https://doi.org/10.29321/MAJ.10.A03960

Review Article:

Studies on lodging in cereals with special reference to Rice - a review

by
K. R. RAMASWAMY [1]

1. **Lodging:** *Definition and assessment:* Fellows (1948) described lodging as "the condition in which the culms in large areas bend at or near the surface of the ground, the bending varying in degree from slight deviation from the perpendicular to a nearly prostrate condition, though commonly the term is applied only if the deviation is more than slight". On a general term, "lodging is a mass falling" and according to Grafius and Brown (1954) it is the response to 'torque', caused by external forces.

Koehler (1925) recorded plants leaning 30° and beyond from the vertical as lodged. Based on the angle of bending Hayes and McClelland (1928) and Ramiah and Dharmalingam (1934) classified the plants into 4 groups. Day and Dickson (1958) followed only two degrees of lodging, 45° and 90° from the perpendicular. Irrespective of angle of bending, Hall (1934) recognised two types of lodging viz., (i) broken stalk type and (ii) leaning stalk type. Likewise, Rodger (1957) recognised three types of lodging, viz., (i) fracture of the stem at some distance above ground level; (ii) bending over at the basal internode and (iii) the partial up-rooting of the plant. In wheat Fellows (1948) distinguished three other types of lodging namely, 'Buckling', 'Bending' and 'Crinkle joint' while Glynne and Moore (1946) have observed a condition variously known as 'straggling' 'scrailing' or 'dog legging'. Donald (1935) described a condition called 'necking' in oats. It is also usual to differentiate lodging as shoot lodging and root lodging.

2. **Loss due to lodging:** The after effects of lodging are (i) imperfect development of the earhead (Beaven, 1947), (ii) poor quality of the seeds, (iii) exposure of the plants to easy invasion by soil organisms and (iv) difficulty during harvesting (Fellows, 1948). Lodging has decreased the test weight of Spring oats (Pendleton, 1954). In wheat Laudi and Pauli (1956) noted reduction in kernel size but the protein content of the grains was found to increase. Colour of grain, percent of plump grain and many other quality factors like malt diastatic power and alpha - amylase activity were found to be affected in barley (Day and Dickson, 1957, 1958). In rice, percentage of chaff, discoloured and illfilled grains were found to be the highest in plants which lodged at the blooming stage (Teiji Shimoyama, 1953).

Forms part of the Dissertation submitted by the author in 1960 in part fulfilment for the award of the M. Sc. (Ag.) degree by the University of Madras. (Received on 28-8-1962).

1. Cytogeneticist, Agricultural College & Research Institute, Coimbatore-3.

Shah and Jalil (1936) and Middleton (1903) recorded 15 to 60% loss in a number of wheat varieties. Nordon and Frey (1959) obtained a loss of 23 to 36 per cent in oats. Subbiah Pillai and Parasuram (1956) found that the rice crop which lodged at the time of flowering and before suffered 50 to 60 per cent loss in the grain yield whereas it was only up to 18 per cent at later stages. The average annual estimated loss in cereals has been computed to be upto 50% in Scotland and Holland and about 30% in Russia (Rodger, 1957)

3. **Causes of Lodging**: The causes of lodging may either be due to the hereditary characters or unsuitable environmental conditions or the interaction of both.

(a) *Heredity:* In most of the cereals resistance to lodging has been found to be a heritable character (Ramiah, 1934; Biffen and Engledow, 1926; Boyce, 1948, etc.)

(b) *Environmental factors:* (i) *Nutrition:* Hypernutrition is one of the chief causes of lodging. Etiolation results in a lesser development of the mechanical tissue and tends to increase the tendency to lodge (Ramanujam, 1950).

(ii) *Root system:* Percival (1921), Cafferey and Carrol (1933) and Derick and Hamilton (1942), Fellows (1948) and Rodger (1957) found that varieties differing in strength of straw also differed in their root systems.

(iii) *Cultural practices:* Srinivasa Iyengar (1933) and Ramiah and Dharmalingam (1934) observed that in rice, lodging in most cases was brought about by too rapid a growth in the initial stages. Welton and Morris (1930) have shown that thick seeding has predisposed the plants to lodge easily. Caffrey and Carrol (1938) reported that clipping and deep seeding prevented lodging to some extent. Malkani and Vaidya (1958) found that deep seeding had little effect in preventing lodging in wheat. Glynne (1949) opined that spraying with H_2SO_4 (to prevent eye spot), spring dressing of ammonium sulphate and adjusting the seed rate will prevent lodging in wheat. Trizno (1954) found bacterization increased resistance to lodging in peat-log soils. In fern soils, Godnev (1956) attributed lodging to deficiency of potassium, phosphorus and calcium, and to a high water table and excess of nitrogen.

(iv) *Climatic factors:* Warm, cloudy and rainy season tends to bring about a low Carbohydrate/Nitrogen ratio in the plant and thus causes lodging (Ramanujam, 1950). Early sown spring crops are less prone to lodge than sown later (Rodger, 1957). Marcarelli (Copeland, 1924) explained that cold weather at the tillering phase of the crop checked root development which later resulted in lodging. Mendiola (Ramiah, 1953) believed that velocity of the wind and depth of water during growing period influenced lodging. Gassner (Ramanujam, 1950) in oats reported that seeds germinated at 25°C and transplanted, lodged very badly. Higher (Welton and Morris, 1931) and sub-freezing (Rodger, 1957) temperatures were also found to be indirect causes of lodging. Welton and Morris (1931) and Rodger (1957) have expressed that light is having a negative effect on lodging. Above all, weather elements like storm, rain and hail are the main agents which bring to light the actual lodging of the plants.

(v) *Pathological factors:* (a) *Fungi:* As reported by Fellows (1948), Glynne and Moore (1946) and Mckineey (1925), the *Cercosporella herpotrichoides* Fron. causes the disease 'eyespot of wheat' wherein the culms are so weakened near the base so as to cause lodging of the crop. The 'Take all' *(Ophiobolus graminis* Sacc., Sacc.) disease, and *Septoria nodorum* Berk. and *Erysiphe graminis* DC had also been recorded as causing lodging in wheat (Ramanujam, 1950).

(b) *Insect:* A number of insects have been noted to cause lodging in wheat and among them, (i) the Hessian fly, *Phytophaga destructor* (Say) as reported by Fellows (1948) and Walster (1920); (ii) the joint worms *(Harmolita* sp.*)*, (iii) Bill bugs (*Calandra* and *Sphenophomis* sp.) and (iv) the Saw fly (*Cephus* sp.) as reported by Atkins (1938) are some of the important ones.

4. **Correlation Studies:** Attempts have been made from early days, to fix some constant and discernible factors morphological, anatomical or chemical which are highly correlated with lodging, so that they may be useful to the breeder for selection of non-lodging types.

(i) *Morphological characters:* Albrecht (Ethirajan, 1956) accepted the strength of straw as an index of lodging resistance. In wheat, Howard and Howard (1912) concluded that a short stiff straw combined with a strong root system considerably increased the standing power of plants. Biffen and Engledow (1926) opined that an optimum soil moisture level and a strong root system were the deciding factors in lodging resistance. Worzella (1932) found greater top growth and comparatively poor development of the roots in lodging varieties. Zade (Brady, 1934) stressed the importance of root system, length of straw and leaf area in determining lodging resistance. Tau (1945) obtained a significant positive correlation between lodging and height of plants. Welton (1928) associated awnedness of the plants with tendency to lodge. Draghetti (Ethirajan, 1956) found that the flexibility of the first internode had a direct correlation with degree of lodging. Garber and Olson (1912); Clark and Wilson (1933) and Goulden and Neatby (1929) failed to establish any association between lodging and certain plant characters. In barley Zavada (Brady, 1934) recorded lodging to be associated with length and elasticity of the culm as well as the number and arrangement of leaves. In oats, Brady (1934) associated lodging of plants with length and diameter of the internodes. Smith (1934) and Hamilton (1941) could not establish any correlation between the different morphological characters and lodging resistance.

In corn, Koehler (1925) and Hamner (1937) have stressed that a strong root anchorage will prevent lodging of the plants. Wilson (1930) recorded shorter lower internodes and greater development of brace roots in resistant types. But Hall (1934) failed to establish little or no correlation between lodging and tillering, length of under ground stem and number and size of brace roots. Hayes (1941) published correlation coefficients between lodging and yield by studying a number of selfed lines.

Atkins (1938, 1948) after his exhaustive work with wheat varieties concluded that the low co-efficient of correlation got by previous workers and by himself was due to the environment conditioned nature of the character and to lack of sufficient data. Likewise Moulder (1954) concluded that lodging mostly depended on resistance to culm bending, relative development of the root system and its anchorage; weight of the above ground plant parts and the force acting on lower internodes and roots.

(ii) *Anatomical characters:* Moldenhawer (Hamilton, 1941) found more number of vascular bundles in non-lodging wheat and barley types. Moulder (1954) showed that excessive nitrogen produced thinner culm walls, with a reduction in the cell wall thickness in oats. Thakur and Shands (1956) showed that larger vascular bundles surrounded by thick layers of mechanical tissue were often found in resistant types. Bhide and Bhale Rao (1925) in rice and Brady (1934) in oats found that thick bands of sclerenchyma at the periphery, numerous vascular bundles and small sub-epidermal girders were absent in lodging types. Magee (Hall, 1934) noted larger diameter of the stalk and widely lignified rind in lodging resistant corn stalks. Holbert and Koehler (1924) associated larger size of trachids, thickened cell walls in the pith and general absence of air spaces in roots with resistant strains of corn. Sowa (1961) recorded (i) a greater distance between the epidermis and the vascular bundle in the parenchymatous layer; (ii) a higher proportion of sclerenchymatous tissue in the culm wall; (iii) a greater number of bundles; (iv) a thicker culm wall; and (v) a smaller distance between the vascular bundles in the sclerenchymatous layer in non-lodging barley types. Michalik - Skucinsska *et al.* (1960) established a negative correlation in wheat between lodging resistance and size frequency of the parenchymatous areas visible in transverse section in the sclerenchymatous ring of the stem. Ozaist (1960) found that the tetraploid rye had stiffer straw than the diploid and he attributed the same to (i) a smaller proportion of parenchyma in the sclerenchymatous ring of the second internode below the ear; (ii) greater thickness of the stem tissues and superior cell size and (iii) a greater amount of sclerenchyma in the lower internodes. Albrecht (1908), Garber and Olson (1919) and Hamilton (1941, 1951) failed to record any significant correlation between lodging resistance and various anatomical characters studied by them.

(iii) *Chemical characters:* Humphrey Davey (1798) speculated that silica had the important function of giving strength to hallow-stemmed grasses. Liebig, (Phillips, 1936) stressed the importance of potassium silicate in the stem of grasses. Later Sweecicki (Phillips, 1936); Hadden (1916); Doughlas (1916) and Davidson and Leclere (1923) have all presented data in support of Davey's silica theory. Davidson and Phillips (1930) and Phillips (1936) found that nitrogenous manures decreased the uptake of minerals particularly, silica. However, the important role of silica from the standpoint of straw strength was questioned by Sachs (1882), Jodin (1883), Knop (1862) and Mayer (1901), with the argument that plants made normal growth up to maturity even in nutrient solutions free from silicic acid (Ethirajan, 1956). Welton and Morris (1931) found that the maximum accumulation of silica in the plant was usually in the leaves and not in the stem and hence were of the view that the silica theory was not strictly corroborated.

Purvis (1919) brought forward the important role played by potassium by showing that the culms loose their capacity for standing rigid when starved of potassium. Tubbs (1930) and Phillips (1936), confirming Purvis hypothesis, found that potassium was essential for straw strength. Phillips (1936) showed that sodium is not capable of replacing potassium to any extent in giving strength to the straw. Krants and Chandler (1952) found that application of potash had its maximum effect in deficient soils in preventing lodging.

Harcourt (1905) observed that lodging of oats was least on lime treated soils and highest on those treated with nitrogen. Gainey and Sewell (1930) found an increase of 37·5 per cent in the breaking strength of stem in plants manured with high nitrogen. Tubbs (1930) observed that nitrogen deficiency increased the strength of lower internodes, while potassium increased the strength of middle ones. Moulder (1954) concluded that higher doses of nitrogen induced elongation of lower internodes with a less sturdy root system while shorter and thinner internodes were noted in potash deficient plants. Thakur and Shands (1954), Singh (1954), Singh and Ananda Rao (1954), Salt (1955), Larsen (1955) and Raheja and Misra (1958) found that application of nitrogen in increased doses progressively increased lodging of the crop. Malkani and Vaidya (1956) found that nitrogen application increased shoot/root ratio, length of lowest internode and reduced the rate of development of mechanical tissue, breaking strength of straw, weight per unit length and number of cells in sclerenchyma as well as certain root characteristics. According to them, application of potash with nitrogen did not decrease lodging significantly. Raheja and Misra (1954) found that potassium and calcium neither increased nor prevented lodging, while phosphate slightly induced lodging in certain wheat varieties.

Sachs (1882), Percival (1921), Welton (1928) and Welton and Morris (1931) found that the lodged plants had a low lignin content. However, opinion is divided on the value of lignin, since conflicting results were obtained by Davidson and Leclerc (1923), Davidson and Phillips (1930) and Phillips (1936). They believed that excess of lignin tended to make the plants brittle, leading to easy lodging. These conflicting results might be due to unsatisfactory methods employed for the determination of lignin (Raheja and Misra, 1958). Mehta (1926) found that whenever the cellulose content of the tissues in cereal went low, there was a marked tendency towards lodging. Low dry matter has been held to be one of the causes of lodging, as also a low amount of polysaccharides (Welton, 1931). Prutzkova (Ramanujam, 1950) found a higher amount of ether soluble substances, hemicelluloses and cellulose and less of sugar in lodging resistant varieties, but with no differences in the ash or nitrogen content between the two types. Ashton (1938) found that strong strawed varieties were richer in ash constituent and poorer in crude fibre than weak strawed types. Paken'o (1958) concluded that the rapid stem formation and early lignification of the lower internodes at the beginning of milk stage were indicators of lodging resistance.

(iv) *Studies in Rice:* Ramiah and Dharmalingam (1934) concluded that (i) depth of planting, length of internodes either below or above ground level, weight of the floral portion, height of the plant, number and size of the vascular bundles, size of the air space, thickness of sclerenchyma around and below vascular bundles have no relationship with the lodging nature of the varieties; (ii) most of the erect types showed thicker sclerenchyma and broader parenchyma; (iii) the erect types more frequently, have strong and persistent leaf sheaths, and (iv) the diameter of the internodes in erect lots were greater than in the lodging types, particularly near the ground level. Alam (1935) found that lodging varieties have thinner and non-persistent leaf sheaths. Srinivasan and Ramiah (1933) showed too rapid a growth in the initial stages resulted in long internodes predisposing the crop to lodge. Srinivasan (1930) indicated that 'topping' may give more stability to the plants. Hedayetullah and Chakravarthy (1941) found among the several species of *Oryza*, a maximum development of the mechanical tissue in *Oryza coarctata* Roxb.

5. **Evaluation of Lodging resistance by mechanical means:** Much attention has been paid to the actual estimation of strength of the cereal stems by subjecting the culms to various mechanical tests.

(i) *Breaking strength of straw:* Albrecht (1908) had employed an instrument, wherein the straw is to be laid horizontally and force applied on the middle of the straw and the weight required to just break the same was taken as the breaking strength of straw. Helmick (1915) described an apparatus with which he established the varietal differences in wheat. Willis (1923) used an improved apparatus, and he suggested the second internode from the top for determining the breaking strength of straw. Clark and Wilson (1933) and Smith (1939) by using a dynamometer, determined the force required in the middle to break 10 internodes supported together on a stand. The instrument devised by Salmon (1931) was extensively used by Salmon and Laude (1932), Davis and Stanton (1932) and Atkins (1937, 1938 and 1948) Bartel (1937) pointed out the major differences among wheat culms harvested between pre-heading and maturity periods and concluded that many workers have erred in taking measurements of the mature plants only.

(ii) *Culm density:* Culm density has been defined by Atkins (1938) as "the weight of the section of the culm taken at the base of the plant". Straw harvested at ground level and dried for some time was cut in equal lengths and made into bundles of hundred and weighed. He showed that "culm density" was having almost a perfect correlation with the breaking strength.

(iii) *Pulling resistance:* Pulling resistance is the resistance offered to a force applied to the stalk to pull the plant out of the soil. Herbert and Koechler (1924) have designed a machine to record the pulling resistance of plants. Hall

(1934) modified this instrument and determined the resistance offered by pulling the plants to an angle of 45° from the vertical. Studtman (Ramanujam, 1950) used two types of instruments, one to measure the resistance of a culm and the other for the whole plant at a time and obtained reliable results by measuring the whole plants than the individual tillers. Harrington and Waywell (1950) used a portable wind machine for exposing field plots to strong controlled wind and recorded the degree of recovery of the treated plants. Grafius (1958) found that the moment of force about the base of the culm caused by wind in the heads was found to be an important factor in determining lodging resistance.

(iv) *Bending tests:* Winderleich (1950) explained the significance of resistance of young plants to bending, in relation to their resistance to lodging. Wettestein (1952) described a 'Straw dyanamometer', with which he measured the elasticity of culms of plants. Grafius and Brown (1954) computed a lodging resistance factor CL_r by suspending action to the base of the panicle. Grafius (1955) obtained a positive association between the stem break in senescence and the CL_r factor. Norden and Frey (1959) adopted the CL_r method and obtained tangible results. Jellum (1962) also obtained significantly positive correlations between the CL_r value and stem diameter at the normal and high seed rates. Murphy *et al.* (1958) found the snap and the CL_r methods, to be reasonably rapid. Sharp (1957) devised an instrument with which the angle of bending of the stalk and the load required to break or bend the same could be measured.

6. **Breeding for lodging resistance:** (i) *Genetics of lodging resistance:* In wheat, Howard and Howard (1912) observed distinct segregation for straw strength and root types. Nilson Ehle (1923) reported transgressive segregation for stiffness of straw (Ramanujam, 1950). Goulden and Elder (1926) and Goulden and Neatby (1929) observed a possible linkage between weak straw and resistance to stem rust. Biffen and Engledow (1926) found a great diversjty of straw types among the progenies of a cross. Clark *et al.* (1928) have reported genetic association between awnedness and tendency to lodge. Waldron (1920) reported the F_1s to be intermediate between the parents in straw strength. Kilduft (1930) found straw strength to be influenced by multiple factors with trangressive segregation in the direction of the weaker parent. Torrie (1936) concluded that polymeric factors might possibly control the lodging character. Bose *et al.* (1937) postulated two independent factors as controlling the degree of development and distribution of the sclerenchyma while width of sclerenchyma and diameter of vascular bundles were being controlled by multiple factors. Boyce (1948) found the lodging character to be partially dominant possibly controlled by one to many genes.

In oats, Berg (1926) reported transgressive segregation for straw stiffness. Carroll (1936) found root types to be a heritable character.

In corn, Hays and Maclelland (1928) found the F_1 plants generally having the lodging index near the mean of the two parents, with resistance possibly controlled by multiple factors. Hall (1934) and Koehler (1928) studied the characters related to lodging and concluded that many of them are heritable, being controlled by many genes. Jenkins has recorded a rootless line while Jenkins and Gerhard have reported plants with a 'lazy' gene that lodged badly (Hall 1934).

Ramiah and Dharmalingam (1934) postulated a simple gene difference designated as *Ld* between erectness and lodging.

Coleman and Strokes (1958) found that the erect stalk was inherited as a simple dominant (EE) to the weak stalk (ee) in *Sorghum.*

(ii) *Breeding for lodging resistance:* Breeding for non-lodging types is being carried on in most of the cereals from the early period of this century and it will be rather voluminous to trace the entire literature on this subject. In 1912 Howard and Howard indicated the possibilities of selecting non-lodging types from segregating progenies. In 1923, Nilson Ehle emphasised the importance of breeding non-lodging types. Pal (1934, 1944) by adopting a judicious hybridization programme isolated four non-lodging types i. e., P_{165}, NP_{225}, NP_{120} and NP_{114}. Harlan and Hayes (1919) reported that stiffness of straw and high yields could be combined by hybridization and selection. "Reward" wheat of Canada and As_{619} oats of Scotland have also been noted for their stiffness of straw. Gustafason (1947) in Sweden by subjecting barley seeds to X-rays obtained stiff strawed economic mutants called 'Erectoides' which are popular in that country. Similarly, Shebeski (1954) obtained a stiff strawed mutant Sask. 5203, which has recorded higher yields and quality produce.

Bhide (1960), successfully transferred in the third back-cross the stiff strawed character to a tall susceptible variety.

Rice breeders working in different parts of our country have evolved stiff strawed varieties such as SC. 1177-6 in Assam; Mtu. 3, 7, 10, 14, 19 and Akp. 9 in Andhra Pradesh; Br. 8 in Bihar; Dhadas 79, Garvel 1-8 in Bombay; Hr. 2 in Hyderabad; Co. 14, Co. 15, Co. 17, Ptb. 9, Ptb. 15 and Asd. 6 in Madras and S. 1092 in Mysore (Ghose *et al.* 1956). A large collection of World rice genetic stocks is being tested for lodging genes at the Central Rice Research Institute, Cuttack. The *Bulus* of Indonesia and *Varylava* varieties of Madagascar, some of the Siamese and Burmese types have been found to be stiff strawed and have been used for hybridization. The *japonica* × *indica* hybridization project undertaken by the Food and Agricultural Organisation of the UNESCO also aims for breeding of high fertility non-lodging paddy strains.

Acknowledgement: The author wishes to record his deep sense of gratitude to Dr. B. W. X. Ponnaiya, Professor of Genetics and Plant Breeding, Agricultural College and Research Institute, Coimbatore-3 and Dr. V. Santhanam, Head of the Regional Research Centre, PIRRCOM, Coimbatore for their kind help in the preparation of this paper.

REFERENCES

Alam, M. 1935 *Annu. Rep. Rice. Res. Sta.*, Sabour; 1934-35.

Albrecht 1908 Untersuchungen Uber. Kor. relation in Auf blau des weizen halms Laudw. *Fahr.*, **37** : 617.

Ashton, W. M. 1938 *Welsh J. Agri.*, **13** : 144.

Atkins, I. M. 1937 *J. Agric. Res.*, **56** : 99.

—— 1938 *J. Amer. Soc. Agron.*, **30** : 309.

—— 1948 *J. Agric. Res.*, **76** : 53.

Bartel, A. T. 1937 *J. Amer. Soc. Agron.*, **29** : 153.

Beaven, E. S. 1947 *Barley - fifty years of observations on experiments.* Duckworth, London.

Bhide, R. K. and Bhale Rao, G. G. 1925 *Mem. Dept. Agric. India, Bot. Ser.*, **14** : 199.

Bhide, V. S. 1960 *Ind. Agric.*, **4** : 144.

Biffen, R. H. and Engledow, F. L. 1926 *Minis. Agric. Res. Monogr.*, **4** : 10.

Bose, R. D., Aziz, M. A. and Bhatnagar, M. P. 1937 *Indian J. Agric. Sci.*, **29** : 209.

Boyce, S. W. 1948 *N. S. J. Sci. Tech.*, **30** : 78.

Brady, J. 1934 *J. agric. Sci.*, **24** : 207.

Cafferey, M. and Carrol, P. T. 1938 *J. Eire. Dept. Agric.*, **35** : 25.

Clark, J. A. Florell and Hooker 1928 *U. S Dept. Agric. Tech. Bull.*, **39** : 1.

Clark, E. R. and Wilson, H. K. 1933 *J. Amer. Soc. Agron.*, **25** : 561.

Coleman, O. H and Strokes, I. E. 1958 *Agron. J.*, **50** : 120.

Copeland, E. B. 1924 *Rice* ; Macmillan & Co., London.

Davey Sir Humphrey 1798 *Elements of Agricultural Chemistry.* pp. **53** :

Davidson, J. and LeClerc, J. A. 1923 *J. agric. Res.*, **23** : 56.

Davidson, J. and Phillips, M. 1930 *Science* (NS)., **72** : 401.

Davis, L. L. and Stanton, T. R. 1932 *J. Amer. Soc. Agron.*, **24** : 290.

Day, A. D. and Dickson, A. D. 1956 *Agron. J.*, **48** : 452.

—— 1957 *Ibid.*, **49** : 536.

—— 1958 *Ibid.*, **50** : 338.

Derick, R. A. and Hamildon, D. G. 1942 *Sci. Agric.*. **22** : 503.

Donald, G. 1935 *Scot. J. Agric.*, **18** : 34.

Doughlas, H. F. K. 1916 *Expt. Sta Rec.*, **37** : 443.

Ethirajan, A. S. 1956 *Certain aspects of lodging in sugarcane varieties.* Thesis submitted to the University of Madras for the award of M. Sc. degree.

Fellows, H. 1948 *U. S. Dept. Agric. Circ.*, 767.

Gainey, P. L. and Sewell, M. C. 1930 *J. Amer. Soc. Agron* , **22** : 629.

Garber, R. J. and Olson, P. J. 1919 *Ibid.*, **11** : 173.

Ghose, R. L. M., Ghatge, M. B., and Subramanyam, V. 1956 *Rice in India.* Indian Council of Agricultural Research, New Delhi.

Glynne, M. D. and Moore, F. J. 1946 *J. Minis. Agric.*, **53** : 305.

Glynne, M. D. 1949 *Agriculture*, **46** : 510.

Godnev, T. N. 1956 *Soils and Fert.*, **19** : 1763.

Goulden, C. H. and Elders, A. T. 1926 *Sci. Agric.*, **3** : 357

Goulden, C. H. and Neatby, N. W. 1929 *Ibid.*, **9** : 576.

Grafius, J. E. and Brown, H. N. 1954 *Agron. J.*, **46** : 414.

Grafius, J. E., Brown, H. M. and Kiesling, R. L. 1955 *Ibid.*, **47** : 413.

Grafius, J. E. 1958 *Ibid.*, **50** : 263.

Gustafsson, A. 1947 *Hereditas.*, **33** : 1.

Hadeen, W. P. 1916 *Colo. Agric. Exp. Sta. Bull.*, **219** : 231.

Hall, D. M. 1934 *Minno. Agric. Exp. Sta. Tech. Bull.*, **103** : 31.

Hamilton, D. G. 1941 *Sci. Agric.*, **21** : 646.

—— 1951 *Ibid.*, **31** : 286.

Hamner, C. L. 1937 *Quart. Bull. Mich. Coll.*, 30.

Harcourt, R. 1905 *Ann. Rept. Ontario. Agric. Coll. Exp. Sta. Rec.*, **17** : 856.

Harlan, H. V. and Hayes, H. K. 1919 *Minno. Agric. Exp. Sta. Bull.*, 182.

Harrington, J. B. and Waywell, C. G. 1950 *Sci. Agric.*, **30** : 51.

Hayes, H. K. and MaClelland, C. K. 1928 *J. Amer. Soc. Agron.*, **20** : 1314.

Hayes, H. K. 1941 *Ibid.*, **33** : 164.

Hedayatullah, S. and Chakravarthy, A. K. 1941 *J. Dept. Sci. Bengal N. S.*, **1** : 21.

Helmick, B. C. 1915 *J. Amer. Soc. Agron.*, **7** : 118.

Holbert, J. R. and Koehler, B. 1924 *J. Agric. Res.*, **27** : 71.

Howard, A. and Howard, G. L. C. 1912 *Mem. Dept. Agric. India. Bot. Ser.*, **5** : 1.

Jellum, M. D. 1962 *Pl. Br. Abs.*, *XXXII* : **2** : 1846.

Kilduft, T. 1930 *Canad. J. Res.*, **8** : 141.

Koehler, B. 1925 *Ia. Agric. Expt. Sta. Bull.*, **266**.

Krantz, B. A. and Chandler, W. W. 1952 *Agron. J.*, **43** : 547.

Laude, H. H. and Pauli, A. L. 1956 *Ibid.*, **48** : 452.

Larson, C. 1955 *Soils and Fert.*, **19** : 3.

Mulkani, T. J. and Vaidya, S. M. 1956 *Indian J. Genet.*, **16** : 121.

Mulkani, T. J. and Shrivastava, P. R. 1958 *Indian J. Agric. Sci.*, **28** : 115.

McKineey, H. H. 1925 *U. S. Dept. Agric. Bull.*, 1347.

Metha, M. M. 1925 *Bio - Chem. J.*, **19**: 958.

Michalik - Skucinska, B. and Miszke, W. 1960 *Pl. Br. Abs.*, *XXX*. **3**: 2531.

Middleton, W. 1903 Fifth annual report of field experiments, Cambridge.

Moore, H. I. 1949 *J. Minis. Agric.*, **56**: 314

Mulder. E. G. 1954 *Plant and Soil*, **5**: 246.

Murphy, H. C., Peter, F. and Frey, K. J. 1958 *Agron. J.*, **51**: 609.

Norden, A. J. and Frey, K. J. 1959 *Ibid.*, **51**: 335.

Ozaist, B. 1960 *Pl. Br. Abs.*, *XXX*. **3**: 2595.

Pal, B. P. 1934 *Agric. Liv. Stk. India*, **4**: 405.

—— 1944 *Emp. J. Expt. Agri.*, **12**: 61.

Peken'O, P. H. 1958 *Field Crop Abst.*, **12** : **4**: 1683.

Pendleton, J. W. 1954 *Agron. J.*, **4**: 265.

Percival, John 1921 *The Wheat Plant.* A monograph. Duck Worth & Co., London.

Phillips, M. 1936 *J. agric. Res.*, **43**: 619.

Purvis, G. N. 1919 *J. agric. Sci.*, **9**: 338.

Raheja, P. C. and Misra, K. P. 1954 *Indian J. Agric. Sci.*, **25**: 87.

Raheja, P. C. & K. P. Misra 1958 *Ibid.*, **28**: 499.

Ramiah, K. and Dharmalingam, S. 1934 *Ibid.*, **4**: 880.

Ramiah, K. 1953 *Rice Breeding and Genetics.* The Indian Council of Agricultural Research, Scientific Monograph No. **19.**

Ramanujam, S. 1950 *Indian J. Genet.*, **10**: 78.

Rodger, J. B. A. 1957 *Indian J. Agron.*, **2**: 107.

Salmon, S. C. 1931 *J. agric. Res.*, **43**: 73.

Salmon, S. C. and Laude, H. H. 1932 *Kansas Expt. St. Rep. Tech. Bull.* **30**: 1932.

Salt, G. A. 1955 *J. agric. Sci.*, **46**: 407.

Sharp, M. A. 1957 *Indian Fmg.*, **7**: 6.

Shaw, K. S. S. I. and Jalill 1935 *N. W.F. P. Dept. Agric. Bull. No.* **13.**

Shebeski, L. H. and Lawrence, T. 1954 *Canad. J. Agric. Sci.*, **34**: 1.

Singh, R. 1954 *Curr. Sci.*, **23**: 199.

Singh, R. and Anand Rao, N. K. 1954 *Agra. Univ. J. Res. & Sci.*, **3**: 449.

Sisler, W. E. and Olson, J. J. 1951 *Sci. Agric.*, **31**: 177.

Smith, D. C. 1934 *Minn. Agric. Expt. Sta. Tech. Bull.*, **103.**

Sowa, W. 1961 *Pl. Br. Abs., XXXI*: **4**: 4702.

Srinivasan, C. R. 1930 *Madras Agric. Sta. Rep.*, 1929–30.

Srinivasa Ayyangar, C. R. and Ramiah, K. 1933 *Abs.Proc. Ass. Econ. Biol.* Coimbatore, **1**: 40.

Subbiah Pillai, M. and Parasuram, M. A. 1956 *Rice News Teller*, **4**: *2*: 71.

Tau, M. T. 1945 *J. Agric. Ass. China*, 182.

Teiji Schimoyama 1953 *Sci. rep. Fac. Agri. Okayama Univ.*, **3**: 31.

Thakur, C. Shands, H. L. and Evans, R. I. 1956 *Agron. J.*, **48**: 123.

Torrie, J. H. 1936 *Canad. Jour. Res., Sec.* **14**: 368.

Trizno, S. I. 1954 *Soils and Fert.*, **19**: 949.

Tubbs, F. R. 1930 *Ann. Bot. Lond.*, **44**: 147.

Waldron, L. R. 1926 *N. Dak. Agric. Exp. Sta. Bull.*, **200.**

Walster, H. L. 1920 *Bot. Gaz.*, **69**: 97.

Welton, F. A. 1928 *Ibid.*, **85**: 121.

Welton, F. A. and Morris, V. H. 1930 *J. Amer. Soc. Agron.*, **22**: 897.

—— 1931 *Ohio. Agrl. Expt. Sta. Wooster. Ohio., Bull.*, **47.**

Wettestein, V. D. 1952 *Hereditas Lund.*, **38**: 345.

Willis, M. R. 1925 *J. Amer. Soc. Agron.*, **17**: 334.

Wilson, H. K. 1930 *Ibid.*, **22**: 453.

Worzella 1932 *Ibid.*, **24**: 626.

Wunderleich 1959 *Plant. Breed. Abstr.*, **20**: 693 : 2212.