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Studies in Cereals-Structure in Relation to Drought Resistance *

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Introduction: The principal rainfed cereals of South India are the Millets which during their growth pass through frequent failure of rainfall. During droughty seasons they are found to withstand drought in varying degrees. It is obvious that these cultivated species have developed variations in adaptations which appear to have servival value in coping with a varying water supply. The earlier workers probing into the cause of drought resistance studied the structure of the leaves alone instead of considering the other component parts of the plant. In this work on the rainfed cereals, detailed studies on the structure of the whole plant have been made and presented.

Previous work: Under conditions of poor soil moisture and high atmospheric temperature the plants are subjected to a complexity of reactions both from within the plant body and outside. Maximov (1925) believed that the ability of the plant to resist drought is due to a multiplicity of morphological and physiological characteristics. It was generally assumed as expressed by Maximov (1929) that the drought resistant plants must have developed structural adaptations to enable them to transpire very slowly. As such, importance was laid on the study of the leaves mainly and to some extent on the stem, the organs concerned with transpiration and water loss. Krishnaswamy *et al* (1942) in their study on the anatomical features of the leaves of the millets, have concluded that the leaf anatomy did not give any clue to identify drought resistant varieties. While the study of the leaf may be expected to show certain characteristics, it, being the component part of the organism, cannot explain the behaviour of the whole body. Viewed from this angle, the present approach has been made in trying to find out the relation of the structure of the various parts of the plant to drought resistance. Daniel Sundararaj (1950) has studied the structure of five grasses and has shown definite correlations of structural adaptations in respect of root, stem and leaf to drought resistance.

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Materials and Methods: The strains studied in each of the millets are presented in Table I. *Zea mays* was also examined so as to get a comparative knowledge of the structural pattern of *Sorghum durra* as related to the former so far as drought resistance is concerned.

TABLE I.

Details of Strains Studied.

S. No.	Species	Strain No.
A.	**Millets:**	
1.	*Sorghum durra.* Stapf. var. Coimbatoricum Snow	Co. 1
2.	*Pennisetum typhoides.* Stapf. and Hubbard	Co. 4
3.	*Setaria italica* Beauv.	Co. 3
4.	*Panicum miliaceum* L.	Co. 1
5.	*Paspalum scrobiculatum* Linn.	Co. 1
6.	*Eleusine coracana* Gaertn.	Co. 7
7.	*Echinocloa frumentacea* Link.	Co. 1
8.	*Panicum miliare* Lam.	Co. 1
B.	**Corn:**	
	Zea Mays Linn.	Local strain

The plants were grown in a field of red loamy soil under replicated conditions during the main and summer seasons of 1959. The details of the plant part studied in relation to drought resistance are presented below :—

Structure of the Plant parts studied		Nature of experimentation made at flowering stage.
Root —	(a)	Morphology of the roots.
	(b)	Transverse section of the nature root.
Stem —	(a)	Transverse section of the 4th internode from the top, taken at the middle of the internode.
Leaf —	(a)	Transverse section at the middle of the 4th leaf sheath and
	(b)	blade.
	(c)	Lower epidermal peal of the 4th leaf at the middle.

The camera lucida drawing of the root was made on a graph sheet and the area of the stele was calculated as a percentage of the total cross-sectional area of the root. The transverse sections were taken by hand sectioning and were stained with Safrannin 1% aquous solution. Camera lucida drawings of the sections were made at 45 degrees at table level. Microphotographs were taken with a Zeiss microscope.

Pot Culture Experiments: A pot culture experiment with nine species of cereals replicated four times was conducted under uniform conditions of soil and water. The size of the pot was 48 cms. in diameter and 65 cms. in depth. Two plants were grown in each pot. After 35 days, the watering was stopped and the observations on temporary and permanent wilting were recorded. The wilting experiment was initially laid out in the field with four replications. A regular grade in the degree of resistance to drought was observed, the maximum in *S. Durra* and the minimum in *P. miliare* with the rest intermediate in the order of *Z. mays, P. typhoides, S. italica, P. miliaceum, P. screbiculatum, E. coracana* and *E. frumentacea* the least but better than *P. miliare.* With these indications observed, pot culture studies were made subsequently to confirm them.

Microscopic measurements were made with the micrometer scale and the rest with the centimeter scale and slide clipers wherever necessary. All the measurements and counts presented in each table are mean of readings recorded for ten plants in each species.

Experimental Observation:

1. *Wilting experiment:* The data recorded on the nature of wilting under pot-culture experiment is presented in table II.

TABLE II.

Particulars of wilting noted in Pot Culture Studies.

Species	Date of showing	Date on which watering was stopped	No. of days after which temporary wilting commenced	Day on which permanent wilting was noted
S. durra	15—12—59	20—1—60	12	16th day
Zea mays	do.	do.	11	15 do.
P. typhoides	do.	do.	9	12 do.
S. italica	do.	do.	8	11 do.
P. miliaceum	do.	do.	8	11 do.
P. scrobiculatum	do.	do.	6	8 do.
E. coracana	do.	do.	5	7 do.
E. frumentacea	do.	do.	4	6 do.
P. miliare	do.	do.	3	5 do.

A perusal of the data presented shows that the water absorbed by the plant has been sufficient for or in excess of the loss by transpiration up-to three and twelve days in the case of *P. miliare* and *S. durra* respectively. In *S. durra* there is more efficiency in controlling the water loss for four days. These observations on wilting confirmed the field studies of drought resistance tried under natural conditions.

2. *Root studies: (a) Root morphology:* Table III presents the morphological characters of the roots studied and the number of roots produced per plant and per tiller.

TABLE III.

Morphology of the roots.

Species	No. of roots per plant		No. of roots		Average length of long roots in cms.	Stiff portion in the thick roots from the base in cms.	Branching habit
	Thick over 1 mm. in diameter	Thin less than 1 mm. in diameter	Total per plant	Average per tiller			
S. durra	36	21	57	57	43.0	10·1	Thick roots unbranched
Zea mays	21	19	40	40	36·6	6·5	,,
P. typhoides	25	11	36	36	34·2	8·1	unbranched
S. italica	20	55	75	10·7	28·0	6·0	Thin roots with few branches
P. miliaceum	15	8	23	11·5	29·0	8·1	Profusely branched thin roots
P. scrobiculatum	...	34	34	11·5	28·3	...	,,
E. coracana	53	49	102	14·6	30·5	1·0	Profusely branched thick roots
E. frumentacea	68	30	98	24·5	26·6	3·5	unbranched
P. miliare	6	13	19	9·5	27·1	0·9	,,

S. durra which is the most drought resistant of the nine species, has more number of roots per tiller, more stiffness in the roots, and more number of thick roots. Further its roots are also longer compared to the rest. *E. frumentacea*, although has more number of roots per tiller, is soft without any stiffness and without any branches. Similarly *E. coracana* has the poorest stiffness in roots. In the case of *P. scrobiculatum*, although it is devoid of thick roots, all the thin roots unlike in the rest of the species, were found to be stiff to a length of 12·4 cms. The most susceptible *P. miliare* has few roots per tiller with poor stiffness.

(*b*) *Structure of the root:* A consolidated picture of the important anatomical features studied in the root is presented in table IV.

TABLE IV.

Comparative Anatomical Features of the root.

Species	Piliferous layer	Exodermal layer	Cortical cells	(*) Area of stele	Endo-dermis	No. of Xylem vessals
S. durra	lignified epidermis	4–5 celled very thick	Uncollapsed	40·6%	Well developed	Big–26 Small–3
Z. mays	thin walled	2-4 celled	do.	37·8%	do.	Big–22 Small–4
P. typhoides	do.	3–4 celled	do.	19·1%	do.	Big–13 Small–2
S. italica	do.	4–5 celled very thick	do.	25·9%	do.	Big–10 Small–1
P. miliaceum	do.	2–3 celled thick	do.	26·6%	do.	Big–8
P. scrobiculatum	do.	1–2 celled	Collapsed	19·7%	Very well lignified	Big–13
E. coracana	do.	do.	do.	21·2%	Well developed	Big–10
E. frumentacea	do.	do.	do.	12·8%	do.	Big–8
P. miliare	do.	2–3 celled	do.	11·7%	do.	Big–8

(*) Area of stele as a percentage of the total cross-sectional area of root.

The stele is the biggest in *S. durra* and the smallest in *P. miliare.* The non-collapsability of the cortical cells with age in *S. durra, Z. mays, P. typhoides, S. italica* and *P. miliaceum* is a protective feature over the stelar region. Although the stele volume is less in *P. typhoides* compared to *P. miliaceum, S. italica, P. scrobiculatum* and *E. coracana*, the well-developed *exodermis* in the cortical region and well lignified sclerenchymatous cells encircling the vascular tissues inside the stele favour better resistance to drought in respect of *P. typhoides.* In *P. scrobiculatum* the endodermis and the sclerenchymatous cells enclosing the vascular tissues are better lignified.

3. *Structure of the stem:* A comparative picture of the important features studied in the stem structure in relation to drought resistance is presented in Table V.

TABLE V.

Comparative anatomical features of the stem.

Species	Vascular bundles along with peripheral hypo-dermal band		Vascular bundles in ground tissue	Total No. of Vascular bundles	Thickness of hypodermal band band	Pith
	Small	Big				
S. durra	156	40	481	677	...	No distinct pith
Zea mays	52	68	492	612	...	do.
P. typhoides	64	72	120	256	...	do.
S. italica	29	14	41	84	0·1 mm	Small pith
P. miliaceum	16	12	25	53	0·08 ,,	hollow pith
P. scrobicultum	29	30	27	86	0·05 ,,	do.
E. coracana	18	20	76	114	0·12 ,,	Small pith
E. frumentacea	29	26	47	102	0·06 ,,	hollow pith
P. miliare	40	15	25	80	0·05 ,,	do.

The most drought resistant *S. durra* and *Z. mays* have a large number of vascular bundles, the number becoming less in the less drought resistant species. In *S. durra* and *Z. mays* the whole ground tissue is scattered with vascular bundles without a distinct pith region. In *S. durra*, towards the periphery, the cells are very small in size and the vascular bundles of the smaller size cluster together forming a protective layer to the tissues inside. Studying from the periphery, the hypodermal thickening is very prominent in the case of *S. italica* and *P. miliaceum* with highly lignified cell walls. But in *E. coracane* though the width of the hypodermal band is more, the lignification of the individual cell walls are too poor to offer a better protection compared to *S. italica* and *P. miliaceum*.

4. *Structure of the leaf sheath :* A comparative picture of the important features studied in the structure of the leaf sheath is presented in Table VI.

TABLE VI.

Comparative anotomical features of the leaf sheath.

Species	No. of vascular bundles in the leaf sheath				Patches of sclerenchyma	Whether the leaf sheath grips the culm
	Big	Medium	Small	Total		
S. durra	28	22	52	102	Prominent	Very tightly gripped
Z. mays	26	16	46	88	do.	do.
P. typhoides	24	16	28	68	not prominent	do.
S. italica	...	26	34	60	small patches	do.
P. miliaceum	...	20	22	42	do.	do.
P. scrobiculatum	...	13	10	23	Very poor	Loosely held
E. coracana	...	15	23	38	do.	do.
E. frumentacea	...	14	18	32	do.	do.
P. miliare	...	7	27	34	Very very poor	do.

The outer surfaces of the leaf sheaths in *S. durra* and *Z. mays* have conspicuous patches of sclerenchyma which give protection to the vascular bundles, thus reducing the adverse effect of heat on the sheath as well as the enclosed stem. As in the case of the stem, the number of the vascular bundles are maximum in *S. durra* and *Z. mays* and minimum in *P. miliare* and *E. frumentacea.*

5. (a) *Structure of the leaf :* A consolidated picture of the anatomical features studied in the leaf is presented in Table VII.

TABLE VII.

Comparative anatomical features of the leaf.

Species	No. of vascular bundles			Presence of scleren-chyma	Presence of motor cells	Motor cell in μ length/width	Protective tissues in the midrib
	Big	Small	Total				
S. durra	56	268	324	Plenty	Upper-surface	54/54	Well developed
Z. mays	49	284	333	do.	do.	78/48	do.
P. typhoides	28	106	134	few	both surfaces	62/62	developed
S. italica	14	72	86	Plenty	do.	44/40	Well developed
P. miliaceum	6	20	26	do.	do.	76/80	do.
P. scrobiculatum	8	21	29	Poor	Upper surface	80/56	Very poor
E. coracana	11	14	25	do.	do.	92/82	Poor
E. frumentacea	22	69	91	do.	do.	104/80	Very poor
P. miliare	11	17	28	do.	do.	60/52	do.

S. durra, Z. mays, S. italica and *P. miliare* have prominent patches of sclerenchyma protecting the vascular bundles both in the leaf blade and in the midrib. Further, the central portion of the midrib in *P. scrobiculatum, E. coracana, E. frumentacea* and *P. miliare* are occupied by big cells of thin walled parenchyma and in the case of *P. scrobicvlatum* the cells get torn off easily and a big vacuole is formed.

(b) Structure of the lower epidermis of the leaf : The important features studied in the lower epidermis of the leaf are presented in Table VIII.

TABLE VIII.

Comparative structure of the lower epidermis.

Species	Thickness of broad-layer of silicated long cells in mms.	*Stomata* No. per unit area	Epi-dermal long cells length/width in μ	Epi-dermal short cells lengh/width in μ	Unicellular hairs in a micro-scopic field	Spines-cent or rounded modifica-tions on the epi-dermis
S. durra	0·17	17	106/26	84/30	6	11
Z. mays	0·13	14	134/32	50/44	1	4
P. typhoides	0·10	12	174/40	134/44	2	2
S. italica	0·07	18	160/16	64/18	12	23
P. miliaceum	0·10	12	200/18	100/26	6	15
P. scrobiculatum	0·08	9	154/26	92/20	2	4
E. coracana	0·10	10	100/22	84/20	...	2
E. frumentacea	0·07	9	100/22	72/30	5	2
P. miliare	0·03	10	174/24	74/32	6	...

S. dura has the thickest layer of silicated long cells while *P. miliare* has the thinnest with the other species intermediate in thickness. More number of stomates are found in the drought resistant species. The tendency of the epidermal cells becoming smaller in size towards the more drought resistant species is noted. The walls of the epidermal cells are more wrinkled due to cutinization and greater number of hairs, spinescent and other rounded modifications are noted in the drought resistant cereals.

Discussion: The indications from the wilting experiment on the degree of resistance to drought have been confirmed by the structural adaptations noted in both underground and aerial parts of the plants.

Root studies and drought resistance: Studies on the morphology of the roots show that the cereals having more number of thick roots with stiffness to a greater length, resist drought to a longer period. Further long roots in the drought resistant species show deeper penetration in the soil. These observations are in conformity with those of Weaver and Clements (1938) who have recorded better developed, longer and thick roots in the drought resistant grasses.

As for the structure of the roots, the volume of the stele is one of the major factors determining the resistance to drought. The non-collapsability of the cortical cells noted in *S. durra* and *Z. mays* is a distinct protective feature to the root against the adverse soil moisture and temperature. The well packed cortical cells with the exodermal layer form an efficient covering over the stele keeping it free form dessication. These observations are in conformity with those of Daniel Sundararaj (1950) who has recorded better drought resistance in the grass *P. antidotale* as due to more volume of stele with un-collapsed cortical cells in the root.

Aerial vegetative parts and drought resistance : In the case of the stem structure more number of vascular bundles with well developed tissue systems favour better drought resistance. Next in importance are the well developed hypodermal layer and the compactness of the parenchymatous cells in between the epidermis and the hypodermal layer. It is possible that the larger number of vascular bundles have a large amount of water in their protected vessels and this keeps the tissues of both stem and leaf from wilting for a long period. As in the case of the stem, the vascular bundles in the leaf sheath are also more in the more drought resistant species. The water loss from the exposed surface of the leaf sheath by transpiration is probably reduced by the sclerenchymatous patches seen in the outer surfaces in *S. durra* and *Z. mays* and to some extent in *S. italica* and *P. miliaceum.* As stated by Eames and MacDaniels (1947) the sclerenchyma may also act as a partial screen against intense light, besides preventing water loss and aiding in the support of the plant tissues in the drought resistant species. The presence of an extra covering in the form of leaf sheath gripping the stem adds protection against excessing atmospheric temperature. The anatomical characteristics of the leaves do not give definite relationship to drought resistance. The structural adaptations noted in the aerial vegetative parts of the plant in these cereals are also in line with those of the drought resistant grasses recorded by Daniel Sundararaj (1950). The findings on the lower epidermal structure of the cells are in agreement with the views recorded by Walter (quoted by Parker—1956). The drought resistant *S. durra* has the thickest layer of silicated long cells below the vein on the lower surface of the leaf, more number of stomates per unit area and better cutinization of the cell walls.

Summary: The structural characteristics of the roots, stem and leaf of the eight millets i. e., *S. durra, P. typhoides, S. italica, P. miliaceum, P. scrobiculatum, E. coracana, E. frumentacea, P. miliare* and corn i. e., *Zea mays* have been studied in relation to drought resistance.

S. durra is more efficient in resisting the drought and controlling the water loss while *P. miliare* is the least efficient out of the rest. Adaptations in the structure of the roots, stem and leaf and in the morphological characteristics of the roots, noted in varying degrees in the above species are discussed. *S. durra* has long and thick roots with stiffness to a greater length. The roots have more volume of stele protected by a well developed exodermis and uncollapsed cortical cells. The stem is provided with more number of vascular bundles and well-developed tissue systems. The leaf sheath also has more number of vascular bundles protected by sclerenchymatous patches on the outer surface. In the leaf blade the lower epidermis is well-cutinized. So far as structure is concerned these are the indications of the basic causes of drought resistance in *S. durra*. It is confirmed, therefore, that the structure in every part of the plant contributes either to the over-all or to the vital drought resistance in these cereals.

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LITERATURE CITED

Daniel Sundararaj, D. 1950 Studies in fodder Grasses-structure in relation to drought resistance and regeneration. M. Sc. Thesis (un-published) Mad. Univ.

Eames, A. J. and MacDaniels, L. H. 1947 *An introduction to plant anatomy.* McGraw Hill Book Co., Inc. New York (Second Edition).

Krishnaswamy, N. *et al* 1942 Anatomical studies in the leaves of the millets. J. Ind. Bot. Soc. **21** : 249—262.

Maximov, N. A. 1925 The physiological basis of drought resistance of plants. Eng. Abs.

Maximov, N. A. 1929 *The plant in relation to water.* (Eng. Trans.) By R. H. Yapp. George Allen Unwin Ltd., London.

Parker, Johnson 1956 Drought resistance in woody plants. Bot. Rev. **22** : 241—289.

Weaver, J. E. and Clements, F. E. 1938 *Plant Ecology.* McGraw Hill Book Company, New York.