The Pharma Innovation Journal 2023; 12(2): 2068-2071

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2023; 12(2): 2068-2071

www.thepharmajournal.com
Received: 12-12-2022
Accepted: 16-01-2023

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Study of crop stem lodging and the importance of suitable device for the measurement of crop strength

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Abstract
Crop strength analysis and lodging are common problems for most field crops. Scientific methodology to quantify the difference in susceptibility to lodging for different varieties of crops is required for this purpose. The lodging nature of a crop plant is generally quantified with its stem strength. Considering this, a study was conducted to find out the lodging nature in the actual field conditions and extract the requirements of a suitable device to use the in-situ measurement of the crop stem strength. The traditional unit constraints such as time, floor spacing, maintenance, expansiveness and bulky instrument size need to be considered and minimized to work in the field.
Competing Interest: The authors have declared that no competing interest exists.

Keywords: Crop lodging, in-situ measurement, crop strength, paddy

Introduction
Lodging is a common problem for most field crops. It is a permanent displacement of crop stems or above parts on the ground from their vertical position. It more often occurs before the harvest. The problem is associated with yield reduction, deterioration in grain quality, difficulty in harvesting as well as increased susceptibility of grain to mycotoxin-producing fungi and subsequently reduces the farmer's profits (Zhang *et al*., 2014) [12]. Improving stem strength can help to arrest these issues, and can be achieved through various cultural practices such as proper fertilizer application and crop management. Hence, crop strength can be defined as the indicator of the respective crop's lodging index. It creates a challenging task for plant breeders and agronomic scientists, making them investigate further to address this problem. Scientific methodology to quantify the difference in susceptibility to lodging for different varieties of crops needs to be developed. Crop stem strength refers to the ability of a plant's stem to resist breaking or bending under the weight of the crop and environmental factors such as wind and rain. Strong stems are essential for the proper growth and development of a crop, as well as for its ability to withstand stress and maintain an upright position. A number of factors can influence crop stem strength, including the plant's genetics, growth conditions, and nutrient uptake.
In food crops, stem strength is viewed as a composite trait. The measurement of crop strength is a tough job in natural field conditions. The farmer is facing a challenge with crop susceptibility to stem lodging before its harvest. A living plant stem is a dynamic structure, cellular and/or porous in nature. The mechanical measurement during the live plant is difficult in the field as compared to isolated (dead and processed) samples (Wu & Ma, 2016) [13] testing in the laboratory. Measurement of important determinants/traits including plant height, stem diameter, and stem strength help in calculating the susceptibility of plants to lodging. Meanwhile, these traits are interrelated to the crop's strength to stand upright by resisting changes that occur in ecology and climate (rains, winds, temperature, humidity, etc.) until its harvest. Plant breeder endeavours to develop improved crop varieties with bigger, healthier stem and root systems to ensure well-rooted plants in the soil with good health for better yield and resistance to lodging. If the measurement of plant lodging characteristics is done objectively, this will facilitate the breeders to incorporate lodging resistance traits into new varieties. Therefore, there is a need to develop a measurement system for the assessment of the crop stem strength of a plant.
Shrestha followed the bending test to resemble the plant stem's natural failure pattern to measure the stem stiffness in the field. (Shrestha *et al*., 2020 [7], Kashiwagi *et al*. 2008) [4], used the Prostrate tester in the paddy crop for measuring the plant's resistive strength at its full-ripen

stage. The plant and tester position should be perpendicular while measuring. The pushing resistance was measured by placing the tester on the plant at the point that lies 200mm above the ground level and pushing or making the plant bend to a 45-degree angle from its vertical position. It is required to do the test for every single plant to know better about the plant's strength. In a similar study led by Hai *et al*. (2005) [2] in wheat, stem strength measurement was made at the second most bottom internode of the plant. They experimented at the milky stage of the crop and followed the technique given by Xiao *et al*. (2002) [10], similar to Kashiwagi & Ishimaru (2004) [3], work. The plant strength was extracted via equation 1.

$$\text{Strength} = \frac{\text{Test Reading}}{40 \times 100/\text{Number of stems in the plant}} \quad (1)$$

Y. Xiao *et al*. (2015) [11], worked on winter wheat with the same instrument and studied the effects of planting density and genetic aspects on the crop yield and lodging characteristics. These studies disclosed the measurements made with whole plant strength but not stated the information about the individual tiller's mechanical traits. A piercing probe with a digital force gauge was used to measure the force by Liu *et al* while penetrating the rind of the Maize stem (Liu *et al*., 2020; Peiffer *et al*., 2013) [5, 6]. Stucker *et al*. (2021) [9] used an electro-mechanical crop-clamp pinch test and followed a non-destructive method to assess the lodging resistance or stiffness of the maize stem. The whole device was weighing about 5 pounds (approximately 2.27 kg) and little costlier about $1200 (Approximately Rs. 97, 320.00 INR). But the device is designed to use with the tabletop, not in the form of hand-held use. The stress-strain analysis test with a Texture analyzer (TA) or the Universal testing unit (UTU) is generally using the separated and stored plant material as a test sample. Those samples cannot bear 100% similar characteristics as that of the live-standing crop in the field. Hence, it will create a problem of pressure conditions for the person, the one who wants to operate it with hands support.

Presently, researchers in the field of plant breeding use the above-discussed force measurement systems. These units are useful for the individual plant or the bulk stem strength analysis. This may help in determining the transverse strength of the isolated crop parts and it might be impractical in some circumstances as the material property alters with the environment. These systems rely on the floor and time constraints, maintenance, and expertise to operate and cannot be available at affordable prices (Cheng *et al*., 2009 [1]; Stubbs *et al*., 2019) [8]. For these reasons, they cannot be installed outside the laboratory conditions. The identified constraints made us to think in this regard. So, we thought to study the nature of crop lodging and disclose the requirements of suitable device development for measuring the crop stem strength in the field conditions.

Methods and Materials

In this study, field investigations were conducted to understand the nature of stem lodging in the crop which is a common problem in agriculture. The study aimed to provide a suitable strategy for reducing its impact on crop yields and quality. The study sites were selected based on the presence of the crop prone to stem lodging and the availability of resources. The research plot of paddy crops was chosen at the Division of Genetics, ICAR-IARI and New Delhi. Fig.1 (a) shows the investigation work carried out at the research field and Fig.1 (b) shows the lodging occurred crops in the field.

(a) (b)

Fig 1(a): Investigation on crop stem lodging (Paddy) in the research field at IARI, New Delhi.; (b) Lodged crop spotted in the field

For the best understanding of the physical traits of the single paddy tiller, the pictorial view of the same showed in Fig 2**.** The visual observations were made on the pattern of crop stem lodging in some crop varieties in the field which were found lodged, and relevant information regarding pattern and nature of lodging occurred among them were noticed.

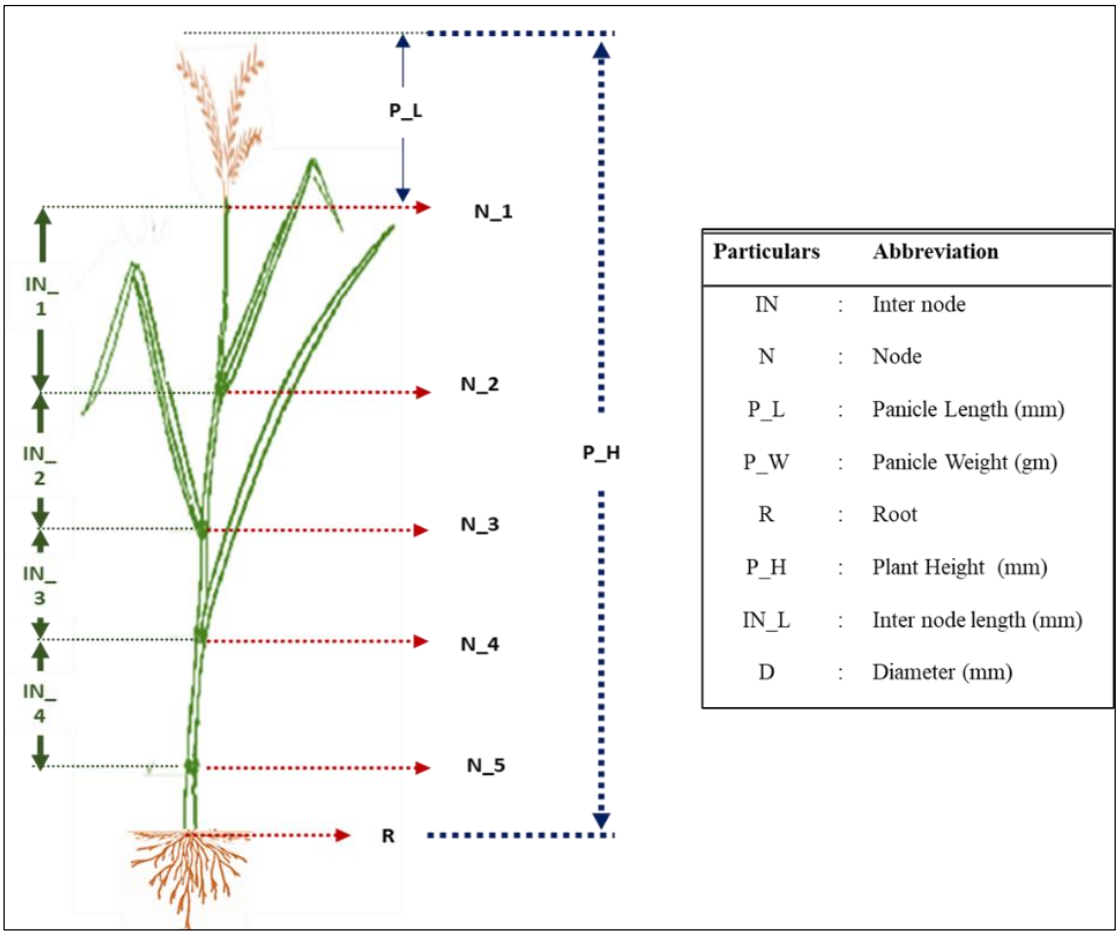

Fig 2: Tiller of the paddy plant: indicating plant height, panicle length, different nodes, and internodes

Results and Discussions

This research paper aims to provide a comprehensive understanding of the nature of stem lodging in paddy crops. Most of the observed samples lodged at the third node and its internode. Some plant stems were bent from the uppermost internode. It may be due to the panicle weight. It was observed that the nature of crop lodging relies heavily on the physical properties of the paddy crop. Some of the most important physical properties that can affect the lodging of paddy crops include stem strength, stem diameter, stem length, and tiller number. Stem strength is a crucial factor, as a weak stem is more prone to bending or breaking under the weight of the plant and its grain. Stem diameter and length may also play a role in determining the strength and its ability to resist lodging. Additionally, the number of tillers can also impact the stability of the plant, as more tillers can provide additional support and reduce the risk of lodging.

Other physical properties of the paddy crop, such as the shape and size of the leaves, can also contribute to the risk of lodging. For example, large leaves with a broad surface area can increase wind resistance and increase the likelihood of lodging. Similarly, the distribution of weight within the plant can also affect its stability, as a plant with an unbalanced weight distribution is more likely to become lodged.

By analyzing the physical properties of the paddy crop, it is possible to identify the factors that contribute to lodging and to develop targeted strategies for reducing its impact. These physical factors and stem strength are related to each other. A plant's stem strength is an influential factor in crop productivity and health, as it indicates a plant's ability to withstand environmental stressors. To make informed decisions about crop growth and development, it is imperative to measure stem strength accurately.

Conclusions

From the results of the field investigation and gained knowledge, detailed conclusions of this work are given here. The observed nature of crop lodging is closely tied to the physical properties of the crop. Understanding of these properties is essential for developing effective strategies to prevent and mitigate lodging.

Measuring stem strength is essential to monitor crop health and productivity, but traditional methods are time-consuming, labour-intensive, and subject to human error. Traditionally, stem strength measurement has been performed using a Texture analyser, a prostrate tester and probe methods. However, these devices are often bulky, expensive, limited to the floor spacing, and require the removal of the stem from the plant, causing potential damage to the crop. To address these limitations, an affordable device for stem strength measurement needs to be developed. The same device must meet the necessities of gap filling in current agriculture research scenarios, employ a non-destructive manner of in-situ stem strength measurement, be compact design, portable, affordable, and must be easier to use. The device must provide accurate outputs to analyze the plant stem's mechanical behavior to define the lodging susceptibility or resistivity. This is important now and in future to mitigate the ever-increasing global population's food needs by supporting agricultural crop safety.

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