dots \quad (\text{Eq. 1})$$

Where,

μ = Coefficient of friction, and

δ = Angle at impending slip, degrees.

3. Results and Discussion

Biometric properties of 20 randomly selected plug-type chilli seedlings from three age groups (25, 30, and 35 days) were studied. The experiments were conducted using the *Saniya* (Acsen Hyveg) variety, commonly cultivated in the Saurashtra region of Gujarat.

3.1 Physical Properties

Table 1 summarizes the physical properties—weight, height, stem diameter, and size—of seedlings across different transplanting ages. It is evident that these properties increase with seedling age (Fig. 7). Their influence on the design of transplanter components is discussed below.

The weight of seedlings ranged from 8.1 g at 25 days to 12.6 g at 35 days. The average seedling weight increased from 9.11 g to 11.4 g between 25 and 35 days (Table 1). While the variation in seedling weight was relatively small, it still played a role in determining the structural strength of the seedling tray. Similar observations were reported by Sharma *et al.* (2023)^[17]. Seedling height ranged from 10.1 cm (25 days) to 22.2 cm (35 days). The average height increased significantly from 11.91 cm to 20.52 cm with age. The rapid increase in height after 30 days aligns with nursery growers' observations that chilli crop height accelerates after one month. A maximum seedling height of 22.2 cm was used to optimize the diameter of the elastic discs in the metering unit. Discs with a 430 mm diameter were deemed

sufficient to prevent clogging, similar to those utilized by Karayel *et al.* (2023)^[7]. Mahapatra and Chattopadhyay (2018)^[12] also noted that seedlings taller than 150 mm are suitable for mechanical transplanting, confirming the suitability of 35-day-old seedlings for height-based parameters.

The stem diameter ranged from 1.32 mm (25 days) to 2.69 mm (35 days), with an average increase from 1.72 mm to 2.31 mm across the three age groups. Stem diameter showed a trend of significant increase after 30 days, correlating with height growth. This parameter was crucial for determining the clearance between elastic discs to securely grab seedlings without causing damage. A clearance of less than 1 mm was optimal.

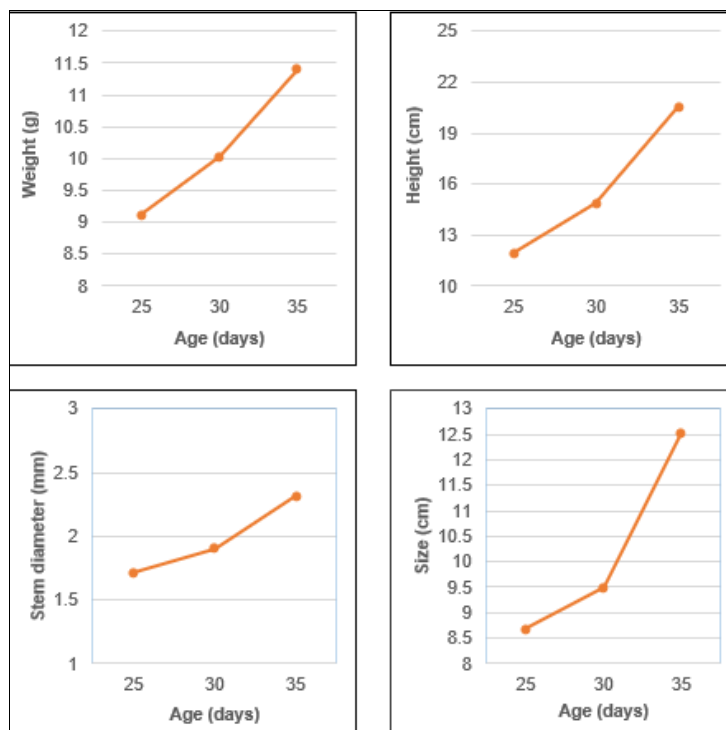


Fig 7: Effect of age of seedlings on weight, height, stem diameter and size of seedlings

The canopy size ranged from 7.1 cm (25 days) to 13.8 cm (35 days). The average size increased from 8.69 cm to 12.52 cm. While the variation in canopy size was less pronounced, it was

critical for designing soil-covering and compacting devices. Based on Sahoo *et al.* (2018)^[18], a base clearance of 75 mm can accommodate seedlings with a canopy size of up to 150 mm.

Table 1: Effect of seedling age on biometric properties of plug chilli seedling

Attributes	Seedling Age			
	25 Days			
	Maximum	Minimum	Average	Std. deviation
Weight (g)	11.1	8.1	9.11	1.046
Height (cm)	12.6	10.1	11.91	0.728
Stem diameter (mm)	1.92	1.32	1.72	0.173
Size (cm)	9.8	7.1	8.69	0.777
Compressive strength (N)	14.44	10.23	12.19	0.64
	30 Days			
	Maximum	Minimum	Average	Std. deviation
Weight (g)	11.4	8.9	10.025	0.688
Height (cm)	16.4	13.8	14.91	0.747
Stem diameter (mm)	2.15	1.67	1.90	0.112
Size (cm)	10.8	8.7	9.50	0.595
Compressive strength (N)	16.71	12.12	13.4	0.72
	35 Days			
	Maximum	Minimum	Average	Std. deviation
Weight (g)	12.6	10.3	11.4	0.620
Height (cm)	22.2	18.8	20.52	0.946
Stem diameter (mm)	2.69	2.1	2.31	0.144
Size (cm)	13.8	11.2	12.52	0.726
Compressive strength (N)	19.3	13.83	16.36	0.16

3.2 Mechanical Properties

Compressive strength is a critical parameter in designing elastic disc-type transplanters, as seedlings gripped between the discs are subjected to compression. The compressive strength of the stem was measured using a texture analyzer, with the compression distance set to 30% of the stem diameter to minimize physical damage. The maximum compressive strength of 19.3 N was recorded for 35-day-old seedlings, while the minimum strength of 10.23 N was observed for 25-day-old seedlings (Table 1).

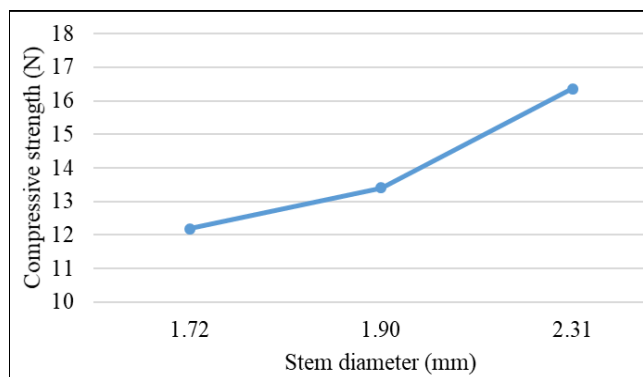


Fig. 8 Effect of stem diameter on compressive strength

Figure 8 illustrates the relationship between the compressive strength of the stem and stem diameter. The compressive strength of seedlings increased with age, attributed to the corresponding increase in stem diameter and root density (Khadatkar *et al.*, 2020)^[9].

Although the coefficient of friction plays a minor role in disc-type metering mechanisms, it was measured for the interaction between seedling stems and Fiber Reinforced Plastic (FRP). The average coefficient of friction was found to be 0.73 ± 0.042 , which falls within the acceptable range for most manufacturing materials.

4. Conclusion

The biometric properties of the Saniya chilli variety, commonly grown in the Saurashtra region of Gujarat, were evaluated. Physical properties such as weight, height, stem diameter, and size increased with the age of the seedlings, with the highest values observed for 35-day-old seedlings. The average values for 35-day-old seedlings were: weight (11.4 g), height (20.52 cm), stem diameter (2.31 mm), and size (12.52 cm). Notably, these physical properties showed a significant increase after 30 days of seedling age. The compressive strength of the seedlings was found to be directly proportional to the stem diameter, with 35-day-old seedlings exhibiting an average compressive strength of 16.36 N. These biometric characteristics are crucial for designing and selecting the components of a chilli transplanter to ensure optimal performance and compatibility.

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