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Influence of rain and wind dynamics on lodging of rice (*Oryza sativa*) varieties under rainfed agro-ecology

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ABSTRACT

The present study was carried during rainy (*kharif*) seasons of 2021 and 2022 at Research Farm of S G College of Agriculture and Research Station (Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh), Jagdalpur, Chhattisgarh to find the characters responsible for lodging of rice (*Oryza sativa* L.**)** under natural condition considering weather parameters. A total of 50 varieties of rice were sown in 5.0 m × 5.0 m plots maintaining strip distance of 10 m for providing proper air movement. However, the lodging tolerance of rice varieties was obviously different from each other and 7 key factors that highly influenced the lodging were studied. Rice varieties were sown as horizontal to the length of plot and just orthogonal to width. The strip was uniformly divided in 50 plots with 0.5 m inter-plot distance and 10 m apart to strips. The recommended doses of 80:60:40 kg of NPK/ha were given through straight fertilizers. The mean annual rainfall was received 1408 mm during June–September. In September, slight shifting of wind was recorded with an average speed of 4.49 km/h in north-east and north-west direction in evening and morning hours, respectively which really impacted on basal nodes. September onwards gradually declined in wind speed from 4.40 to 3.15 km/h was recorded. Correlation study was synchronized both the factors, wind and rain together made susceptibility to lodging the varieties like Benisar, Bewara,Chhota Kabari, Chhota Kabari 1, Dagad desi 2, Kakai 1, Kankeri 1, Kanji 1, Kanji, Kantabuta, Kardhana, Karahani, Kari, Karikhuji, Kohikari and Koliya. The variety (Barhi, Benisar, Kalasu and Kanji 1) attained more than 140 cm height coupled with >6 leaves per plant (Chanda and Kanji 1) had higher lodging. Lodging was also observed in leaf length >70 cm that produced more biomass in Bhaya gonad, Butabari and Kankeri 1. Plant height showed the highest eigen value and reverse was in stem thickness; whereas number and length of leaf were almost similar and expressed greater affinity than leaf width and 1st nodal distance in lodging.

Keywords: Lodging characters, Rice lodging, Rice varieties, Wind velocity, Wind direction

Rice (*Oryza sativa* L.) is a major staple food for almost more than 3.5 billion people in the world and lodging is a threat in rice cultivation due to rain and wind. High wind speed and heavy rains enhance the crop lodging while extreme weather events. Many research already suggested that lodging limits the yield and quality of rice and major concern for growers (Liu *et al.* 2018, Zhao *et al.* 2019). Under natural conditions, lodging associates with upper part of the rice and increases weight due to grains, characters support in tolerate against strong winds (Zhao *et al.* 2019, Shrestha *et al.* 2020). In couple of wind pressure and rain, the external forces increases lodging of rice plant. Cereal crop involves two ways of lodging i.e. root lodging and shoot lodging, which is distinguished by uprooting and shoot bend; the bending pressure on inter-nodes cause intermodal lodging (Shah *et al.* 2019), difficulties in harvesting coupled with additional demand for grain drying, lower harvesting efficiency (Islam *et al.* 2007, Liu *et al.* 2018) are prominent issues. Two main factors are responsible for lodging resistance i.e. genetic and growing environments. Shorter stems are more prone to resist lodging than longer ones and heavier panicles (Ookawa and Ishihara 1992).

Crop lodging is profusely increased as storm wind and heavy rain occurs during extreme events (Liu *et al.* 2018, Zhao *et al.* 2019). As top part of rice enhance their biomass and coincides with high rain and heavy wind mostly affects the lodging (Zhao *et al.* 2019, Shrestha *et al.* 2020). Plant height, dry weight, basal intermodal length, diameter and thickness of stem are critical feature in lodging (Zhang *et al.* 2019). Researchers found that higher lodging of rice was at harvest (Wu *et al.* 2015). Quantity of rainfall is also a key factor in lodging, and found that barley was influenced more about 300 mm rain for lodging while grain filling stage,

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resulted in grain damage and reduced yield (Schelling *et al.* 2003). Therefore, present study was carried out to find the characters responsible for lodging of rice under natural condition considering weather parameters.

MATERIALS AND METHODS

The present study was carried during rainy (*kharif*) seasons of 2021 and 2022 at Research Farm of S G College of Agriculture and Research Station (Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh), Jagdalpur, Chhattisgarh. The special layout was framed to accommodate all 50 varieties of rice sown along the length of plot, across to width and orthogonal direction (Fig. 1). The strip was uniformly divided in 50 plots of 5.0 m × 5.0 m at 0.5 m interval of plot to plot and 10 m distance between each strip was maintained for providing proper air flow into plot to know the lodging strength of these 50 rice varieties. As a result total plots replicated four time and observations were recorded. Equal quantity of rice seeds of each variety were sown to each plot maintaining 20 cm row to row and 8 cm plant to plant spacing during sowing of seeds. After sowing, irrigation was immediately given for awakening and fast germination. At the time of sowing, 80:60:40 kg NPK/ha was given through straight fertilizers [Urea, Single super phosphate (SSP) and Muriate of potash (MOP)] and total quantity of nitrogen was given in two splits at basal and flowering. The soil of the experimental field was clayey loam, acidic in reaction (*p*H 5.90), low organic carbon (0.38%), available nitrogen was 187.5 kg/ha, whereas medium in available P_2O_5 (15.4 kg/ha) and K_2O (156.8 kg/ha).

The region is characterized by warm and moist climate with hot summer. The mean annual rainfall of trial site during the experiment years was 1408 mm, most of which was received during June to September. The average rainfall in cropping season (May–October) ranged as 78% of total rainfall. Daily observations of maximum and minimum temperature, rainfall and wind velocity for cropping season were recorded at Agro-meteorological Observatory, S G College of Agriculture and Research Station (Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh), Jagdalpur, Chhattisgarh. Meteorological data on daily rainfall, temperature, wind velocity and direction in two years were also recorded daily and average of wind direction and speed was clubbed together for three phases (0–10, 11–20, 21–30 days) of each month (Fig. 2). Data pertaining to morphological characters of rice varieties were noted as plant height (cm), number, length and width of leaves/plant, two intermodal length from ground surface, stem thickness (cm), grain weight (g), panicle weight (g) and number of tillers/hill were recorded from each plot at harvest.

Culm length (CL) was measured from the lower node to panicle base by measuring scale. Panicle length (PL) was measured from the bottom node of the panicle to the tip of the panicle (Ookawa and Ishihara 1992). Number of leaf was recorded by counting total leaf present at the time of lodging. Length of leaf was measured from tip of the leaf

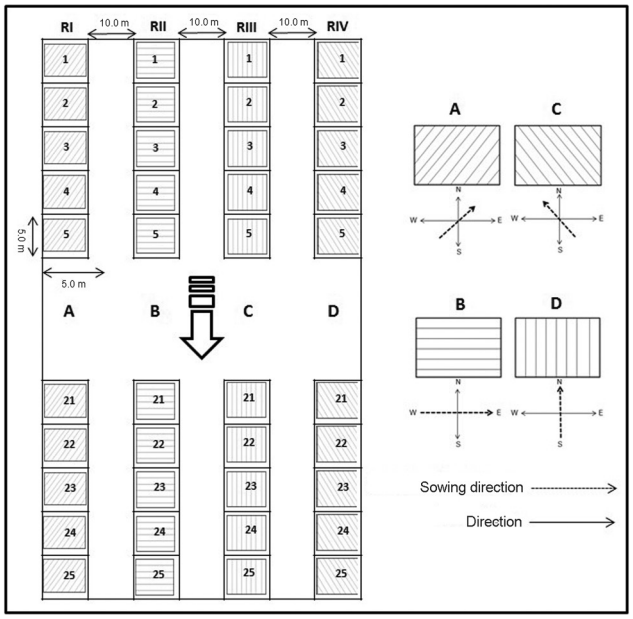

Fig. 1 Layout plan for studying wind effect on rice crop.

to transaction of leaf lamina and sheath, whereas width was measured at centre of leaf length. First and second intermodal length was measured at first and second basal internodes, respectively. Stem thickness was measured by caliper at second node. Lodging observation was noticed with 50% lodged plants of particular plot on visual basis. To analyze the impact of wind and rainfall event the intensity was correlated to morphological characters of rice varieties.

Statistical analysis: Statistical analysis was executed in Statistix 8.1 (version 2.0.1) statistical tool. The response of the varieties to wind dynamics was analyzed by two-way ANOVA and tested least significant difference (LSD) of two year data. The significant differences between varieties means were compared with the least significant difference (LSD) at a 5% level of probability ($P \leq 0.05$). Covariance matrix was used to represent the covariance values between pairs of elements in a random vector (Weng *et al.* 2017). The covariance matrix was also referred to as the variance covariance matrix, and calculated as:

$$\text{Cov}_{x1,x2} = \frac{\Sigma(x_{1,i} - \bar{x}_1)(x_{2,i} - \bar{x}_2)}{n - 1}$$

RESULTS AND DISCUSSION

Wind flow and direction: The velocity and direction of wind is regularly changed under the influence of month and rainfall event directly affects lodging of the rice plants and cause huge loss in yield. Although, many characteristic features of rice plants directly involves in resisting and susceptible toward external factors. The mode value of wind in 10 days was considered as actual wind speed and direction in morning and evening recorded at 8^{o}O'Clock and 4^{o}O'Clock, respectively as prevailing soft and hard condition of rice stem. The moist and dry condition of stems is easily suppressed by wind and gets bend according to their phenotypic features along with load on the stem.

Considering this phenomenon, correlation study has been done between speed and direction of wind at three phases of a month. June month was assumed as base month of beginning crop cultivation; June behaved similar as previous month in first 10 days in south-western direction of wind in evening as well as in morning. The critical period of crop sowing in second phase of June had east ward flow, in which morning wind was in south and south-east direction, but evening wind was in north-east. Later both evening and morning wind flew was in north-east to north-west direction (Fig. 2). The occurrence of strong wind and heavy rain increases the frequency of crop lodging as a result it limits the yield and quality of rice (Liu *et al.* 2018, Zhao *et al.* 2019). When the upper portion of the crop increases weight due to rainfall interception while growth, lodging is more accelerated (Zhao *et. al*. 2019, Shrestha *et. al*. 2020).

Velocity for lodging: During first phase of July, August and October, wind flow was in south-west direction in morning as well as evening, but in second phase, morning and evening wind were more haphazard except August when wind in evening and morning direction was differed and reverse i.e. north-east and north-west in evening and morning, respectively. This indicated that mid month influenced rice crop more due to wind flow and chance of lodging was more owing to inconsistent flow. Although, it was a short period impact that's why plant characteristics were more pronounced to mitigate resistance of lodging. Studies have noticed that rice lodging occurs during the grain-filling period and reduces the starch synthesis rate by resulting high chalkiness (Lang *et al.* 2012). The varieties (Barhi, Benisar, Kalasu and Kanji 1) attained more than 140 cm height plus 6 or more leaves per plant (Chanda and Kanji 1) were highly susceptible to lodging while heavy wind and rain; another aspect of lodging was considered as leaf length (>70 cm) had more biomass than shorter length found in Bhaya gonad, Butabari and Kankeri 1 were sensitive to lodging.

Mid August to November is more critical period of rice farming because early, mid and late duration rice crops are at flowering and maturity stages. As reproductive phase starts with flowering, increases load on rice plant and lodging is more accelerated with wind speed and direction. Early varieties of rice coincided in second phase of August when wind speed was >5.00 km/h which was sufficient to lodge rice plant at milking stage and direction of sowing was a effective measure as done in south-east and south-west direction in minimizing lodging. Rain dampened the crops causes mainly lodging in rainy season, correlation study was synchronized both the factors together for susceptibility, which was seen in tested varieties, viz. Benisar, Bewara, Chhota Kabari, Chhota Kabari1, desi, Dagad desi 2, Kakai 1, Kankeri 1, Kanji 1, Kanji, Kantabuta, Kardhana, Karahani, Kari, Karikhuji, Kohikari and Koliya. Similarly wind direction in third phase of August was in north-west flow in evening and south-east in morning, both times soil had sufficient moisture and plants remained watery had extreme tendency to bending the stems. Further, the wind movement exhibited impacts on strength of stem in first two phases of September, by shifting wind with average speed of 4.49 km/h in north-east and north-west direction in evening and morning, respectively via another side impact on the same stem which weakened the stem at basal nodes. Hence, the role of stem thickness is very important in resistance to lodging pressure and it depends on plant characteristic. Although rice varieties like Barhi, Basabhog, Batroo, Benisar, Bhaya, Bhaya gonad and Bohita possessed more than 3.00 cm stem thickness. Last 10 days of September, wind flowed in south-east and north-west in morning and evening, respectively impact on rice.

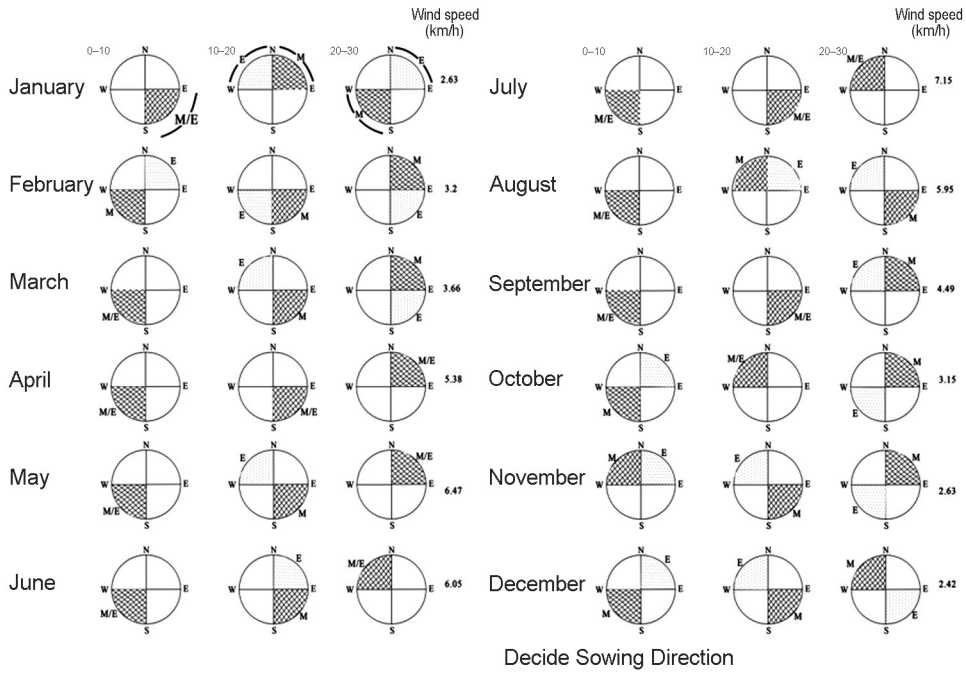

Fig. 2 Mean wind direction and wind velocity of experimental sites.

September onwards wind speed gradually declined from 4.4–3.15 km/h till initial October. Morning wind flowed in south-west direction whereas evening had north-west direction along with marginal wind speed and just shifted in opposite direction i.e. north-east in morning and south-west direction in evening balanced the lodging under low moisture condition of soil as well as crop dryness which do not provide susceptible condition to rice lodging. However, at this point of time most of the rice varieties were either in milking and dough stage. The rice varieties

sown in appropriate direction were highly susceptible to lodging. The yield components of rice consists as number of ears/hill, number of spikelets/panicle, seed setting rate and 1000-grain weights are found greater conformity with findings of Ho *et al.* (2012). The maximum numbers of tillers at panicle initiation stage were almost identical; thus, the culm diameter might increase at the panicle initiation stage, as reported by Li *et al.* (2013) and Wu *et al.* (2015) and gets chance of susceptibility.

November coupled with harvesting of varieties, and panicles ripen with grain weight was easily influenced by wind direction and speed which later limits mechanical as well as manual harvesting due to lodging. As per observed data it seemed to be very crucial time for lodging, morning wind followed north-west direction and turned to north-east direction in first phase of November, 2nd phase flow of wind associated with north-west and south-west direction in evening and morning, respectively, gets bend from both side of crop due to flow of wind in different direction impacted on stem. Further, wind direction turned inside being north-east in morning and south-west in evening had average wind speed of 6.63 km/h. December 1st phase was important period because some of the varieties remained in fields and wind speed influenced more to tall and thin stem rice varieties which was seen in all traditional varieties except Barhi, Basabhog, Batroo, Benisar, Bhaya, Bhaya gonad and Bohita.

Correlation and eigen values: The varieties showed higher differences in their own characteristic features for management of lodging (Table 1). Mean variation in characteristics features of rice varieties ranged from 20.77–35.04 with Kohikari and Karahani. The highest mean value was recorded with the Karahani being similar to Barhi, Deshilal Dhan, Butani, Dhan safed, Dubraj, Kakeri, Kanji1, Kantabuta and Koliya. Based on standard deviation, Barhi, Deshi Lal Dhan, Dhagaddeshi, Dubraj, Karahani and Kari found be higher deviation among own characteristic features of rice varieties. Standard error exhibited nominal variation among varieties which was mostly 15–30%, but hardly found more than 20% in Barhi and Dubraj.

Covariance matrix exhibited that 1st and 2nd intermodal distance was negatively correlated to leaves and leaf length, whereas 1st intermodal length had negative correlation with leaf width. Although, 2nd intermodal distance of stem showed negative correlation with 1st intermodal length, whereas stem thickness correlated negatively with leaf length and 2nd intermodal distance. Rest of covariance matrix were positive regardless the varied level of value (Table 2).

Parameters showed huge variations on eigen value and percentage of variance as shown in Table 3. Plant height

Table 1 Mean, standard deviation and standard error of rice varieties

SI. no.	Variety	Mean		Standard deviation		Standard error	
		2021	2022	2021	2022	2021	2022
V1	Barhi	28.39	32.54	52.99	57.54	19.41	21.75
V2	Badi Barik	26.65	30.54	39.52	42.92	14.48	16.22
V3	Basabhog	25.27	22.05	30.96	33.62	11.34	12.71
V4	Batroo	26.6	23.21	36.37	39.52	13.33	14.93
V5	Benisar (Halka)	28.33	24.65	44.25	48.61	16.42	18.37
V6	Bewara	21.96	19.16	33.83	36.74	13.89	12.39
V7	Bhaya	32.62	28.44	43.98	47.76	18.05	16.11
V8	Bhayagoda	24.79	21.62	38.07	41.35	15.63	13.95
V9	Bohita	27.39	23.89	37.53	40.76	15.41	13.75
V10	Budali	24.26	21.16	32.56	35.42	13.39	11.95
V11	Buta Bari	24.04	27.56	36.87	40.04	15.13	13.51
V12	Butani	27.42	31.43	42.26	45.91	17.35	15.48
V13	Chanda	23.71	27.17	34.95	37.96	14.35	12.81
V14	Char Khotali	23.24	26.64	39.76	43.18	16.32	14.57
V15	Chhota Kabari	23.22	20.26	30.27	32.87	11.09	12.42
V16	Chhota Kabari 1	29.26	25.52	37.02	39.12	13.21	14.79
V17	Chiggi	22.14	19.32	26.32	28.58	9.64	10.81
V18	Chingi	27.49	23.98	38.45	41.76	14.09	15.78
V19	Desi	29.87	26.06	42.81	45.41	15.31	17.16
V20	Deshi Lal	29.71	25.92	40.49	43.97	14.83	16.62
V21	Deshi Lal Dhan	30.51	34.97	50.23	54.55	18.43	20.62

Contd.

Table 1 (*Concluded*)

SI. no.	Variety	Mean		Standard deviation		Standard error	
		2021	2022	2021	2022	2021	2022
V22	Deshi Safed	23.72	27.19	34.95	37.95	12.81	14.35
V23	Dagad Deshi 1	24.91	28.56	38.27	41.56	15.71	14.02
V24	Dagad Deshi 2	24.22	27.76	38.86	42.01	15.88	14.17
V25	Dagad Deshi 3	26.01	29.81	49.38	53.63	20.27	18.09
V26	Deshi no. 17	23.48	26.91	39.69	43.12	16.29	14.54
V27	Dhan Safed	26.66	30.56	37.57	41.88	15.83	14.13
V28	Dokra Menchha	24.79	28.41	37.95	41.21	15.58	13.91
V29	Dubraj	28.02	32.11	48.63	52.82	19.96	17.82
V30	DudhBursi	26.66	23.26	34.58	37.56	14.2	12.67
V31	Kakai 1	26.89	23.46	34.52	37.49	14.17	12.65
V32	Kakai 2	25.74	22.46	40.44	43.92	16.61	14.82
V33	Kakeri 1	31.21	27.23	43.64	47.43	15.99	17.92
V34	Kakeri	34.83	30.38	43.85	47.62	16.06	18.08
V35	Kalasu	30.87	26.93	42.97	46.67	15.74	17.64
V36	Kanji 1	31.83	27.77	45.63	49.56	16.72	18.73
V37	Kanji	29.86	26.05	41.01	44.54	15.02	16.83
V38	Kanji (Kali) 1	29.40	25.65	43.05	39.64	14.52	16.27
V39	Kanji (Kanji)	28.09	24.51	50.97	46.93	17.19	19.26
V40	KantaButa	32.11	28.04	47.26	43.51	15.94	17.86
V41	Kantadhan	30.84	26.91	42.06	38.73	14.19	15.91
V42	Karanga	25.75	29.51	38.04	35.02	14.38	12.83
V43	Kardhana 1	25.25	28.94	46.22	42.54	17.46	15.59
V44	Kardhana	18.43	21.13	31.33	28.84	11.84	10.57
V45	Karahani	30.57	35.04	53.65	49.44	20.28	18.11
V46	Kari	29.83	26.02	51.01	46.97	19.28	17.21
V47	Kari khuji	30.22	26.35	42.53	46.19	17.46	15.58
V48	Kohi Kari	20.77	18.12	23.36	25.37	9.59	8.56
V49	Koliha	24.93	28.57	38.22	41.51	15.69	14.02
V50	Koliya	27.07	31.03	44.23	48.04	18.16	16.21

Table 2 Mean covariance matrix of plant characters of rice varieties of 2 years' experimentation

Plant height (cm)	No. of leaf	Leaf length (cm)	Leaf width (cm)	1st nodal distance (cm)	2nd nodal distance (cm)	Stem thickness (cm)
No. of leaf	0.153	0.505	0.181	-0.1729	-0.032	0.037
Leaf length (cm)		0.243	0.026	-0.3454	-0.476	-0.090
Leaf width (cm)			-0.031	-0.346	0.0006	0.009
First nodal distance (cm)				0.02311	-0.145	0.045
Second nodal distance (cm)					0.579	-0.023
Stem thickness (cm)						0.092

Table 3 Mean eigen values of plant characters of rice varieties of 2 years' experimentation

Parameter	Plant height (cm)	No. of leaf	Leaf length (cm)	Leaf width (cm)	1st nodal distance (cm)	2nd nodal distance (cm)	Stem thickness (cm)
Eigen value	2.18	1.37	1.08	0.98	0.65	0.47	0.26
Per cent of variance	31.21	19.59	15.42	14.05	9.27	6.69	3.78
Cumulative (%)	31.21	50.79	66.22	80.27	89.54	96.22	100.00

had highest eigen value than 1st nodal distance, being lowest stem thickness and number and length of leaf were almost similar in eigen value which showed greater affinity compared to leaf width and 1st nodal distance. These leaf width and 1st nodal distances were comparatively lower with number of leaf and leaf length. Among the varieties, the lowest variation was seen with stem thickness.

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