THE INHERITANCE OF HEIGHT *CUM* DURATION IN SORGHUM*

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In cereals, height and duration are important economic factors. Their mode of inheritance has been the subject of extensive studies. These factors are of special interest in sorghum in view of its great importance from the fodder point of view and especially since it is a cereal of dry tracts.

In maize there are several forms of dwarfishness, all of which proved monogenic recessives to the normal type (Matsuura, 1933). In wheat many instances of height segregations have been recorded, in most of which the dwarf forms were recessive to the normal (Matsuura, 1933). Winge (1924) has recorded the occurrence of dwarf types, some of which segregated into dwarfs and normals in the ratio of 3: 1, while other dwarfs gave a 1 : 1 ratio. " The results were not satisfactorily explained." In barley both dominant and recessive types of dwarfs have been met with and described (Matsuura, 1933). Parnell *et al* (1922), Akemine (1925), and Nagai (1926) have described dwarf rice plants which behaved as recessive to normal. Sugimoto (1923) reported a dominant type of dwarf plant. Ramiah (1933) observed that shortness may be a simple dominant to tallness or *vice versa*. The behaviour of the F_1s and F_2s in complicated cases strictly conforms to a Mendelian interpretation on multiple factor hypothesis.

As regards the time for maturing many instances have been reported on wheat, oats, and rice. In most cases the late maturing quality is dominant and is governed by two or more genes. However, Tschermak (Matsuura, 1933) observed that in wheat earliness was dominant in F_1 and obtained a complex segregation in F_2. Similar results were also reported by Nilsson-Ehle (Matsuura, 1933). Florrel (1924) has recorded an instance of dominance of earliness in heading period in F_1 and an F_2 segregation approximating 3 : 1, indicating one allelomorphic pair of factors, with possibly a number of minor modifying factors. Clark (1924) also has reported a similar experience. Aamodt (1927) obtained an F_2 ratio of 15 : 1 for early and late heading types in a cross between a late heading Marquis-Kanred hybrid with Marquis wheat. In rice,

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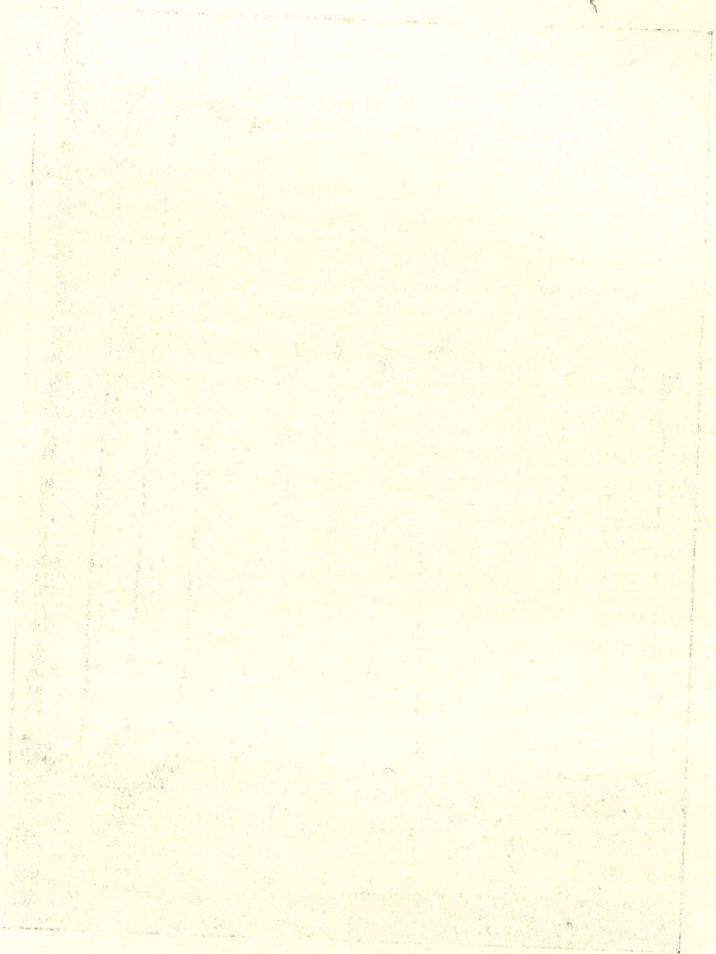
Hector (1922) obtained a clear monogenic ratio in F_2 of a cross between an early and a late veriety, earliness being recessive. Bhide (1926) also reported a similar experience. Ramiah (1933) observed that the inheritance of earliness in rice may be quite simple in some cases showing a single factor difference, and rather complicated in others, which could be explained only under the multiple factor hypothesis. As regards earliness and lateness, earliness is generally found to be dominant though a single case has been recorded where earliness was recessive.

Conner and Karper (1927) while pursuing hybrid vigour in sorghum studied inter-varietal and intra-varietal crosses between different height groups in feterita, kafir and milo. "The three inter-varietal crosses made were characterised by marked hybrid vigour both in F_1 and F_2, but the intra-varietal crosses showed no hybrid vigour. Crosses between Extra Dwarf milo and Standard milo gave the F_1 which was intermediate between the parental heights, and the F_2 distribution ranged from one extreme to the other. Extra Dwarf milo crossed with Dwarf milo showed increased height of plant in F_1. The difference between these two varieties was considered to be due to several genes, the increased height in the hybrid being probably an expression of two or more complementary genes for height. Crosses between Extra Dwarf feterita and Standard feterita displayed a monogenic difference between the parents, the tall variety dominating." (Matsuura, 1933). Later Karper (1932) obtained "tall" mutants in kafir as hybrids which gave simple segregations for tall and normal in the F_2, tall being dominant. The increase in height was considered to be entirely due to the elongation of the internodes and not due to increase in the number of nodes. Sieglinger (1932) reports that in crosses between Standard broom-corn and Western Dwarf or Whisk Dwarf, the F_1 was like the Standard parent, and the F_2 gave a simple monogenic segregation for Standard and Dwarf. But in a cross between the two Dwarf types, the F_1 was of the Standard type and the F_2 gave a di-hybrid segregation of 9 Standard to 3 Western Dwarf to 3 Whisk Dwarf to 1 Double Dwarf. Sieglinger (1933) obtained also a monohybrid segregation for normal and dwarf plants in the F_4 generation of a cross between Red kafir and Reed kafir. The dwarf type is considered as resulting from a mutation due to the loss of a single height factor from the normal. Except in height and head length, the normal and dwarf plants were very similar.

In this paper an experience in sorghum in which "short-early" plants proved simple dominants to "tall-late" plants is recorded (Rangaswami Ayyangar 1934 a, b). In the Kurnool area of the Madras Presidency, sorghum is sown in the month of September and harvested early in January. Varieties that are longer in duration than the local variety, *Patcha Jonna* (*Sorghum Durra* var. *mediocris*, Snowden), do



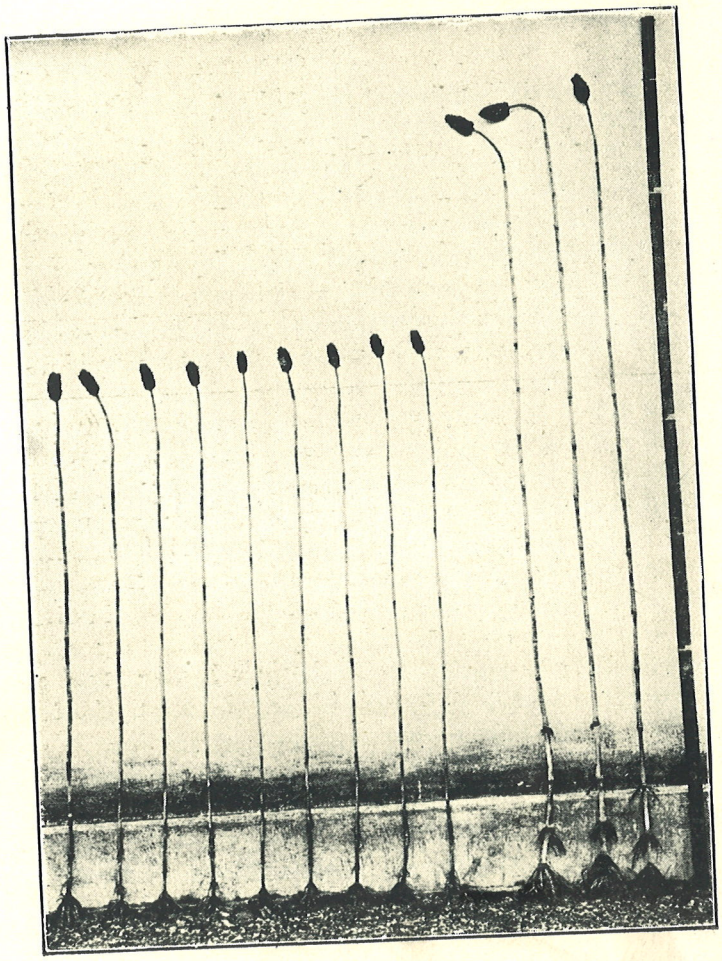


Fig 1. Segregation for Height *cum* Duration in Sorghum.

not fare well in that area. They remain leafy without heading. In a *Patcha jonna* selection (N. 29/15) grown at the Agricultural Research Station, Nandyal (Kurnool Dt.), in 1930, it was observed that out of a population of 130 plants, 95 were normal plants while 35 were rather tall, late, and un-headed at the time of harvest. Five ear-heads of the normal plants were taken over to Coimbatore and sown in August 1931. The subsequent behaviour of the progeny of these at Coimbatore is given in this paper. The August sowings at Coimbatore helped in bringing to maturity the "tall-late" plants that under Nandyal conditions could produce no earheads. This advantage of heading and seed setting was a great help in the pursuit of the character "tall-late."

By duration of a crop is generally meant the time for the crop to mature and be ready for harvest, from the time of its sowing. This duration can be divided into two parts: (1) the period of vegetative growth, and (2) the period of reproductive development. In dealing with duration, different writers adopt different indices, such as the first appearance of the earhead, complete emergence of the earhead, first opening of flowers, or complete maturity of the crop. In sorghum it was found that the duration, for comparative purposes, is best expressed in terms of the number of days from sowing to the flowering of the first spikelet on the earhead. This period can be recorded more accurately than other phases in the development of the plant, such as the appearance of the shoot, emergence of the earhead or ripening of grain. The height of plant was measured from ground level to the top of the earhead at maturity, rounded to the nearest multiple of 5 cm. The components of this height were gone into by recording internodal measurements.

Of the five earheads that were sown at Coimbatore, three proved pure for short-early and the other two segregated for short-early and tall-late. (See illustration and Table I.)

Table I.

Segregations for height and duration—F_3.

Family No.	Parental Character.	Progeny behaviour: Short -- Early 120—220 cm. 69—79 days	Tall — Late 190—300 cm. 85—98 days.	Value of P.
A. S. 631	Short-Early	93	32	
„ 634	„	88	21	
	Total	181	53	>0·30

It being now possible to secure seed from both the groups and to measure the heights of the tall-late group after heading, at harvest time, selections were carried forward from both the groups of these two families with the full complement of data on height and duration.

The F_4 was raised in 1932 and consisted of the following 24 selections (16 short-early and 8 tall-late) taken from both the families, A. S. 631 and A. S. 634. Of the 16 short-early selections sown, 10 segregated and 6 bred pure, while all the 8 tall-late selections sown, bred pure. The behaviour of the 24 selections is presented below :—

Table II.

Behaviour of F_4 Progeny.

a. Pure for Short-Early—(6 families).

A. S. 3140	A. S. 3145
,, 3141	,, 3150
,, 3142	,, 3151

b. Pure for Tall-Late—(8 families).

A. S. 3146	A. S. 3160
,, 3147	,, 3161
,, 3148	,, 3162
,, 3159	,, 3163

c. Segregating for Short-Early and Tall-Late—(10 families).

Family numbers.	Short-Early.	Tall-Late.	Unheaded and Sickly.
A. S. 3143; 3144; 3149; 3152; 3153; 3154; 3155; 3156; 3157; 3158,	840	226	108

It will be seen from the above that the short-early plants were a simple dominant to the tall-late plants, Owing to the newness of the introduction into Coimbatore, the long duration and excessive height, there were proportionately more casualities in the tall group, which accounts for the paucity of talls that flowered and ripened their earheads and whose duration and height could be recorded.

In Table III the height ranges and mean heights of the 6 shorts and 8 talls that bred pure are given. It will be noticed that there is a slight overlap in their height ranges. This overlap never obscures their separation as, "lateness" always helps in the determination of the shorter end of the talls.

Table III.

F_4 Selections from A. S. 631 and A. S. 634.
Range of Height in pure families.

Family numbers.	Height range cm.	Mean cm.
Pure short A. S. 3140; 3141; 3142; 3145; 3150; 3151;	100—240	175·1±0·6
Pure tall A. S. 3146; 3147; 3148; 3159; 3160; 3161; 3162; 3163.	190—375	296 1±0·8

In Table IV the height ranges of the 10 segregating families are recorded. The segregation is clear and the zone of overlap is guarded against with the help of the "late" part of the "tall-late" group.

Table IV.

Range of Height in segregating families in F_4.

Family numbers.	Height range in cm.		Mean cm.	
	Short.	Tall.	Short.	Tall.
A. S. 3143; 3144; 3149; 3152; 3153; 3154; 3155; 3156; 3157; 3158;	120—280	200—335	180·5±0·1	264·5±1·4

In Table V the ranges in the durations of the above 24 selections, both pure and segregating are given. The break in the durations is marked.

Table V.

Selections from A. S. 631 and A. S. 634.

Range in Durations.

Family numbers.	Duration range Days.		Mean duration Days.	
	Early.	Late.	Early.	Late.
Pure early A. S. 3140; 3141; 3142; 3145; 3150; 3151.	57—80	—	66·9±0·1	—
Pure late A. S. 3146; 3147; 3148; 3159; 3160; 3161; 3162; 3163.	—	90—119	—	100·6±0·1
Segregating A. S. 3143; 3144; 3149; 3152; 3153; 3154; 3155; 3156; 3157; 3158.	55—83	86—114	68·0±0·1	97·9±0·3

The early plants flowered from about 57 to 80 days after sowing. The late plants flowered between 90 and 119 days. In height, the short-early ranged from 100-240 cm. and the tall-late, 190-375 cm. The segregation was sharp, the combination of earliness with shortness and lateness with tallness gave, in the pursuit of each of these characters individually, a check on the other character, so that the accuracy of dates of flowering and measurements of height ran no risks in correct recording.

A fifth generation was raised by carrying forward 15 selections from family No. A. S. 3143. Of these 7 were tall-late and all of them

bred true. Of the 8 short-early selections 6 of them segregated again and two of them bred true for short-early. The segregations are given below:—

Table VI.

Segregation for Height *cum* Duration in F_5.

Family numbers.	Short-Early.	Tall-Late.	Unheaded and Sickly.
A. S. 3319; 3321; 3323; 3324; 3325; 3326.	812	266	16
Calculated 3:1	808·5	269·5	

It will be noticed that with greater acclimatization the number of tall-late plants is tending to show an increase there being a comparative absence of sickly unheaded plants. This late type probably mutational in origin, did not have optimum conditions for a healthy existence under Nandyal conditions.

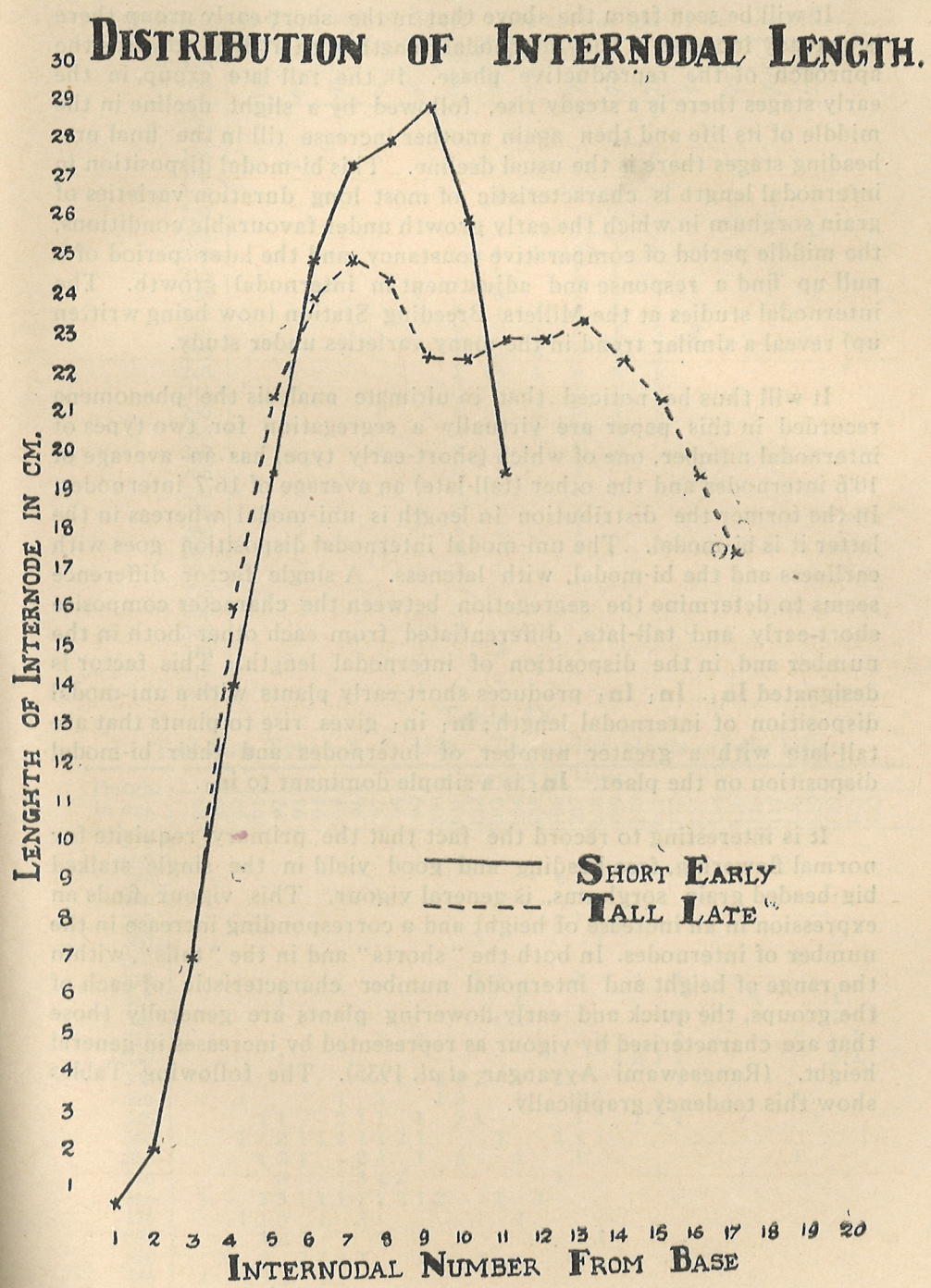
This close association of the character pairs 'short-early' and 'tall-late' led to the examination of the components constituting the more definite and closely pursuable characters, short and tall, with which duration is associated. It was noticed that the average number of internodes in the short-early was 10·6 (average of 3935 plants) and that in the tall-late, it was 16·7 (average of 2020 plants). The internodal number remained the same in both homozygous and heterozygous families.

Table VII.

Number of internodes in the selections from a family segregating for height and duration.

Selection numbers.	Internodal range	
	Short.	Tall.
A, S. 3320; 3322.	7—13	—
A. S 3327; 3328; 3329; 3330; 3331; 3332; 3333.	—	12—22
A. S. 3319; 3321; 3323; 3324; 3325; 3326.	7—14	12—22

It will thus be noticed that tallness is the resultant of a definite increase in the *number* of internodes and not an increase in the length of each of the internodes. The length of individual internodes in each of the two groups was measured, and the trend of their lengths from the base upward is given in the following graph representing the average measurements on ten plants.


DISTRIBUTION OF INTERNODAL LENGTH.
LENGHTH OF INTERNODE IN CM.
30
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SHORT EARLY
TALL LATE
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
INTERNODAL NUMBER FROM BASE

It will be seen from the above that in the short-early group there is a steady increase in the internodal length with a drop towards the approach of the reproductive phase. In the tall-late group, in the early stages there is a steady rise, followed by a slight decline in the middle of its life and then again another increase till in the final pre-heading stages there is the usual decline. This bi-modal disposition in internodal length is characteristic of most long duration varieties of grain sorghum in which the early growth under favourable conditions, the middle period of comparative constancy and the later period of a pull up find a response and adjustment in internodal growth. The internodal studies at the Millets Breeding Station (now being written up) reveal a similar trend in the many varieties under study.

It will thus be noticed that in ultimate analysis the phenomena recorded in this paper are virtually a segregation for two types of internodal number, one of which (short-early type) has an average of 10·6 internodes and the other (tall-late) an average of 16·7 internodes. In the former the distribution in length is uni-modal whereas in the latter it is bi-modal. The uni-modal internodal disposition goes with earliness and the bi-modal, with lateness. A single factor difference seems to determine the segregation between the character composite short-early and tall-late, differentiated from each other both in the number and in the disposition of internodal length. This factor is designated $\mathbf{In_1}$. $\mathbf{In_1}$ $\mathbf{In_1}$ produces short-early plants with a uni-modal disposition of internodal length; $\mathbf{in_1}$ $\mathbf{in_1}$ gives rise to plants that are tall-late with a greater number of internodes and their bi-modal disposition on the plant. $\mathbf{In_1}$ is a simple dominant to $\mathbf{in_1}$.

It is interesting to record the fact that the primary requisite for normal flowering, free heading and good yield in the single stalked big-headed grain sorghums, is general vigour. This vigour finds an expression in an increase of height and a corresponding increase in the number of internodes. In both the "shorts" and in the "talls", within the range of height and internodal number characteristic of each of the groups, the quick and early flowering plants are generally those that are characterised by vigour as represented by increases in general height. (Rangaswami Ayyangar *et al*, 1935). The following Tables show this tendency graphically.

Table VIII.

Short-Early Type—A. S. 3346. The earlier plants are the taller.

Height in cm.	Duration in Days. 63	64	65	66	67	68	69	70	71	72	73	74	75	76	77
175											1				
180															
185											1				
190															
195							2				1				
200										2			1	1	
205										1					1
210							1	1	2	3	1	2			
215							1		1	1				1	
220					1		6		1	4		1			1
225						3	4	1	2	1	1				
230						2	7	1	8	2	3	2			
235						1	2	3	4	3	3				
240						5	13	1	6	4	1				
245						2	6		12	3	3				
250				1		4	8	2	5	4	2				
255						3	7	1	3	1	2				
260				2		5	5		1	1					
265					2	6	3		7						
270		2		1	1	4	2	1	2	2					
275					5	5	1		1						
280		1			6	6	2		1						
285				2		2			1						
290		2			1	3	1								
295															
300		1			2	1									
305					1	2									
310				1	1		2		1						
315					1			1							
320					1		1								

Table IX.

Tall-Late Type—A. S. 3328. The earlier plants are the taller.

Height in cm.	Duration in Days. 88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122
275																																1			
280																																			
285																			1																
290																																			
295																				1		1													
300															1						1														
305																															1				
310								1							1	1				1			1		1										
315					1												1												1				1		
320									1							1	1			3					1								1		1
325										1		2								2	1				2						1			1	
330					1																	1	2	1	1								1	1	
335											1		2	1	2				1						1										
340			1					1		1			1	2			1			1	1			1							1				
345				1	1			2	1	1		1		1	1					1			1	2	1							1			
350			1		2	1	1	1	1	1	2	1				1			1	1	1														
355				1	2	1			2	1		1		3			1			1											1				
360					3				3	4	2								1					1											
365	1			2	3	1	1	1	1	1	2	1	2			1		1																	
370			1	1	3		1		3								1																		
375				3	4	3				1		3									1														
380		1		2		2	2	1	1			1			1																				
385	1		2	3	3		1																												
390				3		1	1		3	1																									
395		1				1			1			1																							
400											1			1																					
405										1																									

It is interesting to note that the earlier plants are those that are taller and more vigorous and that the comparatively weaker ones lag behind in flowering. This fact explains why in this single stalked cereal a fine equipoise of favourable agronomic and environmental conditions from the time of sowing right up to harvest means a bumper crop and a disturbance in this optimum condition means famine. The grain sorghum is so big that if the main stalk gets a set back, the tillers never have a decent chance to pull up and replace the first head.

The impact between the definite tall-late with its pair short-early, giving a sharp segregation as between late and early, has not been without its effect on the composition of the short-early group. As has been experienced in such and similar quantitative characters, selections within the segregating groups, gave progenies which while being within the broad framework of the genetic group short-early, gave evidence of the existence of "shifts" (Engledow, 1923; Philiptschenko, 1927) the probable result of modifier genes. In Table X the behaviour of pure breeding short-early selections at various points in the height range is given.

Table X.

Pure Short-Early – Selections in the height range.

Selection No.	Character of Selection.		Progeny Behaviour			
			Height in cm.		Duration in Days.	
	Height cm.	Duration Days.	Range.	Mean.	Range.	Mean.
A. S. 3335	140	64	150—260	228 1±1·2	57—72	61·7±0·2
,, 3334	150	63	170—250	216·6±1·0	57—68	61·1±0·1
,, 3336	150	66	160—265	224·9±1·1	58—72	62 6±0·1
,, 3337	160	66	170—260	219 9±1·0	58—73	63·6±0·2
,, 3345	160	77	190—290	233·0±1·2	58—74	66·5±0·3
,, 3342	170	74	160—295	241·7±2·0	62—77	68·0±0·3
,, 3343	180	76	150—280	231·3±1·6	59—77	67·5±0·3
,, 3338	190	63	185—270	224·5±1·0	57—77	64·5±0·3
,, 3339	190	63	165—270	225·4±1·0	57—73	63·6±0·2
,, 3340	200	63	170—255	223·5±0 6	57—74	62·9±0·2
,, 3341	200	63	170—280	225·3±0 8	57—73	62·8±0·1
,, 3346	225	75	175—320	249 6±1·0	64—77	69·7±0·1
,, 3347	240	74	175—335	281·0±1·2	64—76	68·6±0·1
,, 3348	240	74	190—345	269·8±1·2	66—77	69 5±0·1
,, 3349	240	76	190—345	263·7±1·0	63—76	68·4±0·1

It will be seen that the progeny of selections taken at the taller end of the short group give a mean height in advance of the general height of the short group, thus enabling slightly taller early selections to be perpetuated. In the single stalked sorghum, as has been pointed already, a fine adjustment of environmental conditions is necessary for an optimum manifestation of height and vigour, and the pursuit of these fine "shifts" can obviously not be made in the tall-late group with its disadvantages in seed setting. The difficulties increase especially since in both the groups the earlier heading ones are more vigorous and give more normal plants whose height and duration

could be recorded without doubt, and whose seed is available for raising further progenies.

The effects of this segregation on the good earheads produced by the two genetic groups tall-late and short-early, were gone into. The average weight of earhead in the tall group was about 15 per cent more than in the short group. An analysis of a few earheads in each group showed, that in the tall group the average number of whorls was 10 as against 9 of the short group. The thickness of peduncle was 0·99 cm. in the tall plants and 0·78 in the short ones. The most noticeable difference was in the number of branches in each whorl. There was an average of 9 branches per whorl in the thicker peduncled tall plant as against the 6 of the comparatively thinner peduncled short plant.

In a number of families whose segregations have been recorded above, the midrib also was found to be segregating into white and dull-green signifying a segregation for juiciness of stalk, (Rangaswami Ayyangar, 1935 and Rangaswami Ayyangar *et al*, 1936). Cross collations between the factors **In**$_1$ and **D** (Pithy stalks) in families segregating for both the factors are given below and prove the independent inheritance of the two characters.

Table XI.

Segregation for Juiciness of Stalk and Height cum Duration.

Family No.	Stalk —Pithy Midrib—White **In$_1$D**	Short-early. Juicy Dull **In$_1$D**	Tall-late. Pithy White **In$_1$D**	Juicy Dull **In$_1$D**
A. S. 634	69	19	15	6
3154	69	15	18	5
Total	138	34	33	11
Calculated 9:3:3:1 ...	121·5	40·5	40·5	13·5

$x2 = 5·137$, $P > 0·1$.

Summary. The inheritance of the character composite "short-early" and "tall-late" in sorghum has been pursued and set down to be due to differences in internodal number and disposition in length. In the short group there are about 10 internodes with a uni-modal distribution in length from the base upwards. In the tall group there are about 17 internodes showing a bi-modal disposition in length.

A factor **In**$_1$ is responsible for the production of fewer internodes with a uni-modal distribution in length, **in**$_1$ gives rise to a greater number of internodes and a bi-modal distribution of their lengths. **In**$_1$ is a simple dominant to **in**$_1$.

The "absorbing influence" of crossing is manifested in "shifts" that give in the short-early group, taller and slightly later plants, but conforming to the general grouping "short-early".

The earheads of the "tall-late" plants were heavier, had more whorls, and more number of branches in each whorl than the earheads of the "short-early" group,

Factor **In_1** was independent of **D** the factor for pithy stalks.

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