GENETIC STUDIES OF THE ANDHRA PRADESH POPULATION

by

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A dissertation presented to the Research & Training School of Indian Statistical Institute, Calcutta for the degree of Doctor of Philosophy.

1964

C O N T E N T S

SUPPORTING WORK

ACKNOWLEDGEMENTS

I am grateful to Professor J. B. S. Haldane, F.R.S. for his inspiring guidance and supervision throughout this work. The assistance of Dr. Helen Spurway in the investigations on butterflies in captivity, and of Dr. P. Meera Khan in the collection of consanguinity data, is gratefully acknowledged.

Professor C. R. Rao made helpful suggestions during the preparation of the thesis.

INTRODUCTION

An understanding of the social structure and mating systems of a population is essential for genetic investigations. The inhabitants of the coastal districts of Andhra Pradesh are of special interest to a population geneticist because of the high rate of inbreeding that is practiced there. This population is specially suited for evaluating the genetic effects of inbreeding on the progeny of consanguineous parents. In most populations of the world the inbreeding levels are much lower than in Andhra Pradesh and where they are slightly higher, as in some Japanese islands, the populations are comprised of only a few hundred people and hence are unsuitable for large scale investigations. The population of coastal Andhra Pradesh is thus best suited to resolve the classic controversy in population genetics regarding the components of genetic variability, i.e. the relative importance of "mutation load" versus "segregation load".

As a by-product of the consanguinity studies information is also obtained on the age of bride at marriage, the age difference between bride and bridegroom, the year of marriage and the rates of consanguinity in different caste groups.

In addition to the study of the mating structure and inbreeding effects, some genetic markers such as colour vision defects, hairy ears and ABO blood groups are also investigated. The frequencies of colour vision defects in the world are reviewed and a new anomaly is reported.

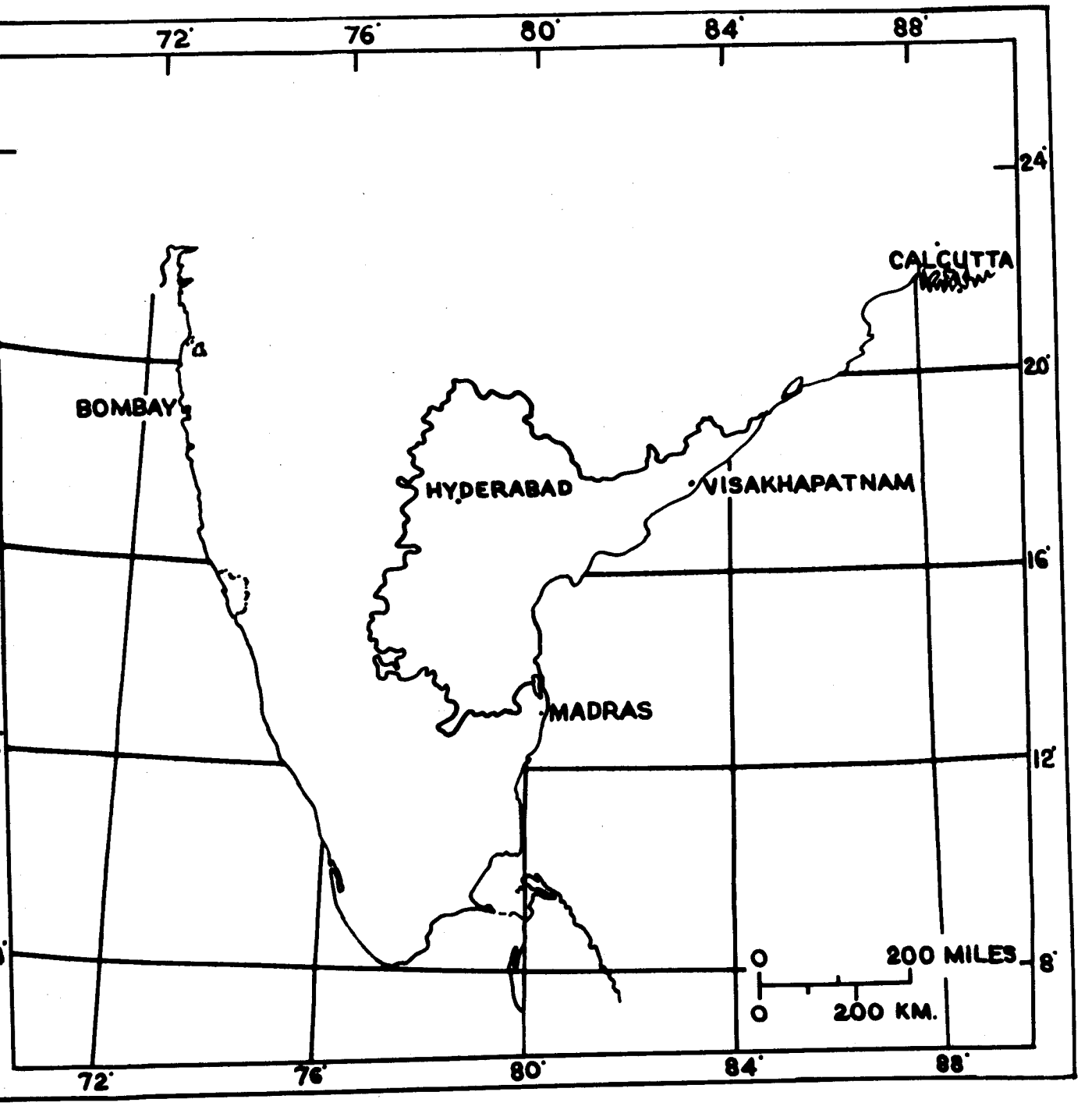
The inheritance of hypertrichosis pinnae auris is investigated in three families and gene frequencies are compared in west Bengal, Orissa, Andhra Pradesh and Ceylon. The age of onset of this trait is also studied.

THE FREQUENCY AND EFFECTS OF CONSANGUINEOUS MARRIAGES

Introduction

The present investigation on the rates of consanguinity among hospital inpatients and their parents was inspired by the work of Julia Bell (1940) who investigated the consanguinity rate in the general hospital population of England and Wales. It has long been known that Telugu-speaking people as well as other south Indians marry their close relatives more frequently than do other Indians (Karve, 1953; Dube, 1955, pages 119 and 160). No records of these marriages were available until the present investigation started in 1959. All information was obtained through direct questioning of the spouses. In European populations such records have been available for several centuries in the parish registers. For example, marriage records are available in uninterrupted sequence in the diocese of Parma in North Italy since the year 1535 A.D. (Moroni, 1960).

Consanguinity gives information on at least two topics. First, it may help in understanding the mating structure of the population; second, it may help in evaluating the genetic effects of inbreeding on the progeny of consanguineous parents. For a recessive gene to manifest its action, it must be inherited from both parents. If the common ancestor of a consanguineous couple carried a recessive gene, this gene can be passed, through the intermediate ancestors, to both members of the consanguineous pair, and thus reach from both parents the offspring of the mating. The probability that this takes place for any particular gene can be calculated for different types of consanguineous matings and is equivalent to the quantity called "coefficient of inbreeding" F. The values of F for different degrees of relationship are given in Table 1. The mean coefficient of inbreeding for different groups of people investigated here are calculated following the method used by Haldane and Moshinsky (1939).



Map of South India showing Andhra Pradesh.

Material and Methods

Investigations were started in 1959 to find out the frequencies of consanguineous marriages in a hospital population and in parents of secondary school children in Andhra Pradesh (Dronamraju, 1963 a and b; Dronamraju and Meera Khan, 1960, 1961, 1963 a and b). Each inpatient of the King George Hospital in Visakhapatnam was questioned for information about his own marriage, his parents' marriage, and his children's marriages, and the answers were recorded on cyclostyled questionnaires. Information regarding other particulars such as age, sex, caste, occupation, and disease or illness of the inpatient were also recorded. Questionnaires about parents' marriages were sent through school children, to their parents. Two schools in Visakhapatnam and one in Waltair were investigated. Admission into the hospital or schools is not restricted to members of any particular religion or caste. This method of direct questioning was necessary to obtain information on consanguinity because marriages are rarely registered.

Twenty-seven out of 746 inpatients interviewed were from Orissa. It was not possible, due to the nature of their illness, to interview a few inpatients. Their parents or spouses, who usually accompanied them, were interviewed in such cases for information regarding the marriage of the inpatient. The inpatients and school children came from all the districts of the state of Andhra Pradesh but most belonged to the coastal districts. Out of 746 inpatients and 564 school children 346 and 272 respectively were females.

Frequencies

Out of 2,177 marriages recorded in the investigations, 666 or 30.6 per cent were consanguineous; 7.2 per cent of the marriages were of women with maternal uncles, 16.6 per cent with first cousins, and 6.7 per cent with remote relatives such as first cousins once removed, second cousins and third cousins

(Table 2). One marriage with a nephew (brother's son) was also recorded. Such marriages are normally forbidden among Hindus, Christians and Muslims though marriages with maternal uncles are favoured among Hindus. In these uncle-niece marriages the bridegroom is usually a younger brother of the bride's mother.

The most frequent kind of consanguineous marriage is the marriage of a girl with her paternal aunt's son. Marriages between children of two brothers or two sisters are socially forbidden among Hindus, though legally permissible. Four kinds of consanguineous marriages in which both spouses are descended from the two marriages of a common male ancestor were also recorded.

Out of 605 inpatients' marriages 238 or 39.3 per cent were consanguineous (Table 3); 14.5 per cent of the marriages were with the paternal aunt's son, 10.7 per cent with maternal uncles, 5.1 per cent with the maternal uncle's son, and 8.8 per cent with remote relatives. There was no significant heterogeneity between the consanguinity rates in different wards. One marriage of each of two special kinds involving the remarriage of the male ancestor was recorded.

Among 746 marriages of inpatients' parents, 187 or 25.1 per cent were consanguineous (Table 4); 5.6 per cent of the marriages were with maternal uncles, 15.0 per cent with first cousins, and 4.3 per cent with remote relatives. Two marriages among Hindus are of special interest; one was with a paternal uncle and the other with a maternal aunt's son. One marriage of each of three special kinds involving the remarriage of a male ancestor was also recorded.

Out of 340 marriages of inpatients' children, 115 or 33.8 per cent were consanguineous; 5.3 per cent were with maternal uncles, 14.4 per cent with first cousins, and 14.1 per cent with remote relatives (Table 5).

Information regarding the consanguinity in 426 marriages of parents of school children was recorded. In these marriages the husband's age and the year of marriage corresponded to those of inpatients. Out of 426 marriages investigated, 126 or 25.9 per cent were consanquineous 6.4 per cent were with maternal uncles, 16.7 per cent with first cousins, and 14.7 per cent with remote relatives (Table 6). One exceptional marriage with a brother's son was also recorded. Such marriages are forbidden to Hindus, Christians and Muslims.

As the information regarding the consanguineous marriages, particularly those between remote relatives, could be incomplete, the percentages of uncle-niece, first cousin and other consanguineous marriages are given separately in Table 7. The frequency of marriages with relatives more distant than first cousins was lowest in inpatients' parents (4.3 per cent), about twice as frequent (8.8 per cent) in inpatients, and highest (14.1 per cent) among the inpatients' children. From this, it may be inferred that the most complete information obtained was about the marriages of inpatients' children. Alternatively it is possible that the larger number of marriages with remote relatives recorded among the inpatients' children are due to the improved transport facilities in recent years. If the former is true, the information about inpatients' marriages is less complete, and about their parents' marriages still less complete.

Coefficients of Inbreeding

The mean coefficients of inbreeding for the marriages in different groups are given in Table 8. The first column gives the coefficients which are calculated taking all the known consanguineous matings into consideration. The coefficients in the second column are calculated considering only those marriages between first cousins or nearer relations to be consanguineous. Thus a more accurate comparison is attempted between the coefficients of inbreeding

in different groups. The difference between the coefficients for the inpatients' marriages and the rest is significant. The values for all the 2,177 marriages are 0.02093 and 0.01947. As was expected, the difference between the first and second coefficients is maximal for the marriages of inpatients' children.

Consanguinity, Illiteracy, Rural Background, and Bridal Age

Out of 605 married inpatients, we have complete information for only 550 regarding their education and place of origin. 5.8 per cent of all marriages were of literate spouses and are rural as well as consanguineous, whereas 21.8 per cent of all marriages were of illiterate spouses and are rural and consanguineous (Table 9). Thus, there is very highly significant positive correlation between consanguinity, illiteracy and rural background. It should be noted that those marriages, in which at least one spouse was illiterate and has rural background, are classified under the category "rural and illiterate".

Data presented in Table 10 show that the percentage of literate spouses significantly increases with the age of the bride at marriage. All the thirteen wives who were married at the age of 12 months or less are illiterate.

Consanguinity, Caste, and Bridal Age

Table 11 gives the classification based on caste and bride's age at marriage. The Hindu community is made up of four classes of unequal size called Varnas whose social statuses are still determined to a large extent in rural Andhra Pradesh by the traditional occupations of the people belonging to them. These are, in the order of their traditional social ranks, Brāhmans, Kshatriyas, Komatis (the local name for the merchant caste called Vaisyas in Sanskirt) and Sudras. The members of various communities like sweepers and tanners (formerly "untouchables") form a "fifth people", known as Panchamas in Sanskirt, subsequently accepted as Hindus by the members of the original four Varnas. With the exception of Kshatriyas large numbers of the people in each

Varna still follow their traditional occupations in rural Andhra Pradesh. The Sudras are in much greater numbers among the inpatients than people of other Varnas. They are classified into the sixteen commonest castes and subcastes. No such attempt is made for Brāhmans, Kshatriyas and Komatis because of their smaller numbers. One Sikh, 9 Muslims and 28 Christian marriages were recorded. It is interesting that no bride under 2 years was recorded in the 3 higher Varnas, nor in the three non-Hindu communities. All the 11 marriages of this category belong to Sudra Varna. The difference between frequencies of consanguinity in Brāhmans and Kshatriyas and other Hindus is highly significant. There are also significant differences between the percentage of consanguinity in certain groups such as Brāhmans and Koppala Velamas, Kshatriyas and Koppala Velamas. The number of marriages recorded per caste or subcaste are, however, not large enough to reach definite conclusions regarding the differences in rates of consanguinity.

Consanguinity, Bridal Age and Year of Marriage

In Table 12 the marriages are grouped according to consanguinity, bridal age and the decade in which the marriage took place. The numbers of consanguineous marriages are shown in brackets. The earliest marriage took place in the year 1893 when the bride's age was 26 months and the bridegroom's 12 years. The percentage of consanguinity fluctuated slightly until 1950 and fell significantly afterwards. Thirteen marriages in which the brides were one year old or younger were recorded. There is a significant decrease in the percentage of consanguinity when the bride's age at marriage exceeded 10 years.

In 147 marriages which took place before 1930 no bride was over 20 years old, whereas out of 159 marriages which took place after 1950 ten were of this kind. The bride was less than 6 years old in 65 marriages which took place before 1951, while in marriages after 1950 no bride was in this age group. Thus

it is clear from these data that the incidence of early marriages and the percentage of consanguinity decreased significantly since 1950.

Bridal Age and the Age Difference between Bride and Bridegroom

The mean age difference between bride and bridegroom is calculated for marriages grouped according to the bride's age at marriage. The mean difference per age group did not change significantly with the increase in bridal age (Table 13). In 43.3 per cent of the marriages the brides were 6 to 10 years younger than their bridegrooms. This value, however, increases to 76.4 per cent if all marriages with an age difference of 1 to 10 years are included. The difference is never more than 20 years for brides who are over 20 years old. With two exceptions the bride was always younger than the bridegroom. In one case the bride was $7\frac{1}{2}$ years old and the bridegroom 5 at the time of marriage, and in another the bride was 25 and the bridegroom 20. Both marriages were among the Sudras. The frequency of marriages with one year or less difference is 1.9 per cent while at the other extreme the marriages with over 25 years difference are 1.3 per cent of the total number of marriages.

Coefficients of Inbreeding among the Parents of Inpatients in Different Disease Groups

The classification of inpatients according to their illness and the percentage of consanguineous marriages among their parents for each group are given in Table 14. The patients with severe mental disorders and defects were not admitted in this hospital. The highest percentage of consanguinity (42.1) was among the parents of patients with pulmonary tuberculosis. The percentage among the parents of patients with malformations was also fairly high (41.7). The coefficients of inbreeding for these marriages are given in Table 15. The coefficient for the parents of patients suffering from pulmonary tuberculosis (0.03289) was significantly higher than in the other groups.

Consanguinity and Sterility

Eighty-one inpatients of the Gynaecological ward are classified on the basis of their fertility or sterility, their consanguineous relationship, if any, with their husbands, and their parental consanguinity (Table 16). Sterility is positively, but not significantly, correlated with the incidence of consanguineous marriages among the inpatients of the Gynaecological ward and their parents. All cases of sterility were involuntary.

DISCUSSION

Frequency

It is clear from the data presented here that marriages between first cousins are preferred in Andhra Pradesh. Among these, cross-cousin marriages, particularly of the type in which the bridegroom is the son of the bride's father's sister are most frequent. This is expected because most of our subjects were Hindus and it is already known that such cross-cousin marriages are preferred among the Hindus (Dube, 1959, page 119). Dube (1959) gives a brief account of consanguineous marriages in the village of Shamirpet, 25 miles from Hyderabad which is now the capital of Andhra Pradesh. He writes "...out of the 340 Hindu marriages analyzed by us, only 18 per cent were cross-cousin marriages, the rest being negotiated marriages into unrelated families. Muslims permit both parallel and cross-cousin marriages, and indeed regard them as highly desirable. Our sample of Muslim marriages is not quite adequate, but out of 40 marriages fully investigated 19 were between cousins." Dube and his co-workers did not record any uncle-niece marriages among Hindus. This may be because of the different way in which the two samples were delimited, i.e. the difference between a small village and the inpatients of a hospital or the parents of school children. Alternatively, because Shamirpet had been within the former Muslim state of Hyderabad for over three centuries it is likely

that the customs of its Hindu inhabitants have come to approximate in some respects those of their Muslim neighbours and thus to differ from those in other Telugu-speaking areas. No parallel-cousin marriages were recorded among Muslims in the present investigation, and this may be due to the small number of Muslim marriages recorded here.

The figures given by Morton (1961, page 265) for the four types of first cousin marriages in India suggest strikingly different frequencies from those presented here. Out of 290 first cousin marriages, 80 were between children of two brothers, 75 between children of two sisters, 87 with a maternal uncle's son, and 48 with a paternal aunt's son. According to these figures, the least frequent type of first cousin marriage was with a paternal aunt's son, whereas this is the most frequent type recorded in the present investigation. Contrary to the frequency of parallel-cousin marriages (155 out of 290 first cousin marriages) quoted by Morton, such marriages between children of two brothers or two sisters are usually forbidden among the Hindus. It was not stated whether all the 290 marriages listed by Morton were of Muslims or Christians.

Sanghvi et al. (1956) reported lower frequencies of consanguineous marriages in twelve endogamous groups in Bombay. Many Marathi-speaking Hindus have preference for a marriage with the maternal uncle's daughter, as do the people of Andhra Pradesh, but Sanghvi et al. did not report any uncle-niece marriages.

The second most frequent type of consanguineous marriage in Andhra Pradesh is with a maternal uncle who is usually younger than the bride's mother. Such marriages are preferred among the Hindus, but are forbidden among the Christians and Muslims.

The mean coefficient of inbreeding in Andhra Pradesh is 0.02093, which is the highest coefficient so far reported for any human population (J.V. Neel, 1963, Personal Communication). In Hiroshima and Kure, Neel et al. (1949),

reported the coefficient of inbreeding to be 0.00372. Lower frequencies were reported in European populations (Bell, 1940; Sutter, 1958; Barrai et al., 1962), and Brazilian populations (Freire-Maia, 1952). The coefficients reported for small island populations and other small isolated communities are, though fairly high, lower than in Andhra Pradesh (Dolinar, 1960; Ishikuni et al., 1960; Spuhler and Kluckhohn, 1953; and Roberts, 1956). For instance, Spuhler and Kluckhohn (1953) reported 0.0066 for Ramah Navaho Indians, and Roberts (1956) reported 0.00153, 0.00096, and 0.00049 for three groups of Dinka tribes. The frequencies reported in Jewish populations were also lower than those found in Andhra Pradesh. Parallel-cousin marriages were reported to be more frequent than cross-cousin marriages in the Jewish communities of Israel (Goldschmidt et al., 1960). However, most of these small isolates contain fewer inhabitants and are not suitable for large scale investigations. The data obtained in the present investigation are representative of a population of 10 million or so from the districts of coastal Andhra Pradesh.

Reasons for the High Incidence of Consanguineous Marriages

The reasons for the high rate of inbreeding in Andhra Pradesh are mainly economic and cultural. There are no geographic barriers and no physically isolated communities. Even the size of "small" subcastes is large enough to permit the choice of an unrelated spouse. In such small isolated populations as the inhabitants of the Japanese island Hosojima (Ishikuni et al., 1960) the people are physically isolated from other populations and this isolation necessitated the choice of related spouses to a large extent. Similarly, small size of the isolate is the reason for the high rates of inbreeding recorded among the Cochin Jews (Cohen and Bloch, 1963, pages 352 and 353).

During the course of the present investigation many inpatients were questioned regarding the possible reasons for marrying a consanguineous spouse.

The frequently stated reasons were (a) to keep the cultivable land in larger pieces for growing food crops, (b) the parental domination in arranging the marriages, as in Japan (Neel et al., 1949), (c) mutual knowledge of families, (d) that relatives are better suited for economic and other reasons to fit into the Hindu joint family system, (e) to fulfill the wishes of grandparents, and (f) until recently the very young age of the bride and bridegroom. According to Schull (1958) two of the more important reasons for consanguineous marriages in Japan are "the custom of arranged marriages (baishaku kekkon) and the family system". Childhood betrothals and economic reasons are two of the causes that are common for both Indian and Japanese populations (Ichiba, 1953). Some of the inpatients whose marriages were non-consanguineous explained, apologetically, that no consanguineous spouse was available to them.

EFFECTS

When the present investigation was started, it was thought possible that many of the deleterious recessive genes were eliminated in the Andhra Pradesh populations, through natural selection, in the course of continuous inbreeding at a high rate for many centuries. The frequency of recessive allelomorphs in a population with a long-established mating system is expected to be near to equilibrium, and the time required to reach this equilibrium in populations like that of Andhra Pradesh, with a high coefficient of inbreeding, is expected to be shorter than in those with a low coefficient.

The obviously biased sample of hospital inpatients was chosen for this study because the patients would more readily accept medical examination and answer the questions regarding their marriages and their relatives' marriages. Also, their hospital records were easily accessible for the study. The parents

of school children were chosen as a "control" to compare the consanguinity rates. The differences between the values of coefficients, or over-all frequencies of consanguinity, between different groups can be due to any of four causes:

(a) true biological effects of inbreeding

(b) correlation of inbreeding with hygienic conditions

(c) differences in knowledge between different groups

(d) "sampling errors", i.e., chance effects due to the small size of the sample.

There may be other possibilities. For example, it is possible that a physician may inspire more confidence in one group of patients than in another and thus obtain more information from them. The remarkable agreement between the values of F for parents of school children and parents of patients agrees against the importance of cause b.

Bell (1940) found that the consanguinity rate in the London neurological hospitals was double that recorded in the general hospitals. She recorded a total consanguinity rate of 0.789% in parents of inpatients of general hospitals and 0.576% in parents of inpatients of children's hospitals in England. Out of these consanguineous rates 0.606% and 0.401% respectively were with first cousins.

The data on parental consanguinity suggest that the coefficient of inbreeding among the parents of inpatients with pulmonary tuberculosis is significantly higher than in the rest of the groups. It is elevated, though not significantly, among the inpatients having children with congenital malformations, and those with abortions. The information about the patients with pulmonary tuberculosis should, however, be treated with reserve until data on more marriages are available to decide the importance of inbreeding in the aetiology of this disease.

In a study of the eighty-one inpatients of the gynaecological ward, 22.2 per cent of the mothers who married consanguineous spouses and 16.6 per cent of the mothers who married non-consanguineous spouses were found to be sterile. The difference is not significant, however. In France, Sutter and Tabah (1952) found that, in Morbihan, 5.57 per cent of the control and 8.40 per cent of the consanguineous marriages, and, in Loir-et-cher, 5.96 per cent of the control and 10.61 per cent of the consanguineous marriages were infertile. The difference, in Loir-et-cher, is significant. In Sweden, Böök (1957) found that one out of 34 first cousin marriages and two among the 32 controls were infertile. In the United States, Slatis et al. (1958) reported that in 17 out of 109 consanguineous marriages and 11 out of 83 controls the female was not known to have been pregnant. In the infertile marriages of 10 years' duration, 15 out of 107 consanguineous and 5 out of 77 control couples were without known pregnancies. This difference is not significant. Dolinar (1960) reported that 13.20 per cent of 53 consanguineous couples and 6.78 per cent of 295 non-consanguineous couples were sterile in the Susak island community in the Northern Adriatic.

The results of the present work suggest that the children of consanguineous marriages are probably more susceptible to pulmonary tuberculosis than those of non-consanguineous unions. It is also suggested that consanguinity may cause more abortions and offspring with congenital malformations, and that the females in such unions may remain sterile more frequently than those of non-consanguineous marriages. These observations need further confirmation and it is very important to obtain more data of this kind from Andhra Pradesh quickly because modern changes such as higher education, industrialization and transport facilities are reducing the frequency of consanguineous marriages. These changes are also breaking up the "genetic isolates" by increasing the

number of marriages between different sub-castes and castes. As shown in this paper, urbanization and literacy are negatively correlated with the consanguinity rate. Furthermore, infectious diseases such as pulmonary tuberculosis are becoming rarer. My work in Andhra Pradesh has so far been useful, in recording, for the first time, the high frequencies (perhaps the highest in the world) of different types of consanguineous marriages which are preferred there and in suggesting more urgent and fruitful lines of research for the future.

SUMMARY

1. Investigations were started, in 1959 in Andhra Pradesh, India, to find out the frequency of different types of consanguineous marriages among the 746 inpatients of King George Hospital in Visakhapatnam, their parents, their children, and the parents of school children of two schools in Visakhapatnam and one school in Waltair.
2. Out of 2,177 marriages investigated, 16.6 per cent were between first cousins, 7.2 per cent with maternal uncles and 6.7 per cent with more distant relatives such as first cousins once removed and second cousins. In all, 30.6 per cent or 666 marriages were consanguineous. The percentage of consanguineous marriages was 39.3 in the inpatients, 25.1 in their parents, 33.8 in their children, and 28.0 in the parents of school children.
3. The mean coefficient of inbreeding for all marriages was 0.02093. It was 0.02777 among the inpatients, 0.01745 in their parents, 0.01862 in their children, and 0.01939 in the parents of school children.
4. Consanguinity was positively correlated with illiteracy and rural background of the spouses.

5. The frequency of consanguineous marriages in the two higher Varnas namely Brāhmans and Kshatriyas is significantly lower than in the rest of the Hindus.

6. The percentage of consanguinity decreases significantly since 1950 when the bride's age in most marriages exceeded 10 years. The mean age difference between bride and bridegroom did not change significantly with the increase in bridal age.

7. The mean coefficient of inbreeding among the parents of inpatients with pulmonary tuberculosis was 0.03289 and was significantly higher than the values calculated for other groups. The value of coefficient among mothers with abortions was 0.03040, and in inpatients having children with congenital malformations 0.03153.

8. Out of eighty-one inpatients of the Gynaecological ward investigated for sterility, 22.2 per cent of the females married to consanguineous spouses and 16.6 per cent of those married to non-consanguineous spouses were sterile. This result is compared with similar data obtained previously in France, Sweden, United States and the Susak island of the Adriatic.

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Relationship	F
Uncle-niece or aunt-nephew	1/8
First cousin	1/16
First cousins once removed	1/32
Second cousins	1/64
Second cousins once removed	1/128
Third cousins	1/256
First cousins twice removed	1/64
Double first cousins	1/8
Double first cousins once removed	1/16
Double second cousins	1/32
Double second cousins once removed	1/64
Double third cousins	1/128
Double first cousins twice removed	1/32

Table 1. Values of the coefficient of inbreeding (F) for different degrees of relationship.

	Number of marriages	Percentage
CONSANGUINEOUS	666	30.6
Aunt-nephew	1	0.05
Uncle-niece	157	7.2
First cousin	362	16.6
Other kinds	146	6.7
NON-CONSANGUINEOUS	1511	69.4

Table 2. Analysis of 2,177 marriages

WARD	Mat. uncle	Mat. uncle's son	Mat. aunt's son	Pat. aunt's son	First cousin once removed	Second cousin	Second cousin once removed	Third cousin	a	c	Con. Total	Non con. Total	Grand Total	Percentage of consanguinity
Maternity	8	1	0	11	2	2	0	0	0	0	24	35	59	40.7
Gynaecology	4	4	0	11	3	5	0	0	0	0	27	54	81	33.3
Medical: Bhavnagar	14	5	0	14	5	0	0	0	0	0	38	52	90	42.2
Medical: Rajendra Prasad	8	5	0	14	3	4	0	0	0	0	34	62	96	35.4
Surgical	17	5	0	20	5	10	3	0	0	0	60	83	143	41.9
Skin & V.D.	4	1	0	1	0	1	0	0	0	1	8	12	20	40.0
Bobbili (Medical)	2	0	0	1	0	0	0	0	0	0	3	10	13	23.1
F.S.B. (Female Medical)	0	6	0	3	2	0	1	0	0	0	12	10	22	54.5
Ophthalmic, E.N.T.	5	3	1	7	0	3	0	1	1	0	21	32	53	39.6
Orthopaedics	3	1	0	6	1	0	0	0	0	0	11	17	28	39.3
Total	65	31	1	88	21	25	4	1	1	1	238	367	605	39.3
Percentage	10.7	5.1	0.2	14.5			8.8				39.3	60.7		

Table 3. Marriages of inpatients; a and c are consanguineous marriages in which the spouses are related through the remarriage of a common male ancestor.

WARD	Mat. uncle	Pat. uncle	Mat. uncle's son	Mat. aunt's son	Pat. aunt's son	First cousin once removed	Second cousin	Second cousin once removed	Third cousin	a	c	d	Con. Total	Non con. Total	Grand Total	Percentage of consanguinity
Maternity	4	0	0	0	8	0	0	0	0	0	0	0	12	47	59	20.3
Gynaecology	7	1	1	0	12	1	0	0	0	0	0	0	22	62	84	26.2
Bhavnagar } Medical	9	0	3	1	13	1	0	0	0	0	0	1	28	86	114	24.6
Rajendra Prasad } Medical	4	0	2	0	12	2	5	0	0	0	0	0	25	80	105	23.8
Surgical	6	0	9	0	19	1	5	0	0	0	0	0	40	107	147	27.2
Skin & V.D.	0	0	3	0	2	0	0	0	0	0	0	0	5	18	23	21.7
Bobbili (Medical)	0	0	0	0	1	0	0	0	0	0	0	0	1	13	14	7.1
F.S.B. (Female Medical)	3	0	2	0	3	0	0	0	1	0	0	0	9	13	22	40.9
Ophthalmic, E.N.T.	2	0	0	0	7	1	2	1	0	0	0	0	13	46	59	22.0
Orthopaedics	1	0	1	0	3	0	0	0	0	1	0	0	6	24	30	20.0
Children's Medical	5	0	1	0	6	1	4	1	0	0	1	0	19	47	66	28.8
Children's Ortho + Surgical	1	0	2	0	1	0	3	0	0	0	0	0	7	16	23	30.4
Total	42	1	24	1	87	7	19	2	1	1	1	1	187	559	746	
Percentage	5.6	0.13	3.2	0.13	11.7			4.3					25.1	74.9		

Table 4. Marriages of inpatients' parents; a, c and d are consanguineous marriages in which the spouses are related through the remarriage of a common male ancestor.

WARD	Mat. uncle	Mat. uncle's son	Pat. aunt's son	First cousin once removed	Second cousin	Second cousin once removed	Third cousin	b	Con. Total	Non Con. Total	Grand Total	Percentage of consanguinity
Maternity	1	0	1	2	0	0	0	0	4	1	5	80.0
Gynaecology	4	0	5	2	2	0	0	0	13	26	39	33.3
Medical: Bhavnagar	1	3	5	3	1	0	1	0	14	39	53	26.4
Medical: Rajendra Prasad	6	2	10	1	4	0	0	0	23	26	49	46.9
Surgical	3	1	8	3	6	0	0	1	22	46	68	32.4
Skin & V.D.	1	0	1	0	0	0	0	0	2	7	9	22.2
Bobbili (Medical)	0	0	0	0	0	0	0	0	0	7	7	0
F.S.B. (Female Medical)	0	0	1	3	3	1	0	0	8	14	22	36.4
Ophthalmic, E.N.T.	0	2	8	1	9	1	0	0	21	42	63	33.3
Orthopaedics	2	1	1	3	1	0	0	0	8	17	25	32.0
Total	18	9	40	18	26	2	1	1	115	225	340	
Percentage	5.3	2.7	11.7		14.1				33.8	66.2		

Table 5. Marriages of inpatients' children; b is a consanguineous marriage in which the spouses are related through the remarriage of a common male ancestor.

	Brother's Son	Maternal Uncle	Maternal Uncle's Son	Paternal Aunt's Son	First Cousin Once Removed	Second Cousin	Non Consanguineous	% of Consanguinity
Boys School	1	16	15	26	3	1	138	31.0
Girls School	0	13	12	15	7	2	172	22.2
Co-Educational	0	2	3	10	0	0	50	23.1
TOTAL	1	31	30	51	10	3	360	25.9
PERCENTAGE	0.2	6.4	6.2	10.5	2.05	0.6	74.1	

Table 6. Marriages of parents of school children

	Uncle	First cousin	Remote relatives	Consanguineous
Inpatients' parents	5.7	15.0	4.3	25.1
Inpatients	10.7	19.8	8.8	39.3
Inpatients' children	5.3	14.4	14.1	33.8
Parents of school children	6.6	16.7	4.7	28.0

Table 7. Percentages of consanguineous marriages.

	Coefficients of inbreeding.	
	1	2
Parents of school children	.01939	.01865
Parents of patients	.01745	.01671
Patients	.02777	.02598
Patients' children	.01862	.01572
TOTAL	.02093	.01947

Table 8. The coefficients in the first column are calculated taking all the known consanguineous marriages into consideration. The coefficients in the second column are calculated considering only those marriages with first cousins or nearer relatives to be consanguineous.

	Urban		Rural	
	Illiterate	Literate	Illiterate	Literate
Consanguineous	31 (5.6)	32 (5.8)	120 (21.8)	44 (8.0)
Non Consanguineous	46 (8.4)	81 (14.7)	134 (24.4)	62 (11.3)

Table 9. Classification of marriages of inpatients based on their education and place of origin.

Figures in brackets refer to percentages.

Bride's age at marriage	Literate		Illiterate		% of consanguinity	% of illiterates
	Con	Non Con	Con	Non Con		
1 or less	0	0	9	4	69.2	100.0
2 - 5	3	8	20	21	44.2	78.8
6 - 10	15	18	68	56	52.8	78.9
11 - 15	38	66	44	87	34.9	55.7
16 - 20	18	59	17	36	26.9	40.8
Over 20	1	8	2	7	16.7	50.0
TOTAL	75	159	160	211	38.8	61.3
Percentage of consanguinity	32.05		43.1			

Table 10. Classification of marriages based on bride's age at marriage and literacy.

Caste or sub-caste	Bride's age at marriage 1 or less	2-5	6-10	11-15	16-20	Over 20	Total	Percentage consanguineous
Hindus								
Brahman	0	4 (1)	12 (6)	16 (3)	8 (1)	0	40 (11)	27.5
Kshatriya	0	1 (0)	3 (1)	12 (4)	8 (0)	1 (0)	25 (5)	20.0
Komati	0	1 (0)	8 (5)	18 (10)	8 (0)	1 (0)	36 (15)	41.7
Koppala Velama	2 (2)	5 (2)	13 (11)	6 (1)	8 (1)	1 (0)	35 (17)	48.6
Gavara	0	2 (1)	10 (2)	3 (1)	1 (0)	0	16 (4)	25.0
Thelega kapu	0	6 (4)	10 (5)	18 (8)	13 (2)	0	47 (19)	40.4
Gazu(la) kapu	1 (1)	4 (2)	9 (4)	5 (2)	2 (0)	1 (0)	22 (9)	40.9
Panta kapu	0	1 (0)	9 (3)	4 (2)	0	0	14 (5)	35.7
Pedda kapu	1 (1)	0	7 (1)	14 (7)	4 (2)	0	26 (11)	42.3
Gampa kapu	1 (1)	4 (3)	7 (3)	3 (1)	2 (1)	0	17 (9)	52.9
Kamma	0	0	4 (2)	5 (1)	6 (1)	0	15 (4)	26.7
Settibalija	0	1 (1)	2 (0)	11 (3)	4 (0)	2 (1)	20 (5)	25.0
Ala golla	1 (1)	2 (1)	9 (6)	5 (1)	2 (1)	2 (0)	21 (10)	47.6
Yadava golla	0	2 (0)	1 (1)	5 (1)	4 (2)	0	12 (4)	33.3
Reddy	0	2 (1)	0	1 (0)	2 (1)	0	5 (2)	40.0
Panta Reddy	0	1 (0)	4 (3)	6 (3)	5 (2)	0	16 (8)	50.0
Sistikaranam	0	1 (0)	1 (1)	6 (2)	2 (1)	0	10 (4)	40.0
Padma Sale	0	0	1 (0)	4 (0)	3 (2)	0	8 (2)	25.0
Agnikula Kshatriya	0	0	4 (2)	1 (0)	0	0	5 (2)	40.0
Other Sudras[1]	5 (3)	11 (4)	39 (24)	71 (27)	36 (13)	5 (2)	167 (73)	43.7
Christians	0	0	1 (1)	9 (5)	13 (4)	5 (0)	28 (10)	35.7
Muslims	0	0	2 (1)	4 (1)	3 (0)	0	9 (2)	22.2
Sikh	0	0	0	1 (0)	0	0	1 (0)	0.0
Total	11 (9)	48 (20)	156 (82)	228 (83)	134 (34)	18 (3)	595 (231)	38.8

Table 11. Classification of marriages based on caste and bride's age at marriage. Figures in brackets refer to consanguineous marriages.

[1] Include one Panchama marriage

Year of marriage	Bride's age at marriage 1 or less	2-5	6-10	11-15	16-20	Over 20	Percentage of Consanguinity
1910 or before	0	6 (1)	14 (8)	1 (1)	1 (0)	0	45.5
1911-1920	3 (2)	7 (3)	11 (6)	11 (5)	7 (2)	0	46.2
1921-1930	4 (2)	13 (6)	31 (15)	25 (7)	13 (3)	0	38.4
1931-1940	4 (3)	16 (9)	38 (15)	41 (18)	20 (5)	3 (1)	41.8
1941-1950	2 (2)	10 (4)	48 (30)	74 (27)	39 (13)	5 (1)	43.3
1951-1960	0	0	15 (9)	83 (24)	51 (12)	10 (1)	28.9
TOTAL	13 (9)	52 (23)	157 (83)	235 (82)	131 (35)	18 (3)	38.8
Percentage of Consanguinity	69.2	44.2	52.9	34.9	26.7	16.7	

Table 12. Classification of marriages based on the year of marriage and bride's age at marriage. Figures in brackets refer to consanguineous marriages.

Bride's age at marriage	Difference of age between bride and bridegroom 1-5	6-10	11-15	16-20	21-25	Over 25	Mean diff.
1-5	23	25	7	2	7	1	8.5
6-10	45	70	22	11	4	4	8.3
11-15	70	107	36	18	3	1	7.8
16-20	53	56	13	3	3	2	6.8
Over 20	9	4	3	3	0	0	7.5
TOTAL	200	262	81	37	17	8	7.8

Table 13. Classification of marriages based on age difference between bride and bridegroom and bride's age.

	Mat. uncle	Mat. uncle's son	Mat. aunt's son	Pat. aunt's son	Other relationships	Total	% Con.
Cancer	5	1	0	10	1	68	25.0
Pulmonary T.B.	6	2	0	6	2	38	42.1
Other kinds of T.B.	1	4	0	6	1	39	30.8
Diseases of C.V.S.	1	2	1	7	3	61	23.0
Diseases of C.N.S.	3	2	0	6	2	62	21.0
Resp. Diseases	6	3	0	8	4	58	36.2
Deficiency disease	2	1	0	4	4	35	31.4
Injuries	1	1	0	5	1	40	20.0
Congenital malformations	2	6	0	1	1	24	41.7

Table 14. Parental consanguinity in different diagnostic groups.

	# of Marriages	F
Parents of school children	486	.01939
Parents of all inpatients	746	.01745
Inpatients	605	.02777
Inpatients' children	340	.01862
All marriages	2177	.02093
Parents of patients with congenital malformations	10	.02500
Patients having children with congenital malformations	14	.03153
Mothers with abortions	55	.03040
Parents of patients with pulmonary tuberculosis	38	.03289

Table 15. Coefficients of inbreeding in different groups.

	Inpatients Consanguineous couples		Non consanguineous couples	
Marriages	Sterile	Fertile	Sterile	Fertile
Inpatients	6	21	9	45
Percentage Sterile	22.2		16.6	
Parents of inpatients	5	17	10	49
Percentage Sterile	22.7		16.9	

Table 16. Classification of inpatients in the Gynaecology ward based on their fertility or sterility, and consanguinity among their parents and themselves.

Y-LINKAGE IN MAN: A STUDY OF THE INHERITANCE AND FREQUENCY OF HYPERTRICHOSIS PINNAE AURIS

Ever since the discovery of mutants completely linked with the Y-chromosome in several species of animals there has been a search for human variants showing similar holandric inheritance. Inheritance through the Y-chromosome, Y-linkage, may occur in two ways, complete and incomplete. The gene responsible for a completely Y-linked trait is solely confined to a locus in the Y-chromosome either because it has no allele in the X-chromosome or because it does not exchange with an X-chromosomal allele. In incomplete sex-linkage, there are homologous loci in the X and Y chromosomes whose alleles crossover from one sex chromosome to the other. In organisms with heterogamy of the male sex complete Y-linkage of genes with full penetrance is characterized by

(a) occurrence of the trait in males only;

(b) its reoccurrence in all sons of affected males; and

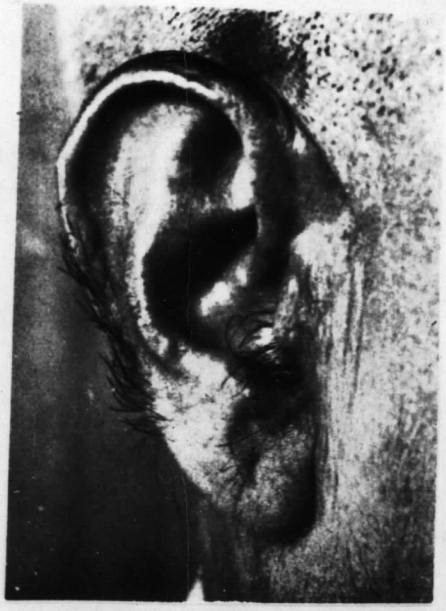
(c) the daughters of affected men being not only phenotypically normal but also having no affected offspring.

The existence of Y-linked inheritance in man was first suggested by Castle (1922) and Enriques (1922), after Schofield (1921) had published a pedigree of webbed toes with 14 affected males and no affected females in four generations. Schofield himself made no mention of Y-linkage, suggesting that the trait was inherited as a secondary sex character. Enriques (1922) coined the word "holandric" (holos = entire; aner = man or male; Gk.) to describe a type of inheritance in which all males are affected and females neither exhibit the trait nor transmit the underlying gene.

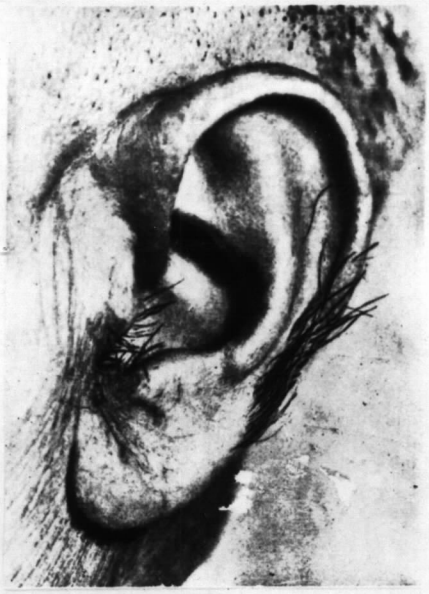
Stern (1957) reviewed the evidence in favour of the possible Y-linkage of seventeen traits in man and concluded as follows: "The evidence for Y-linkage in man is at best ambiguous. The 'best' pedigrees taken by themselves, have only a low probability of being interpretable as the result of chance segregation of autosomal genes but such an interpretation becomes more acceptable if one realizes that these pedigrees have been selected from thousands showing ordinary autosomal or X-linked inheritance...A decision not to accept any one of the known conditions as due to proven Y-linkage should, however, not be equivalent to a neglect to search for new evidence...That the Y-chromosome has a function of its own is attested by its very existence. What it is still must be discovered."

The seventeen traits considered by Stern are given below:

1. Ichthyosis hystrix gravior
2. Black hairs in the ears
3. Webbed toes
4. Coloboma iridis (?). Sedgwick's case
5. Cataract (?). Harman's case
6. Keratoma dissipatum
7. Peroneal atrophy
8. Epidermolysis bullosa simplex
9. Radio-ulnar synostosis
10. Hyperextensibility of thumbs (?)
11. Hypermobility of joints (?)
12. Blue sclera and brittle bones
13. Adherent tongue (?)
14. Camptodactyly (?)



A



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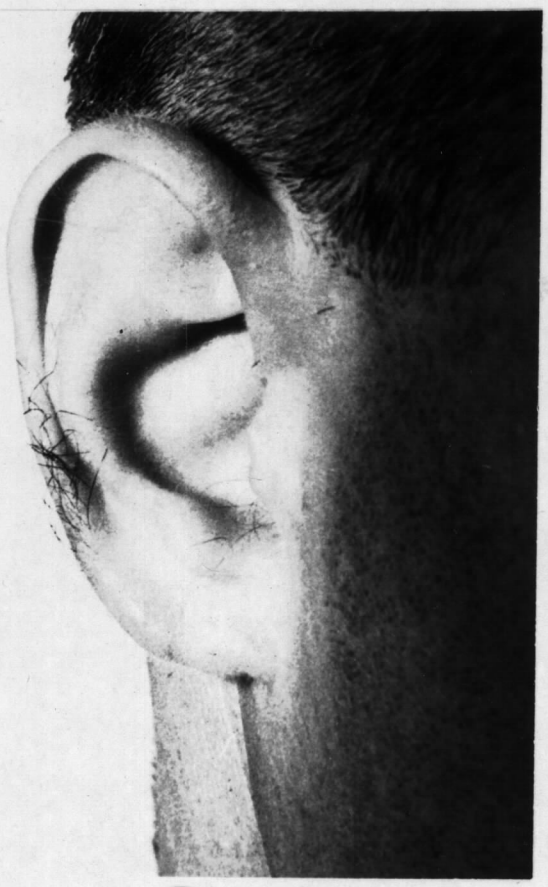

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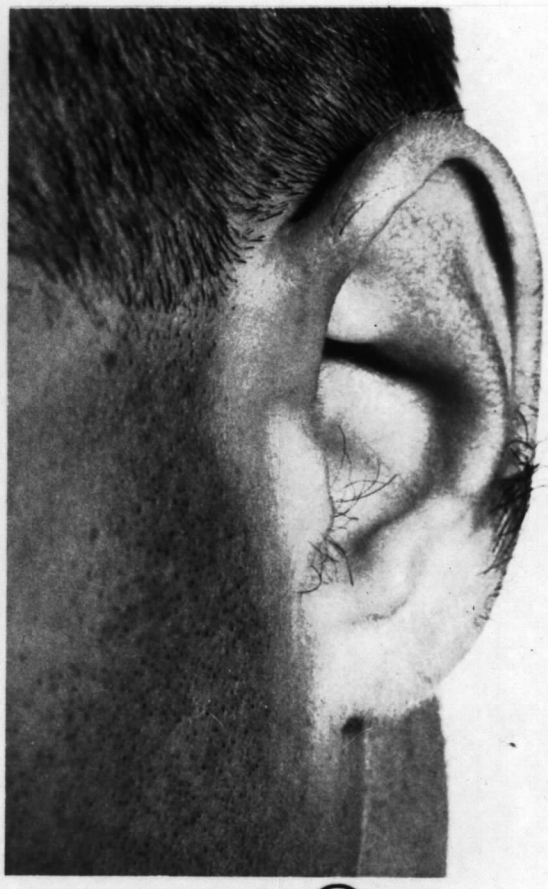

D

Plate 1. Hypertrichosis pinnae auris.

a & b: right and left ears of a Telugu Brahmin male aged 66 years (A-N-5, Fig. 1).

c & d: right and left ears of a North American male of European stock, aged 36 years.

15. Foot ulcers (?)

16. Colour vision anomaly

17. Abnormality of the external ear

Stern further concluded that for a few pedigrees, the probabilities for the assumptions of sex-linked autosomal inheritance were small and a final decision must await further data. One such trait is "black hairs in the ears". According to Stern (1957) "There is no evidence against complete Y-linkage of the characteristic and further studies should be attempted."

Hypertrichosis Pinnae Auris

The trait "black hairs in the ears" may be more precisely referred to as "hypertrichosis of the pinnae of the ears" or hypertrichosis pinnae auris (Dronamraju, 1960). It is characterized in most cases by the presence of long hairs growing closely together on the helix of the ears. The hairs may extend along the whole length of the helix or they may be localized on the lower part of the helix only. The number of hairs may range from one or two on either ear to a thick bushy growth on both ears. When the expression is mild the hairs could appear on one ear and not on the other, but in cases of average or more striking growth it is always bilateral (Plate 1; a,b,c, and d). The youngest affected male observed by me was 17 years old. The age of onset varies considerably within and between populations. No affected female has been observed for this trait (Table 1). Recently, however, Vella (1963) described a Maltese girl aged 3 months who had fine dark brown hairs of 1.5 cm on her ear rims, but this trait differs from hypertrichosis pinnae auris in at least 3 ways: (1) it occurs in both sexes, (2) it disappears within a few months, and (3) the hair is fine and extends over most of the edge of the pinna. Hypertrichosis pinnae auris, having once appeared on the ears of a man never disappears.

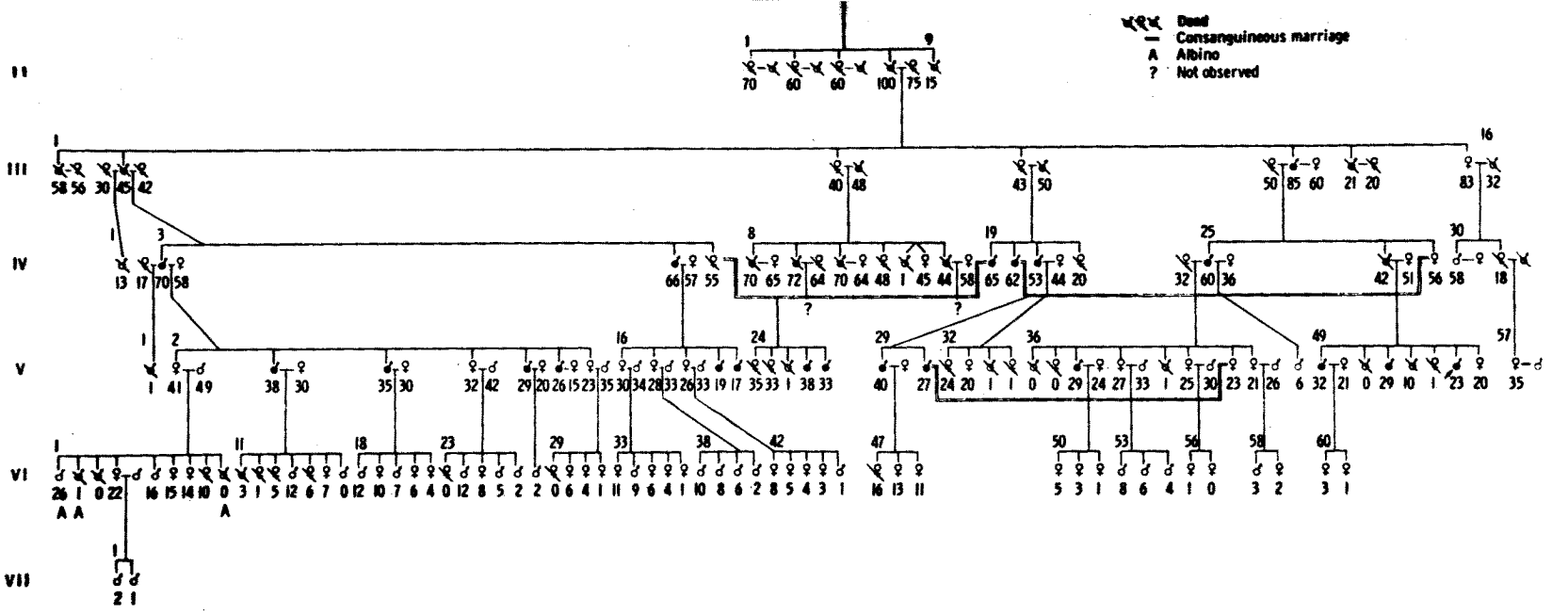

Fig. 2

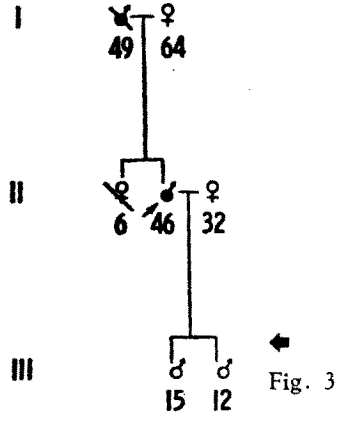

Fig. 3

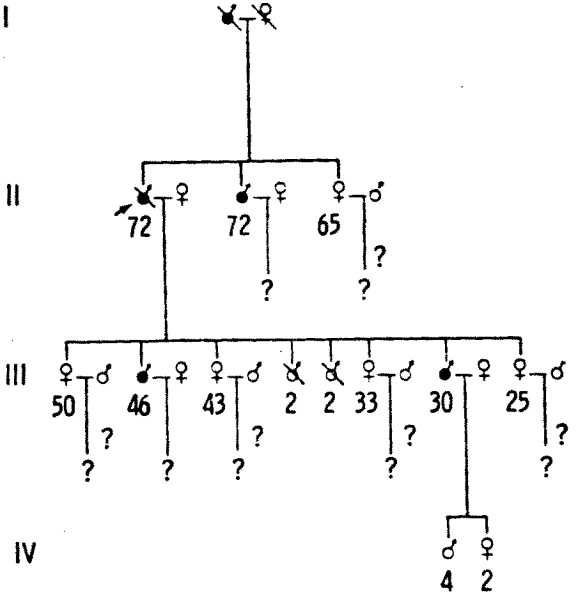

Fig. 4

Early Work

A pedigree of hypertrichosis pinnae auris was first published by Tommasi (1907 a,b). All the ten male descendants in the male line from an affected male ancestor and none of the seven female descendants had hairy ears. The pedigree thus shows good agreement with the hypothesis of complete Y-linkage for this trait. Stern (1957), however, criticized the pedigree and doubted the accuracy of evidence because "the propositus, III-6 and his wife III-7, were the only individuals personally seen by Tommasi and all information on the other members of the five generation pedigree comes from them. But III-6 was 81 years old when questioned and an inmate of a mental institution." It is questionable, however, whether information of this kind obtained through an inmate of a mental institution could be considered particularly unreliable. (Penrose, 1961, personal communication.)

Present Work

The present investigation includes a study of three pedigrees from Andhra Pradesh (Figures 1-3, Pedigrees A, B, and C). Pedigree A is of my own family for which I am the propositus. Pedigrees B and C are of unrelated families. The members of the Pedigrees A and B belong to the Brāhman caste and those of C to the Aryakshatriya caste in Hindus.

Description of Pedigrees

All people recorded in Pedigree A as being alive were seen by me during the investigation.

I tried to avoid asking a direct question about any dead individual, and this was rarely necessary. As we were talking within the family, once the subject was raised all cases known to the immediate informant were promptly

volunteered. On comparing lists given me independently by different people with each other and with my own observations I have found no inconsistencies. A positive statement concerning a man having hairy ears is more likely to be accurate than a statement that hair was absent. In women for social reasons such a character would be less noticed. This particular hairiness of the ears is noticed and remembered because of a certain belief connected with it in the society of which people in the pedigree formed a part. It is considered as correlated with longevity of the man having it. For a man this is regarded as extremely fortunate. Contrarily any excess hair on a woman is regarded as unfortunate, as this again portends longevity and therefore the danger of outliving her husband. In the state of Andhra Pradesh, Hindu women (except Brahman widows) do not cover their heads, unlike women from other parts of India, and were not known to do so over the last 200 years. This facilitates clear observation. All the informants, on being asked, told me that they had never seen any woman showing hairy ears, nor heard of such a case. For information about a girl or woman another woman is more reliable than a man, as the former is apt to be more intimate with unrelated females. The examination of ancient photographs has proved disappointing. In these the edge of the ears is usually blurred either through being slightly out of focus, or by "touching" of the negative or the print. Two photographers have told me that it is their practice to touch in this way to obliterate what modern people may consider as a blemish.

Table 2 lists my informants for those people over 17 who are recorded as dead in Pedigree A (Fig. 1, Table 3). Two points need clarifying. The memory of A-III-11 is very good and as will be seen is extensively relied upon, that of A-III-15 is much less good in all matters. Though I have relied on

my own memory for A-IV-8, A-IV-10 and A-IV-11, who died after I became an adult, I have not used it for A-IV-27, who died when I was 6 years old.

Because the collection of Pedigrees B and C has only just begun I have listed all sources of information in Table 4. I have known B-I-2, B-II-2, and B-II-3 quite intimately, but I did not know B-I-1. The character is very striking in B-II-2 (surnamed Kamarushi) who being a high school teacher and also a practitioner of ayurvedic medicine is a well known figure, so that several people spoke to me about him.

C-I-1 was Voleti Parvatisam, a distinguished poet and novelist in the Telugu language. He had an impressive presence and voice as a public lecturer, and I and many others have a vivid memory of him, including his hairy ears. He died in the year 1957. As I intend to see all living people in this Pedigree I have not collected all hearsay information possible because I did not wish to cross-question my informants.

Pedigrees A and C belong to the large caste called Brāhman and Pedigree B to the Aryakshatriya caste, a much smaller group. Each caste is endogamous and is divided further into endogamous subcastes within itself. For example Pedigrees A and C are both from the Niyogi subcaste. Pedigree A contains one intercaste marriage out of 48 (A-III-11 x A-III-12 who is a Padma Sāle by birth). Marriages between close relatives are frequent, and three (A-IV-7 x A-IV-19, A-IV-20 x A-IV-29, A-V-31 x A-V-45) of the marriages in Pedigree A are between first cousins. Within a subcaste, marriages between people of the same surname are prohibited. Because the surname is inherited from the father and a woman changes her surname on marriage, we can consider A-I-1, A-III-7, A-III-9, C-I-1, and B-I-1 as carrying Y chromosomes which have been separated for a long period of time. The situation is even more complicated,

however. Each subcaste is divided into groups of families, and therefore of surnames, which are not only exogamous but are only permitted by custom to marry members of a fraction of the other groups. These are called gotras and are patrilineal. Exogamous groups in some form, as far as I know, are characteristic of all Hindu and most aboriginal societies in India.

It is interesting to note that 2 out of 3 outside male spouses in A-III are affected, in contrast to none out of 10 in A-V.

DISCUSSION

It will be convenient to give a symbol for the gene responsible for hypertrichosis pinnae auris. The symbol Hp is already preempted for haptoglobins. I suggest the symbol He.

All pedigrees are completely compatible with the hypothesis that the character is determined by a gene carried by the Y chromosome, and hence confined to males, present in all the sons of affected males, and not transmitted to their daughters' sons. But before this hypothesis is accepted, we must show that other alternatives are very improbable. I shall consider two.

The first is that He is a dominant gene only manifested in males, but that, like some of the genes described by Winge and Ditlevsen (1947) in Lebistes reticulatus, it can occur on the Y or on the X chromosome, whether its occurrence on the X is due to crossing-over or to mutation.

Now the gene is quite common, and cannot be due to any great extent to recent mutation. If it crosses over, even with a frequency of 1% or less, it should be about as common on the X as on the Y. If it has arisen by repeated independent mutations, we should expect the same. If a man carried the gene on his X, he could only transmit it to his sons by crossing-over, which is known to be rare. In the pedigrees there are 5 "independent" sources

of the gene in the males A-I-1, A-III-7, A-III-9, B-I-1, and C-I-1. All these transmitted it to sons, and there is a strong presumption that it was on their Y chromosomes. In fact they confirm the former pedigrees. I do not think that the hypothesis of facultative X-linkage need be further considered, on the existing evidence.

The second hypothesis is that the gene He is an autosomal dominant, but only manifested in males, like premature baldness (Harris 1946) and one gene in Lebistes reticulatus. It is clear that the pedigrees are all compatible with this hypothesis, but, as we shall see, extremely improbable if it is true. The exact calculation of their improbability is very difficult, but it is easy to get a rough estimate of it. I shall first consider these pedigrees on the hypothesis that the gene He is extremely rare, so that one can neglect the possibility that any of the wives of affected males may have carried it.

Consider Pedigree B; if He were an autosomal dominant only manifested in males, B-II-2 could have inherited it from either parent. The probability that he should have got it from his father is $\frac{1}{2}$. In Pedigree C, C-II-1 could have inherited He from either parent. The probability of his doing so from his father is $\frac{1}{2}$. The probability that his heterozygous parent should also have contributed He to C-II-3 is $\frac{1}{2}$. Finally the probability that both C-II-1's adult sons should have inherited He is 1/4. These probabilities multiply together to 1/16. That is to say, out of a large number of pedigrees including a grandfather, his two sons, and two sons of one of them, in which one male was He, the probability that we should expect all five males to be affected is 1/16.

In Pedigree A, I-1 had 18 descendants in the direct male line. The probability that all should be $\widetilde{He}$* is 2^{-18}. A-III-7 married A-III-6 who, on our

*I use Stern's (1949, p. 126) symbol of the tilde so that $\widetilde{He}$ means $\frac{He}{He}$ or $\frac{He}{+}$.

hypothesis, is equally likely to have been $\frac{He}{+}$ and $\frac{+}{+}$. If she was $\frac{He}{+}$ the probability that their 4 sons were all $\widetilde{He}$ is $(3/4)^4$, 81/256, if she was $\frac{+}{+}$ the probability is 2^{-4}. The joint probability is thus $\frac{1}{2}[(3/4)^4+(\frac{1}{2})^4] = 97 \times 2^{-9}$. Similarly A-III-9 had three $\widetilde{He}$ sons with probability $35 \cdot 2^{-7}$. Finally A-IV-19 and A-IV-20 each had two $\widetilde{He}$ sons. As both paternal and maternal genotypes are doubtful I shall not consider them, though between them they contribute a probability of about 1/4. The rest give 3395×2^{-34}, or $1 \cdot 97 \times 10^{-7}$. The correct value is well under 10^{-7}. Multiplying in the probabilities of pedigrees B and C we get an over-all probability less than $6 \cdot 2 \times 10^{-9}$. Such a probability means that the hypothesis of an autosomal gene must be decisively rejected. But first we must ask how this probability is altered if we allow for the fact that the condition $\widetilde{He}$ is not rare.

Let p be the frequency of the supposed gene He. Twenty-three out of 345 males (co-travellers and husbands) had hairy pinnae. So our estimate of p is given by

$$(1-p)^2 = \frac{322}{345}$$

that is to say $p = 0.0339 \pm .0097$.

The value may be higher in the Niyogi brahmans.

The exact calculation of the probability of a pedigree on the supposition that He is an autosomal sex-limited dominant is extremely complicated, and I only give it for Pedigree C. Let $q = 1-p$.

We now ask how much the probability of 1/16 is increased because p is not zero. The propositus C-II-1 certainly carried one He gene. The probability that his other gene at this locus was also He is p. That is to say the

probability that he was $\frac{He}{He}$ is p. The probability that he was $\frac{He}{+}$ is q. If he was $\frac{He}{He}$ his father and both his sons must have been $\widetilde{He}$, but his brother II-3 might not have been so. Since I-1 and I-2 both had one He gene, the probability that they had a second is in each case p; the probability that they were both $\frac{He}{+}$ is q^2. If so the probability that C-II-3 should be $\widetilde{He}$ is 3/4. But if either was homozygous C-II-3 must have been $\widetilde{He}$. Thus given that C-II-1 was $\frac{He}{He}$, the probability of the rest of the pedigree is $1 - q^2 + 3/4\ q^2$, or $1 - 1/4\ q^2$, or $1/4(3 + 2p - p^2)$ or $1/4(4p^2 + 8pq + 3q^2)$.

If C-II-1 was $\frac{He}{+}$ one parent contributed a He gene, the other a + gene. Thus their probable genotypes were $[p\ \frac{He}{He},\ q\ \frac{He}{+}]$ and $[p\ \frac{He}{+},\ q\ \frac{+}{+}]$. The probability that his father was $\widetilde{He}$ is therefore $\frac{1}{2}(1 + p)$. However we must also consider the brother C-II-3. The four possible pairs of parental genotypes with their probability, and the consequent probabilities that C-I-1 and C-II-3 were both $\widetilde{He}$ are

Mating	Probability of	Probability for I-1	Probability for II-3	Product
$\frac{He}{He} \times \frac{He}{+}$	p^2	1	1	p^2
$\frac{He}{He} \times \frac{+}{+}$	pq	$\frac{1}{2}$	1	$\frac{1}{2}\ pq$
$\frac{He}{+} \times \frac{He}{+}$	pq	1	3/4	$3/4\ pq$
$\frac{He}{+} \times \frac{+}{+}$	q^2	$\frac{1}{2}$	$\frac{1}{2}$	$1/4\ q^2$

The sum of these probabilities is $p^2 + 5/4\ pq + 1/4\ q^2 = 1/4(4p + q)$. Next consider the two sons C-III-3 and C-III-11. C-II-2 was $\frac{He}{He}$ and $\frac{+}{+}$ with

probabilities $\underline{p}^2$, $2\underline{pq}$ and $\underline{q}^2$. The probability that C-III-3 and C-III-11 were both $\underline{\tilde{He}}$ is 1, 9/16, and 1/4 in these three cases if C-II-1 was $\underline{\frac{He}{+}}$. The over-all probability is $\underline{p}^2 + 9/8\ \underline{pq} + 1/4\ \underline{q}^2 = 1/8\ (2 + 5\underline{p} + \underline{q}^2)$. Thus if C-II-1 was $\underline{\frac{He}{+}}$ the probability that his four male relatives were all $\underline{\hat{He}}$ is $1/32\ (4\underline{p} + \underline{q})\ (8\underline{p}^2 + 9\underline{pq} + 2\underline{q}^2)$. Thus for the whole pedigree the probability is

$$P_p = 1/4\underline{p}\ (4\underline{p}^2 + 8\underline{pq} + 3\underline{q}^2) + 1/32\underline{q}\ (4\underline{p} + \underline{q})\ (8\underline{p}^2 + 9\underline{pq} + 2\underline{q}^2)$$

$$= 1/32\ (32\underline{p}^4 + 128\underline{p}^3\underline{q} + 132\underline{p}^2\underline{q}^2 + 41\underline{pq}^3 + 2\underline{q}^4$$

$$= 1/32\ (2 + 33\underline{p} + 21\underline{p}^2 - 21\underline{p}^3 - 3\underline{p}^4)$$

If $\underline{p} = .0339$, which is the value estimated, $P_p = .0982$, and if $\underline{p} = .05$, $P_p = .11562$ as compared with $P_o = .0625$.

Let us take $\underline{p} = .05$ which is improbably high. The logarithm of the probability is altered from -1.20412 to -.93697, that is to say multiplied by .778. A correction of this order only brings the joint probability of the three pedigrees up to 4.1×10^{-7}. It is hard to suppose that $\underline{p}$ is large enough to bring it up to a millionth.

In fact the hypothesis of an autosomal gene may be decisively rejected. It is not of course impossible that an indistinguishable, but autosomally determined character may be found in another family.

Later Work

Gates and his collaborators subsequently (1961, 1962) published several pedigrees from India which are compatible with the hypothesis of complete Y-linkage of hypertrichosis pinnae auris.

Sarkar, Banerjee, Bhattacharjee and Stern (1961) published seven small pedigrees on the inheritance of this trait. One of these pedigrees is fully

compatible with the hypothesis of complete Y-linkage but the others contained affected and unaffected males in the same sibship. Dronamraju and Haldane (1962) criticized the methodology of this work and concluded that the evidence published was insufficient to support the hypothesis of autosomal dominance. They pointed out that in the work of Sarkar et al. only one person in each of three pedigrees and two in another were seen by the authors. These pedigrees, like the one published by Tommasi (1907 a,b), were largely prepared on hearsay evidence. It is important, in favour of the hypothesis of autosomal dominance, to look for affected men whose fathers are unaffected but whose maternal grandfathers are affected. However, no such case has been recorded by Sarkar et al.

As emphasized by Dronamraju (1961 a) earlier, hearsay evidence could be unreliable for at least three reasons:

(a) slight manifestations are easily overlooked and reported as negative cases,

(b) a heavy hair growth near the external auditory meatus is misreported by an informant as a positive, and

(c) considerable manifestations may be regarded as negative by persons who are accustomed to seeing extreme manifestations.

For these reasons, all the individuals in my family (Pedigree A) alive at the time of investigation were examined by me.

Slatis and Apelbaum (1963) made observations on Israeli men carrying the same Y chromosome as an affected propositus, to test the assumption that hairy pinna of the ear is Y-linked. They concluded that "An assumption of autosomal inheritance either as a dominant or a recessive sex-limited trait gives unsatisfactory results with far too many affected relatives of affected men. Thus it would appear that hairy pinna is Y-linked..."

Frequencies in India and Ceylon

I have examined the ears of 345 men who were my daytime co-travellers in buses and railway trains of Andhra Pradesh (Table 1). By changing my seat more than once I was able to make an approximately complete inventory of a compartment, no one being scored from a distance more than 1.5 metres. It is possible that a few mild cases may have been unrecognized among my co-travellers. The milder expressions of the trait are not common in the population. Out of 345 men, 6.1 per cent had hairy ears.

A closer examination of the ears had been made in West Bengal, Orissa, and Ceylon (Dronamraju, 1961 b; 1963 a and b).

Out of the 150 men-workers examined at the Indian Statistical Institute in Calcutta, 16.0 per cent showed clear manifestation of hypertrichosis pinnae auris. The over-all incidence among 871 males in Orissa was 14.5 per cent.

The 414 men examined in Ceylon included outpatients of General Hospital in Colombo, workers of the Coconut Research Stations and the staff of the Peradeniya Botanic Gardens, etc.; 295 of them were Buddhists, 97 Christians (mostly Roman Catholics), 12 Muslims and 10 Hindus. There was no significant difference between the frequencies among Buddhists (37.8 per cent) and Christians (39.2 per cent). Three of the Muslims and three of the Hindus had hairy pinnae. The over-all incidence in Ceylon was found to be 36.9 per cent.

Statistical analysis shows that: (a) there is no significant heterogeneity between frequencies in different parts of Ceylon; (b) the frequencies in Ceylon and Andhra Pradesh, West Bengal and Andhra Pradesh, and Ceylon and West Bengal differ significantly.

The results presented here show significant differences in the frequency of the hairy pinnae between different populations. It would seem worthwhile making counts of the frequencies in various parts of the world. For a careful observer there is no ambiguity in scoring and this trait may prove useful as an anthropological marker in population studies (Dronamraju, 1961).

Frequencies in Different Age Groups

The men are classified on the basis of their age in Tables 5-7. The frequencies in West Bengal, Orissa, and Ceylon increase with age and this increase is significant in men aged 45 years or over in Orissa ($\chi_1^2 = 7.30$). This is presumably due to the phenotype appearing at the late age of 45 years or over in some cases, and as suggested by Dronamraju (1963 a,b), several genes are probably involved in controlling the expression of the phenotype.

Slatis and Apelbaum (1963) reported that in Israel the proportion of men with hairy pinnae increases with age, perhaps up to 60 years or so, and they postulated a hairy pinna allele that causes early onset of the trait among Indians. Out of 373 men of the age group 18-29 years examined by them, only 1.1 per cent had hairy pinnae. In Orissa, the incidence among the men aged 18 to 20 years was 5.4 per cent.

It is probable that there are different alleles for the early and late ages of onset, and that the relative frequencies of these alleles may vary significantly between and within populations. It is further possible that the phenotypes investigated by different authors are not the same. As suggested by Dronamraju (1960, 1964), genetic heterogeneity might exist for this trait as it does for so many other human traits such as muscular dystrophy (Morton and Chung, 1959) and deaf-mutism associated with and without albinism (Stevenson and Cheesman, 1956; Margolis, 1963; Tietz, 1963).

Y-Linkage in Animals and Plants

The first gene which was shown to be on the Y-chromosome in any species was discovered by Johannes Schmidt in the year 1920 for a pigment spot in the fish Lebistes reticulatus. This was also reported in the succeeding year by Aida for colour inheritance in the fish, Aplocheilus latipes. Further examples in Lebistes were reported by Winge (1922 a,b). A colour trait in the beetle Phytodecta variabilis was also reported (Zulueta, 1925). Stern (1926, 1927) reported bristle size in Drosophila to be Y-linked. The only Y-linkages in plants concern the general morphological abnormality in Melandrium album and chlorophyll variegation in Melandrium rubrum (Winge, 1931). The Y chromosome in Drosophila is known to influence the degree of position effect variegation (Gowen and Gay, 1933, 1934). It was also reported to cause variegation of eye colour if present in double dose in normal females, or triple dose in normal males (Cooper, 1956). The influence on quantitative characters of Drosophila was reported by Mather (1944), Barrigozzi (1948), and Barrigozzi and di Pasquale (1953; also see Hannah, 1951).

A Y-linked antigen in the mouse was suggested by various authors (Eichwald and Silmser, 1956; Billingham and Silvers, 1960; Hauschka and Holdridge, 1962). They described a more rapid rejection by female recipients of skin isografts from male than from female donors of inbred strains of mice. So far this is the only other species in mammals in which a Y-linked gene is reported besides man.

The Y-chromosome is concerned with sex determination in the fishes mentioned above, the gypsy moth Lymantria dispar (Goldschmidt, 1934), the silkworm Bombyx mori (quoted from Goldschmidt, 1955), the mosquito Culex molestus (Gilchrist and Haldane, 1947), many species of the midge Chironomus

(Beermann, 1955) and the plant Melandrium (Warmke and Blakeslee, 1939; Warmke, 1946; Ono, 1940 a and b; Westergaard, 1940, 1948).

In Drosophila, animals without a Y chromosome but one X chromosome are males (Bridges, 1916), and those with one or two Y chromosomes but two X chromosomes are females (Bridges, 1916; Stern, 1929). Spermatogenesis in XO males does not lead to motile sperm and thus results in sterility (Bridges, 1916; Stern, 1932; Schultz, 1947).

In the mouse (Mus musculus), Welshons and Russell (1959) have shown that animals with XX or XO constitution are fertile females and that Y chromosome is male determining. McLaren (1960) reported an XXY mouse which was anatomically fully male but died before breeding tests could be performed.

In man the Y chromosome is known to play a more definite role in sex-determination (Jacobs and Strong, 1959; Ford et al., 1959 b). The main function of the human Y chromosome is probably to secure that the foetal gonad develops into a testis rather than an ovary. For XY zygotes develop into normal males, while some XXY zygotes develop into males with Klinefelters syndrome (Ford et al., 1959 a). Once a Y chromosome that carried genes playing a positive part in male determination has been involved in a species, it is possible that some economy in the genetic system would be effected if genes responsible for male epigamic characters were also to become Y-linked. The argument is similar to that explaining the close linkage observed between the various traits in a heterostylic system. The effect of the gene He may be said to be a slight extension of the area of the head in which fairly large hairs develop under the influence of male hormones. It is possible that the control of this area is a subsidiary function of the Y. If so we might expect that the males of the first generation from a cross of two human races which differ considerably in the development of the beard might

resemble their fathers rather than their maternal grandfathers in this respect. It seems worth looking for such an effect, even if the hypothesis is thought to be rather improbable.

SUMMARY

Inheritance of hypertrichosis pinnae auris was investigated in two Brāhman and one Aryakshatriya pedigrees from Andhra Pradesh. The mode of inheritance is compatible with the hypothesis that the character is Y-linked and thus confirmed Tommasi's (1907 a,b) suggestion of holandric inheritance.

The youngest affected male recorded in this investigation was 17 years old. The age of onset was found to vary in different populations and the frequency of affected males increased significantly with age, especially among those aged 45 years and over in Orissa and Ceylon. The over-all frequencies recorded were 6.1 per cent in Andhra Pradesh, 16.0 per cent in West Bengal, 14.5 per cent in Orissa and 36.9 per cent in Ceylon.

It is suggested that there may be different alleles for early and late ages of onset whose frequencies may differ significantly between populations. It is further suggested that pedigrees showing exceptions to the hypothesis of Y-linkage, published by other authors, could be due to one or more of the following causes:

(a) mistakes made by those who supplied hearsay evidence,

(b) differences in ages of onset between individuals,

(c) the existence of genetic heterogeneity as in deaf-mutism and muscular dystrophy.

In view of the significant differences in the frequencies of men with hairy pinnae in different populations, it is suggested that this trait can

be useful as an antropological marker in studying the affinities and differences between human populations.

Evidence for Y-linkage in man and other animals and plants is briefly reviewed.

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Date	Conveyance		un-affected	♂ affected	un-scored	un-affected	♀ affected	un-scored
27-11	Bus from Visakhapatnam	to Yerada Park	24	1		6	0	
28-11	Bus from "	to Vizianagram	76	5		21	0	
29-11	Train from "	to Kakinada	44	2		1	0	
30-11	Kakinada city bus		30	1		2	0	
1-12	Bus from Kakinada	to Pithapuram	24	3		2	0	
2-12	Bus from "	to Rajahmundry	33	3		2	0	
3-12	Train from "	to Pulla	6	0		1	0	
4-12	Bus from Pulla	to Katur	30	2		7	0	
5-12	Bus from "	to Bhimavaram	37	1		5	0	
6-12	Bus from Bhimavaram	to Gudivada	12	1		3	0	
9-12	Bus from Hyderabad	to Ramannapet	8	2	1	5	0	1
			324	21	1	55	0	1

Table 1. Samples of the population of Andhra Pradesh

A-I-1	A-III-11 through A-II-7; A-IV-3 through an unrelated acquaintance of A-I-1
A-I-2	"
A-II-1	"
A-II-2	"
A-II-3	"
A-II-4	"
A-II-5	"
A-II-6	"
A-II-7	A-III-11, A-IV-3, A-IV-5, A-IV-20, A-IV-25, A-IV-28, A-IV-29
A-II-8	A-III-11, A-IV-3
A-III-1	A-III-11, A-IV-3, A-IV-5, Photograph
A-III-2	"
A-III-3	no information
A-III-4	A-III-11, A-IV-3 and A-IV-5 through an acquaintance of A-III-4
A-III-5	"
A-III-6	A-III-11, A-IV-3, A-IV-19, A-IV-20
A-III-7	"
A-III-8	A-III-11, A-IV-19, A-IV-20, A-IV-21, A-IV-25, A-IV-28, A-IV-29
A-III-9	"
A-III-10	A-III-11, A-IV-25, A-IV-28, A-IV-29
A-III-13	A-III-11
A-III-14	no information
A-III-16	A-III-11
A-IV-2	A-IV-3
A-IV-7	A-IV-3, A-IV-5
A-IV-8	author (A-V-55)
A-IV-10	author (A-V-55)
A-IV-11	author (A-V-55)
A-IV-12	A-III-11, A-IV-3, A-IV-5, A-IV-25, A-IV-28, A-IV-16
A-IV-14	A-IV-16, A-IV-28, A-III-11
A-IV-17	A-IV-28, A-IV-16, A-IV-3, A-III-11
A-IV-23	A-IV-19, A-IV-20, A-IV-21
A-IV-24	A-IV-25, A-IV-28, A-IV-29
A-IV-27	A-II-11, A-IV-3, A-IV-5, A-IV-19, A-IV-20, A-IV-21, A-IV-25, A-IV-28, A-IV-29
A-IV-32	A-IV-28
A-IV-33	A-IV-30
A-V-24	A-IV-19, A-IV-20
A-V-25	"
A-V-32	A-IV-21, A-IV-20

Table 2. Sources of information concerning dead people in the pedigree A who reached the age of 17.

OVER 17 YEARS OF AGE

		♀ affected	♀ un-affected	♀ un-scored	♂ affected	♂ un-affected	♂ un-scored
I-1	dead	1	--	--	--	--	--
Children of affected males	alive	21	0	0	0	15	0
	dead	9	0	0	0	11	0
Descendants of daughters of affected males married to normal males	alive	0	2	0	0	2	0
	dead	0	0	0	0	1	0
Unrelated spouses	alive	0	11	0	0	17	0
	dead	2	5	0	0	8	2

UNDER 17 YEARS OF AGE		♀ seen	♀ not seen	♂ seen	♂ not seen
	alive	23	0	29	0
	dead	0	17	0	10

Table 3. Summary of data in Pedigree A

Pedigree-B

B-I-1	B-II-2
B-I-2	seen by the author
B-II-1	B-II-2, B-II-3
B-II-2	Propositus, seen by the author
B-II-3	seen by the author
B-III-1	"
B-III-2	"

Pedigree-C

C-I-1	C-III-3
C-I-2	C-III-3
C-II-1	Propositus, seen by the author
C-II-2	seen by the author
C-II-3	"
C-II-4	C-III-3 and C-III-11
C-II-5	C-III-3 and C-III-11
C-II-6	no information
C-III-1	C-III-3 and C-III-11
C-III-2	no information
C-III-3	seen by the author
C-III-4	"
C-III-5	C-III-3 and C-III-11
C-III-6	no information
C-III-7	C-III-3
C-III-8	C-III-3
C-III-9	C-III-3 and C-III-11
C-III-10	no information
C-III-11	seen by the author
C-III-12	"
C-III-13	C-III-3 and C-III-11
C-III-14	no information
C-IV-1	seen by the author
C-IV-2	"

Table 4. Sources of information for Pedigrees B and C.

Age Group (in years)	Total No. of men examined	No. with hairy pinnae	Percentage
15 - 17	50	0	0
18 - 20	353	19	5.4
21 - 23	200	34	17.0
24 - 26	84	9	10.7
27 - 29	33	6	18.2
30 - 32	50	17	34.0
33 - 35	23	7	30.8
36 - 38	14	5	
39 - 41	21	6	
42 - 44	7	2	
45 and over	36	21	58.3
TOTAL	871	126	14.5

Table 5. The classification of Oriya men based on their age and presence or absence of hairy pinnae.

Age Group (in years)	Total No. of men examined	No. with hairy pinnae	Percentage	
15 - 17	0	0		
18 - 20	10	0	0	6.3
21 - 23	23	0		
24 - 26	21	3	14.3	
27 - 29	25	2	8.0	
30 - 32	22	4	18.2	
33 - 35	10	3	35.3	26.02
36 - 38	7	3		
39 - 41	16	5	27.3	
42 - 44	6	1		
45 and over	12	3	25.0	
TOTAL	152	24	15.8	

Table 6. West Bengal

Age Group (in years)	Total No. of men examined	No. with hairy pinnae	Percentage
15 - 17	1	0	0
18 - 20	13	1	7.7
21 - 23	42	4	9.5
24 - 26	53	11	20.8
27 - 29	52	13	25.0
30 - 32	53	18	33.9
33 - 35	31	15	48.3
36 - 38	23	13	56.5
39 - 41	31	11	35.5
42 - 44	22	12	54.5
45 and over	92	55	59.8
TOTAL	413	153	37.04

Table 7. Ceylon

A STUDY OF THE FREQUENCY OF INHERITED COLOUR VISION DEFECTS IN ANDHRA PRADESH AND ORISSA: REPORT ON A NEW COLOUR VISION ANOMALY

A REVIEW OF WORLD FREQUENCIES WITH A NOTE ON SELECTION RELAXATION.

INTRODUCTION

Most cases of congenital colour vision deficiency are characterized by a red-green deficiency which may be of two types; first, a protan type which may be absolute (protanopia) or partial (protanomalia), and secondly, a deutan type which may be absolute (deuteranopia) or partial (deuteranomalia).

In protanopia the visible range of the spectrum is shorter at the red end compared with that of the normal and that part of the spectrum which appears to the normal as blue-green, appears to those with protanopia as grey. The whole visible range of the spectrum in protanopia consists of two areas which are separated from each other by this grey part. Each area appears to those with protanopia as one system of colour with different brightness and saturation within each area, the colour in one area being different from that of the other. The red with a slight tinge of purple which is the complementary colour of blue-green appears also as grey.

In deuteranopia, that part of the spectrum which appears to the normal as green, appears as grey, and the visible range of the spectrum is divided by this zone into two areas, each of which appears to be of one system of colour. The visible range of the spectrum is not contracted, in contrast to protanopia. Purple-red which is the complementary colour of green appears also as grey.

In protanomalia and deuteranomalia, there is no part of the spectrum which appears grey, but the part of spectrum which appears to those with protanopia as grey, appears to those with protanomalia as a greyish

indistinct colour, and likewise, the grey part of the spectrum seen by the person with deuteranopia appears to those with deuteranomalia as an indistinct colour close to grey.

Consequently, one of the peculiarities of red-green deficiencies is that blue and yellow colours appear to be remarkably clear compared with red and green colours.

In the congenital colour vision deficiencies, although very rare, there is total colour weakness. The colour sensitivity of the total colour weakness to red and green, as well as to yellow and blue is very low and only the clear colours can be perceived; but, except for the colour sensitivity, there is no abnormality in the visual functions.

There is also a very rare group of persons who suffer from total colour blindness and show a complete failure to discriminate any colour variations, usually with an associated impairment of central vision with photophobia and nystagmus.

Furthermore, a failure in the appreciation of blue and yellow may be termed tritanomalia if partial, and tritanopia if absolute. Kalmus (1955) suggested that congenital tritanopia is generally due to one or several autosomal dominant genes, with somewhat imperfect manifestation. On a single-gene hypothesis, he estimated the incidence of the gene in England at about 1 in 20,000.

Inheritance

Deuteranopia, deuteranomalia, protanopia and protanomalia are collectively called colour blindness. During the late eighteenth and the nineteenth century, it became known that colour blindness is inherited. It was, however, E. B. Wilson (1911) who first pointed out that all of the facts about the heredity of colour blindness could be explained by the assumption that the recessive

gene responsible for this condition is contained in the X-chromosome and that in man the male is the heterogametic sex. Later work confirmed this hypothesis of X-linked inheritance for all colour vision defects except the very rare congenital defect tritanopia. Since only in the rare cases where the husband is affected and the wife is also affected (homozygous) or is a carrier (heterozygous) can there be affected daughters, the incidence of colour blindness is much lower in women than in men.

It is controversial whether the four common types of colour blindness are controlled by four different genes at two or more different loci in the X-chromosome, or by different alleles at a single locus. The hypothesis of two loci is favoured by most geneticists.

ANDHRA PRADESH

Visakhapatnam and Waltair

The first survey in Andhra Pradesh was made in one girls' school, one boys' school and one co-educational school in the adjacent municipalities of Visakhapatnam and Waltair. These are:

(a) Kurupam Durga Psasad Memorial High School, Waltair,

(b) Mahatma Gandhi Municipal High School, and

(c) Municipal High School for Girls

} Visakhapatnam

All three are secondary schools and admission into them is not restricted to members of any particular caste or religion. Many of the students have homes in Visakhapatnam and Waltair, but a considerable number come from other parts of the state, mostly from the coastal districts. It was attempted to test complete classes. A few individuals unavailable when the class was first tested were examined if they returned to school while we were still working in it.

The students' ages ranged from 12 to 18 years. Ishihara (1959) plates numbered 1, 2, 6, 10, 14 and 16 were used to test all the students. So-called normal people read these as 12, 8, 15, 45, no number, and 42 respectively. Plate No. 1 was always shown first, and the order of the other five plates was changed between each test. All the tests were made in bright daylight but not in direct sunlight.

Results

The number of students tested in the three schools are given in Table 1. Twenty-two out of 292 boys tested and one out of 272 girls were judged to have abnormal colour vision; i.e. the incidence of colour blindness is 7.53 per cent among boys and 0.367 per cent in girls. The subclassification of the colour blind students is given in Table 2. Where two figures are given, the first was the first attempt and the second, in brackets, the definite reading. These answers are given in such detail because as was to be expected subclassification by using the Ishihara plates has not always been satisfactory, especially when only six plates are used. Students numbered 22, 39, and 192 gave inconsistent answers. Student 22 gave answers which would place him among normals but for his inability to read the numbers on plate 16. This record may be due to an error on the part of the observer. Students 39 and 192 are no doubt colour blind, but they do not fit any clear patterns for subclassification. It is also not clear if they are totally colour blind; 18 and 67 who gave the same final readings but hesitated over different plates, are borderline cases and it is not certain if they are protanomalous or deuteranomalous. There are other cases such as 109, 248 and 339 whose answers were not clear enough for a definite subclassification. Few previous authors discussed the problems that arise out of using these plates. The use of an older edition has, however, been briefly discussed by von Planta (1928).

According to Ishihara the majority of normals see no number on plate 14 and the majority of those with red-green deficiencies read it as 5. The "normals" in this investigation are classified according to their ability to read 5 on plate 14 in comparison with "mistakes"*, if any, they made on other plates. These other "mistakes" were always over the plates 2, 6, and 10 (Table 3). Among these "normals" 12.2 per cent of the boys and 16.2 per cent of the girls read 5 and there is no significant correlation between this and the mistakes they made on other plates. Plates 1 and 16 were read correctly by all 541 normals.

Polavaram

Polavaram is the headquarters of the Polavaram Taluk in the West Godavari district and has a population of 20,000 Hindus, Christians and Muslims. It is over 20 miles from the nearest railway station of Kovvuru on the Southern Railway. There are several tribal villages to the north and west of Polavaram which are classified into seven areas for the purpose of this investigation. Each of these areas is named after the largest and more prominent village in that area. These are Puliramudigudem, Vinjaram, Achayyapalem, Rajanagaram, Kondrukota, Dondapudi, and Koya Kannapuram. The non-tribal students and staff of the Gorvernment Higher Secondary School in Polavaram were also tested for colour blindness. All the tribal and non-tribal peoples investigated are males.

Tribal People

The tribes investigated for colour vision were Koya Doras, Koya Kammaras, Koya Musaras, Konda Reddis (also known as Pandava Reddis or Hill Reddis), Konda Rajus, Pandava Nayakas and Sugalis (also known as Lambadis). The distance between two adjacent villages ranges from 0.5 mile to 3 miles. These people live in thatched huts with floors and walls made of hard earth. The chief

in each village was usually tested first and he then asked other villagers to submit themselves for the test. The Koyas speak a dialect which sounds similar to Tamil, but they can also speak Telugu, in which I conversed with them during the investigation. They are good archers and their occupations include agriculture, animal husbandry and hunting. As there are no proper roads in this area many villagers such as Chegondopalli can only be reached on foot through rice and tobacco fields. Some of the "roads" are dried up stream-beds and are strewn with large boulders. During the monsoon the roads and paths are washed away and the villages are isolated from each other and also from Polavaram.

There are certain villages where a market (called "shandy" by local officials) is held each week for the tribal people who attend in large numbers. They were tested for colour vision at three such shandys: Koya Kannapuram, Dondapudi and Madhavapuram. The most important Telugu festivals namely Bhogi, Sankranti, and Kanuma are celebrated each year on 13, 14 and 15 of January. The celebrations include cock-fights at which large numbers of tribal people congregate. Colour vision tests were made at one such cock-fight which was held in the "Mamidi Thota" (Mango Grove) near the village Kondrukota.

As most of the tribal people are illiterate they were tested on Ishihara plates numbered 26 to 38, in reverse order, and the literates on 1 to 25 (Ishihara, 1960). Those who were found to be colour blind were also tested on Farnsworth's test. The staff and students of the Government Higher Secondary School, Polavaram, were tested on plates numbered 1 to 25.

Results

Out of 1155 subjects tested the largest number, i.e. 437, were in the Kondrukota area while only twenty-five were available in the Puliramudigudem area (Table 4). These differences between areas are primarily due to the accessibility of each region, the number of village chiefs who can be relied upon to

cooperate with us and the density of population. Twenty-six tribal students of the Government Higher Secondary School in Polavaram are also included here. The figures for Kondrukota area include those at a cock-fight and also a weekly market place at Madhavapuram. Besides these, twelve villages were visited in that area and altogether 437 tribal people hailing from thirty-three villages were tested. Data from Dondapudi and Koya Kannapuram also include the results of visits to two weekly market places in both villages. In all, twenty-nine colour blind tribals were found, out of which twenty-four were deuteranomalous or deuteranopic including doubtful cases, four protanamalous or protanopic and one totally colour blind. The man diagnosed as totally colour blind could see the line on plate 38 only. One out of twenty-six tribal students of the Higher Secondary School was found to be a protanope.

The tribals are subclassified according to their tribe or substribe and colour vision (Table 5). The tribe with the largest number tested is Koya Doras. Twenty-five out of 966 were found to be colour blind. Two defectives were found among the Koya Kammaras, and one in each of Sugalis and Konda Rajus, while no colour blind individual was found in the Konda Reddis, Pandava Nayakas, and Koya Musaras. Though the numbers tested for some of these tribes are not very large it is interesting that the difference between the frequency among Koya Doras (2.6%) and the remainder (2.1%) is quite significant ($\chi^2 = 0.1286$).

A comparison between the tribals and the non-tribals is attempted in Table 6. Data on the non-tribals recorded in Visakhapatnam and Waltair are also included here. Out of 569 non-tribals and 1155 tribals tested in Andhra Pradesh 6.5% and 2.5%, respectively, were found to be colour blind. The difference between these two groups is highly significant ($\chi^2 = 16.40$).

ORISSA

Boys

The students and members of the staff of an Agricultural College (Utkal Krushi Mahabidyalaya, Bhubaneswar), trainees of Gramsevak Training Centre, Bhubaneswar and fifteen caste Hindus from a tribal school were tested for colour vision using Ishihara plates (1959). Most students of the Agricultural College come from Orissa, a few from other states of India. Thus out of 577 subjects tested, 504 were Oriyas, and 73 were Bengalis, Andhras and Nepalis, etc. (Table 7). All the districts of Orissa are represented among the students. The subjects were all unrelated males and their ages range from 15 to 50 years in the Agricultural College and the Gramsevak Training Centre, and 10 to 17 in the tribal school. Admissions into these institutions are not restricted to any particular religion or caste.

Ishihara (1959) plates numbered 1 to 17 were used to test all the subjects except one who could not read the Arabic figures. He was tested on plates 18 to 24 and found to be normal. Plate No. 1 was always shown first, and the order of the other sixteen plates was frequently changed. The tracing brush provided with the Ishihara plates was sometimes used because some of the younger subjects were not familiar with certain Arabic numerals.

Results

The results are summarized in Tables 7 and 8. Out of 504 Oriya males tested twenty-five were judged to have abnormal colour vision, i.e. 4.96%. One out of seventeen Nepalis was also colour blind. Nepalis (other than students) are rarely found in this region of India. No colour blind individual was detected among the other linguistic groups, but the numbers tested are few.

The subclassification of the subjects judged to be abnormal is given in Table 8. The answers of a normal are given at the top of this Table. Where

the definitive reading. On plates 16 and 17 a normal, according to Ishihara, reads 42 and 35, respectively. Mildly deuteranomalous people see 4 more clearly than 2 on plate 16, and 3 more clearly than 5 on plate 17; while mildly protanomalous people see 2 more clearly than 4 on plate 16, and 5 more clearly than 3 on plate 17. The clearer number is italicized in the answers for these plates. For instance, subject No. 445 read 48 (*42*) on plate 16 and *35* on plate 17. *42* was his definitive reading on plate 16, and 4 was clearer to him than 2. Similarly on plate 17, 3 was clearer to him than 5. Accordingly he was classified in the deuteranomalous subgroup. Full answers of the abnormals are given in full here because, as in Andhra Pradesh, the subclassification by using the Ishihara plates was not always satisfactory. The diagnosis of subjects No. 255 and 360 is doubtful. No definite diagnosis is possible for some others such as subject No.432. Hesitation by subjects over certain plates is also taken into consideration in the analysis.

Girls

A similar investigation was made on 608 girl students and women teachers of the Capital Girls' High School in Bhubaneswar. Their ages ranged from 9 to 48 years. Ishihara (1959) plates No. 1 to 17 were used.

One girl was found to be colour blind, probably a deuteranope.

Association Between Colour Blind People

On two occasions in the investigation of college students in Bhubaneswar two colour blind subjects came one after another. Their serial numbers are 208 and 209, 301 and 302 (Table 8). Both 208 and 209 are deuteranopes whereas 301 and 302 are protanopes! Thus two of each set belonged to the same subgroup of colour blindness. The probability that the occurrence of two such sets is due to chance is less than 0.0003. This has also been observed in the investigation of tribal school where two deuteranopes came one after

another. In the Gramsevak Training Centre a protanope (10S) and a deuteranope (11S) came one after another. In the investigation of school children in Visakhapatnam and Waltair two such sets were observed. Serial Nos. 109 and 110 were deuteranopes and 228 and 229 were deuteranomalous and protanomalous, respectively. It is possible that a colour blind individual tends to associate more closely with other colour blind people than with non-colour blind people, and that such association may be more frequent between colour blind people of the same defect as happened in three of the five sets mentioned above.

Colour Blindness in Different Castes

The students of Visakhapatnam and Waltair are classified according to their religion and Varna. No detailed subclassifiecation of Varnas is attempted because of the small numbers of students in each group. These groups are arranged in the order of their numbers (Table 9). There is no significant heterogeneity between the frequencies of colour blind people in various Varnas among Hindus. There are a few Muslims and Christians in the tested sample but none of them were colour blind.

In Table 10 the Oriya subjects are classified according to their religion and caste. Out of 504 Oriyas tested, 495 were Hindus, five Tribals, three Muslims and one a Christian. The Hindus are subclassified into the four Varnas. Among these, Sudras are in larger number and they are subclassified into Khandayats, Karans and other Sudras. There is no significant difference between the frequencies of colour blindness among Brāhmans and Khandayats. Out of five Tribals tested one belonging to the Santal tribe was found to be colour blind (subject No. 432 in Table 8).

A NEW COLOUR VISION ANOMALY

Evidence is presented here to show that the ability to read plates 14 and 15 on Ishihara (1959) test is determined by a group of X-linked recessive genes. The genetical analysis of this ability, which is far more frequent than the known types of colour blindness in any population hitherto studied is based on studies of population samples and six pedigrees. Haldane (1963) gives the methods for testing the agreement of theory and observation as to the data published on the frequency of the sex-linked antigen Xg^a (Sanger, Race, Tippett, Hamper, Gavin & Cleghorn, 1962), and to the data presented here.

The ability to read plates 14 and 15 was first observed in the studies on Andhra Pradesh school children. This was later investigated further in Orissa to establish the mode of inheritance and the frequencies in both sexes. Dronamraju (1963, a and b) investigated, using Ishihara (1959) plates (numbered 1 to 17), the different types of colour blindness among 577 males and 608 females in Orissa.

Description of the Test

Plate 1 was always shown first but the order of the other 16 plates was frequently changed. The readings of normal and colour blind persons, as listed by Ishihara (1959) are given in Table 11. The normal as well as those with all sorts of colour blindness read 12 on plate 1. The majority of those with colour vision deficiencies are not able to read plates 8 to 13 or read them incorrectly. The majority of those with red-green deficiencies read 5 on plate 14 and 45 on plate 15, while the majority of the normal and those with total colour blindness and weakness are not able to read any numeral. The normal and those with mild protanomaly or mild deuteranomaly read 42 on plate 16 and 35 on plate 17. Protanopes and strongly protanomalous defectives read only 2 on plate 16 and only 5 on plate 17 while deuteranopes and strongly

deuteranomalous defectives read only 4 on plate 16 and 3 on plate 17. Persons with total colour blindness read 12 on plate 1 and no number on all the rest.

Results

One out of 608 females and 26 out of 577 males were found to be colour blind (Table 12). Among those who were judged to be normal some misread one or more plates. The majority of such misreadings were made on plates 14 and 15 while fewer misread plates 2 and 6 to 13. Women made far fewer "mistakes" than men (Table 13). If the frequency of all genes producing this effect is g, we have, for plate 14, g = 0.2062. The expected frequency in females would be 0.2062^2, or 0.042518. The expected number of females is 25.8 and the observed number is 21 (Table 14). Similarly, for plate 15, g = 0.1698. The expected frequency in females would be 0.1698^2, or 0.028832. The expected number of females is 17.5 and the observed number is 19 (Table 14). Thus, there is a preliminary fit to the hypothesis that if a man carries the genes for the known types of colour blindness or some others at the same locus he can usually read "14" and/or "15". A woman carrying two such genes can also do so. Among normal males, 17.1% read 5 on plate 14, 14.2% read 45 on plate 15 and 6.9% read both. Among normal females, 3.3% read 5 on plate 14, 2.9% read 45 on plate 15 and 1.5% read both. Altogether, 31.2% of normal males and 6.3% of normal females were able to read either or both of plates 14 and 15 (Table 14).

Out of 577 males tested, only 219 or 37.9% gave perfectly normal answers as listed by Ishihara (1959). This number, however, increases to 300 or 51.9% if we include those normals who read plates 14 and 15 (Table 15). Similarly, out of 608 females tested, only 344 or 56.6% gave perfectly normal

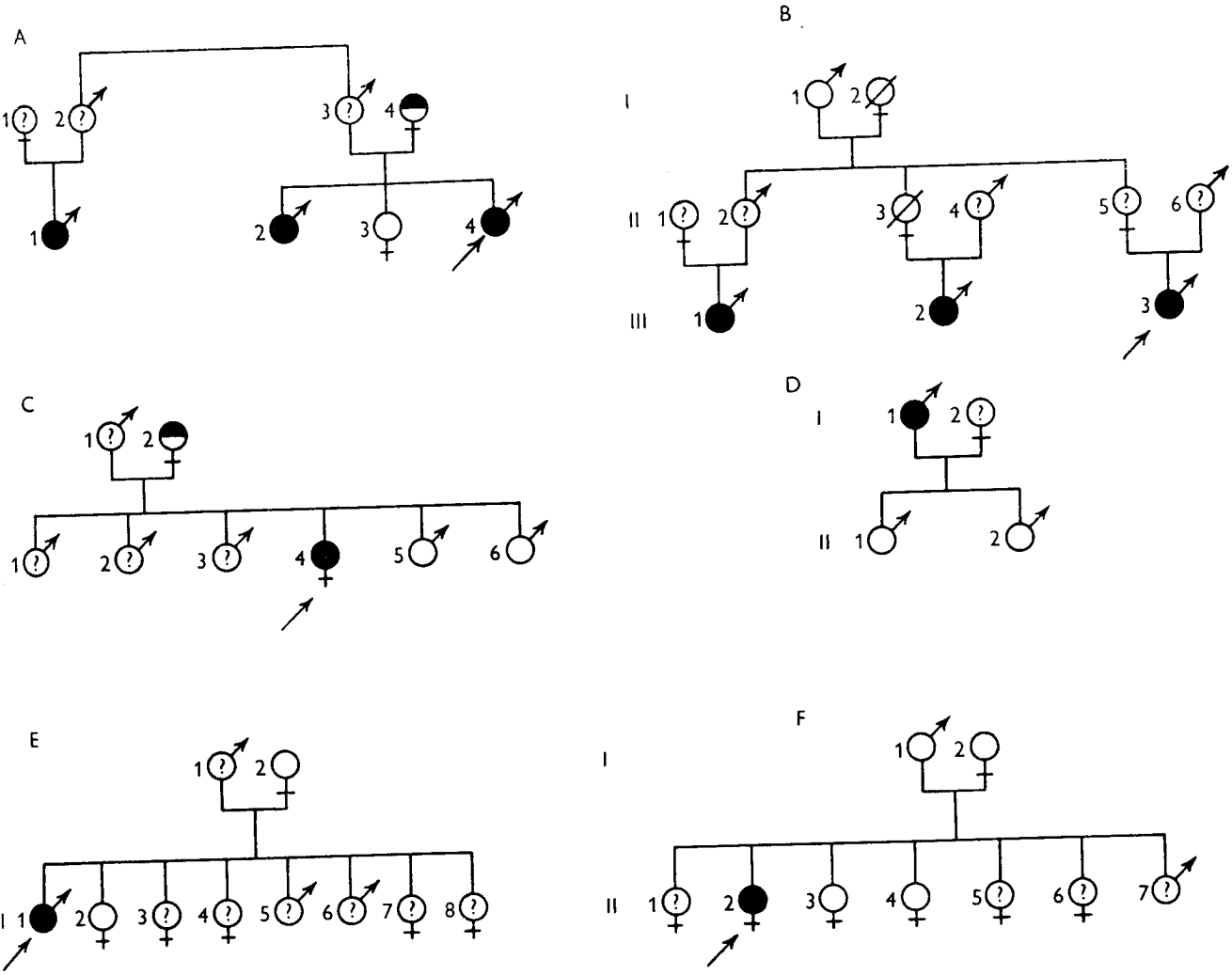

Fig. 1. Pedigrees A–F.

answers according to Ishihara (1959). If we include those normals who read plates 14 and 15, this number increases to 384 or 63.1%.

Pedigrees

Six pedigrees are given in Fig. 1 (A-F).

(A) (P.V.R.). A Telugu Brāhman family of Bhubaneswar. I.1, I.2, and I.3 were not available for the test. I.4 read 5 on plate 14 and no number on plate 15. Her two sons II.2 and II.4 read both, while the daughter II.3 could read neither. II.1 read both. His parents were not available for the test.

(B) (N.M.). An Oriya Brahman family of the village of Sri Ramchandrapur in the Puri district. The only available person in the second generation--II.5--could not read Arabic numerals. All the three grandsons of I.1 were able to read both.

(C) (S.D.). An Oriya Brāhman family of Bhubaneswar. I.1 was not available for the test. His wife I.2 was tested and read 5 on plate 14 and no number on plate 15. Among their children, II.1, II.2, and II.3 were unavailable, II.4 read both plates, II.5 and II.6 could read neither.

(D) (K.C.R.). An Oriya Brāhman family of Bhubaneswar. I.1 read both, his wife I.2 was unavailable, and their two sons II.1 and II.2 could read neither.

(E) (P.N.R.). An Oriya Brāhman family of Bhubaneswar. I.1 was unavailable his wife I.2 could read neither. II.1 read both but his sister II.2 could read neither. II.3 and the rest could not read Arabic numerals.

(F) (K.C.M.). An Oriya Brāhman family of Bhubaneswar. I.1 and I.2 could not read either plate. II.2 read both, II.3 and II.4 could read neither. II.1, II.5, II.6 and II.7 were unavailable.

Pedigrees A, B, C, D and E are all fully compatible with the hypothesis of sex-linked recessive inheritance. In pedigree F, the daughter II.2 could

read both while both parents could not read either plate. This is the only exception I have come across so far and this may be, as suggested by Haldane (1963), due to the inexperience of some of my subjects, particularly females, in reading Arabic numbers.

DISCUSSION

There is a good agreement between the observed and expected gene frequencies among females. Five of the six pedigrees investigated so far are all compatible with the hypothesis of sex-linked (i.e., X-linked) recessive inheritance.

The frequency of colour blindness (in the usual sense) in Orissa is 4.6% among males and 0.16% among females. The colour vision anomalies which enable people to read plates 14 and 15 are much more frequent; 34.3% of 577 males and 6.5% of 608 females in Orissa could read them. Thus, a colour vision anomaly of very high frequency and of probable X-linked recessive inheritance is reported here. The advantages of using this marker genetical studies are obvious. For example, this marker can be used in the linkage studies of such X-linked traits as the blood group antigen $\underline{Xg^a}$ and G-6-PD deficiency of the red cell. Screening of large sample can be rapidly done with the aid of the two Ishihara plates.

It is desirable to study this polymorphism in other populations. Studies of population samples and large pedigrees will throw more light on the frequency and inheritance of this trait which will help in confirming or rejecting the hypothesis presented here.

POPULATION DIFFERENCES AND SELECTION RELAXATION

No attempts were made until recently (Post, 1962; Dronamraju and Meera Khan, 1963) to interpret the differences in the frequencies of colour blindness between different populations in terms of natural selection. This

was partly due to the unawareness of ophthalmologists, physical anthropologists and geneticists of each others' work, and partly due to the unavailability of data on remote populations of the world. Both have been remedied in recent years by the extensive and often collaborative researches of population geneticists and physical anthropologists in diverse populations. Colour vision defects are particularly suitable as genetic markers in population studies because of the following reasons:

(a) clear cut identification of deutan and protan defects in the field with the aid of simple tests,

(b) convenient frequencies of colour blindness in most populations - neither too high nor too low,

(c) the apparent lack of non-penetrance and age effects, and

(d) the sex-linked nature of inheritance and simple genetic control.

I shall first attempt to review briefly the literature published on the incidence of colour blindness types in different populations.

In Asia much information is now available for several populations in India, China and Japan, etc. (Table 16).

The highest incidences among the non-tribal people of India were recorded in the Brahmins of Gujarat and Bombay (Table 16). The numbers tested, however, were only a hundred in each case and more men in these communities should be tested before these frequencies can be regarded as correct. The frequency of colour blindness in Andhra Pradesh school children is slightly higher than in the caste Hindus of Orissa but the difference is not significant. The over-all frequency in Brahmins of Gujarat and Bombay ranges from 10.0 per cent to 1.0 per cent. In the tribal populations of Andhra Pradesh, Koyas were tested in large numbers and the over-all incidence was found to be 2.5 per cent. Smaller numbers of tribesmen were tested in Gujarat and the frequencies range from 9.0 per cent to 0.7 per cent. In most Indian tribes,

however, where larger numbers were tested the frequencies seldom exceeded 2.8 per cent (Table 16). Information regarding the incidence in females is available for only two populations in India: the Hindus of Orissa and Andhra Pradesh where the frequencies were found to be 0.2 per cent and 0.4 per cent respectively (Dronamraju, 1963 b; Dronamraju and Meera Khan, 1961).

The frequencies found in the settled and non-tribal populations of other Asian countries range from 3.1 per cent to 7.4 per cent. The populations investigated include Chinese, Philippinos, Persians and Japanese. In most populations the incidence is well over 4.0 per cent (Table 17).

In Africa, five different populations were studied and the frequencies range from 1.7 per cent to 3.0 per cent. The populations investigated are Bechuanas, Bugandas, Batutsis, Bahutus and the Congolese of the Belgian Congo. The incidence in Bechuana women was found to be 0.4 per cent. The lower frequencies observed in the African populations are in agreement with those found in the tribal people of Gujarat and Andhra Pradesh in India (Table 18).

Much information is available regarding the frequencies in several European populations in Norway, Switzerland, France, Germany, Poland, U.S.S.R., Bulgaria, Great Britain and other countries. The frequencies recorded in European men range from 10.1 per cent in Norway to 4.7 per cent in Komi S.S.R. (Table 19). The frequency recorded in Australian whites was 7.3 per cent, in half-castes 3.3 per cent and only 1.9 per cent in the aborigines! Out of 608 Fiji islanders tested 99 or 0.8 per cent were found to be colour blind.

In South America, no colour blind individual was detected among 230 male and 129 female Brazilian Indians tested! Out of 164 Brazilian Caingang men tested 4.3 per cent were colour blind. Kalmus (1957) tested 250 male Brazilians of mixed negro and mulatto ancestry and found 8.8 per cent to be colour blind (Table 20). Frequencies of 2.3 to 2.5 per cent were recorded in Mexican men,

and 0.6 to 0.9 per cent in women. Frequencies ranging from 4.2 to 2.8 per cent were recorded in the American Negro men in Virginia, Colorado, North Carolina, Tennessee and Connecticut. Lower incidences were reported among the north American Indians; 1.1 to 2.5 per cent in men and 0.7 to 1.0 per cent in women. The frequencies reported in the North American whites are in general agreement with those reported for European and non-tribal Asian populations; they range from 4.4 to 9.5 per cent.

The frequencies reported in Jewish men range from 4.0 per cent in Denver, Colorado to 9.5 per cent in Central Europe (Table 21). These frequencies are in agreement with the values found in well settled populations of Asia and Europe.

Selection Relaxation

It is clear from the data presented in Tables 16-21 that the over-all frequencies of colour blindness observed in the settled and non-tribal populations of Asia, Australia, Europe and North America are generally higher than in the tribal or aboriginal peoples of Asia, Australia, Brazil and North America, and the indigenous peoples of Africa. It was proposed that this difference could be explained assuming that colour blindness would be a serious handicap in a primitive environment and may prove frequently fatal under stress (Post, 1962; Dronamraju and Meera Khan, 1963 b). It is reasonable to assume, for instance, that an individual with red-green colour vision deficiency would be an easy prey to wild animals and hostile tribesmen in the forest of south India or in the African or Australian bush and that such individuals would die more often than individuals with normal colour vision before the attainment of reproductive age. It is also assumed that a colour blind individual could be as successful as a normal person in living in a pastoral-agricultural habitat. According to this hypothesis selection against

colour blindness is relaxed as a community becomes more civilized. (It is possible that this relaxation is reversed in highly industrialized and prosperous countries such as United States where colour blind motorists may be involved more often in fatal automobile accidents than those with normal colour vision. There is however no evidence at present to support this hypothesis.)

Frequencies in Different Ethnic Groups and Countries

An examination of the frequencies recorded suggests that there are no significant differences in the frequencies of colour blindness in different ethnic groups or countries. The differences between settled and tribal or aboriginal communities are universal and the hypothesis of selection relaxation can reasonably be applied to all the populations so far studied.

Deutan and Protan Types

It is attempted to examine the data for deutan and protan types separately (Table 22) in populations for which these were reported. The proportion of individuals with protanopic defects is higher in Andhra Pradesh, Orissa and in some Jewish communities of Israel than in other populations. This may be due to the differences in the intensities of selection (or rather the differences in the extent to which selection is relaxed) at the two loci in certain populations. The data available at present are small and more information is required before these differences can be satisfactorily explained. It is, however, obvious that the prevalence rates of protans and deutans support the relaxation hypothesis as well when considered separately as do the joint rates in previous tables. The tribal and aboriginal communities have the lowest frequencies of protans and deutans.

SUMMARY

Out of 569 Hindu boys and 272 girls tested in Andhra Pradesh schools, 6.5 per cent and 0.4 per cent respectively were found to be colour blind. Several groups of Andhra Pradesh tribals were also tested and one or more colour blind individuals were detected among the Koya Doras, Koya Kammaras, Konda Rajus and Sugalis. The over-all incidence among the tribal males is 2.5 per cent.

In Orissa, 4.9 per cent of 504 Hindu boys and 0.2 per cent of 608 girls were judged to have abnormal colour vision.

The pooling of all degrees of deutan and protan defects separately suggests the following frequencies:

	Deutan	Protan
Andhra Pradesh (Hindus)	.049	.015
Andhra Pradesh (Tribals)	.020	.004
Orissa (Hindus)	.028	.022

The difference in the over-all frequencies between tribal and non-tribal peoples of Andhra Pradesh is statistically significant ($\chi^2 = 16.40$). It is suggested that this observation is in agreement with the lower frequencies recorded in the tribal, aboriginal or nomadic communities of Australia, Africa, Brazil and North America and that the higher incidences observed in Europeans, Japanese, Chinese and Asiatic Indians are due to relaxation of selection against colour blindness in settled communities with pastoral-agricultural economies.

New Colour Vision Anomaly

Frequency data on 577 males and 608 females in Orissa suggest that the ability to read plates 14 and 15 of Ishihara (1959, second edition) test is

determined by a group of X-linked recessive genes. Five out of the six pedigrees investigated are compatible with the hypothesis. The frequency among males is 34.3% and among females 6.4%. The frequency of colour blindness (in the usual sense) is 4.9% among males and 0.2% in females.

Haldane's (1963) test confirmed the hypothesis of X-linked inheritance of this new anomaly.

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Name of the School	Number tested ♂	♀	Totals
M.G.M.H. School	237	0	237
M. H. School for Girls	0	255	255
K.D.P.M.H. School	55	17	72
TOTALS	292	272	564

Table 1. Number of school children tested in Waltair and Visakhapatnam.

Student no.	Sex	Chart nos. 1	2	6	10	14	16	Diagnosis
	♂,♀	12	8	15	45	x	42	Normal
2	♂	12	3	17	x	5	4	Deuteranope
57	♂	12	3	17	x	5	4	Deuteranope
102	♂	12	3	17	x	5	4	Deuteranope
110	♂	12	3	17	19	6	4	Deuteranope
109	♂	12	8 (3)	19	x	5	6 (4)	Deuteranope (?)
67	♂	12	8	17	45	x (5)	42	Deuteranomalous or normal
205	♂	12	8	17	x	5	4	Deuteranomalous
228	♂	12	8	19 (17)	x	5	4	Deuteranomalous
213	♂	12	8	17	50	5	4	Deuteranomalous
127	♂	12	3	15	16 (43)	5	4	Deuteranomalous
18	♂	12	8	17	x (45)	5	42	Deuteranomalous (?)
21	♂	12	8 (3)	19 (17)	x	5	6	Protanope
5	♂	12	3	19	18	5	6	Protanope
100	♂	12	3	x	x	5	2	Protanope
649	♂	12	3	17	x	6 (5)	2	Protanope
248	♂	12	3	17	x	5	42	Protanomalous or protanope
48	♂	12	8	25	x	x	42	Protanomalous
24	♂	12	8	17	x	5	9	Protanomalous
229	♂	12	3 (8)	17	x	5	2	Protanomalous
22	♂	12	8	15	45	x	x	Inconsistent
39	♂	12	8	x	x	5	x	Inconsistent
192	♂	12	x	17	x	5	x	Inconsistent
339	♀	12	8	17	15	5	42	Protanomalous (?)

Table 2. Classification of abnormals; x indicates no number read (Andhra Pradesh)

	Made no "mistake" according to Ishihara		Made one or more "mistakes"		Total	
Did not read 5 on Chart 14	223	217	14	10	237	227
Did read 5 on Chart 14	30	42	3	2	33	44
TOTAL	253	259	17	12	270	271

Table 3. Classification of normals

	Number Tested	Deutans	Deuteranomalous or normal	Protans	Total Colour Blindness?
Puliramudigudem	25	1	0	0	0
Vinjaram	234	1	1	0	1
Achayyapalem	143	5	1	1	0
Rajanagaram	89	2	0	0	0
Kondrukota	437	5	5	1	0
Dondapudi	101	1	0	0	0
Koya Kannapuram	100	2	0	0	0
Tribal students of Higher Secondary School, Polavaram	26	0	0	1	0
Total	1155	17	7	4	1

Table 4. Classification of the tribals according to the area of investigation and the type of colour blindness. All males.

	Tribe or Sub-Tribe							
	Konda Reddi	Konda Raju	Koya Dora	Koya Kammara	Koya Musara	Sugali	Pandava Nayaka	Total
Normal	61	5	941	42	3	50	24	1126
Colour Blind	0	1	25	2	0	1	0	29
Total	61	6	966	44	3	51	24	1155

Table 5. Classification of the tribals according to their tribe or sub-tribe and colour vision.

All males.

Subjects	Source	Number Tested	Colour Blind D	P	?	Percentage Colour Blind
Non-Tribals						
School boys in Visakhapatnam and Waltair	Dronamraju and Meera Khan (1961)	292	11	8	3	7.5
Staff and school boys in Polavaram	Dronamraju and Mehakhan (1963)	277	14	1	0	5.4
Total for Non-Tribals		569	25	9	3	6.5
Tribals	Dronamraju and Mehakhan (1963)	1155	24	4	1	2.5

Table 6. Frequencies of colour blindness among the tribals and non-tribals of Andhra Pradesh. D = Deuteranope or Deuteranomalous, P = Protanope or Protanomalous. ? = Inconsistent or Totally colour blind. All males.

	No. tested	Colour blind	Colour blind (%)
Oriya	504	25	4.96
Bengali	34	0	0
Nepali	17	1	5.9
Telugu	17	0	0
Punjabi	2	0	0
Tripuri	1	0	0
Malayalam	1	0	0
Hindi	1	0	0
Totals	577	26	4.5

Table 7. Classification of subjects in Orissa, based on language spoken.

	Ishihara plate nos.																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Diagnosis
	12	8	6	57	5	15	74	2	6	45	5	7	16	X	X	42	35	Normal
Subject no.																		
192	12	8(3)	6	85	9	17	21	X	X	X	X	X	X	5	45	2	5	Protanope
205	12	8	5	33	2	17	21	X	X	X	X	X	X	5	45	2	5	Protanope
284	12	8	6	85	8	17	21	X	X	X	X	X	16	X	45	2	5?	Protanope
302	12	3	8	35	2	17	21	X	X	x	X	X	X	5	25(45)	2	5	Protanope
10S	12	3	6?	55	2	17	21	X	X	X	X	X	X	5	X	2	5	Protanope
26S	12	8	6	55	2	X	21	10	2	X	5	7	16	5	45	2	5	Protanope
42S	12	8	6	35	8(2)	17	21	X	X	X	X	X	X	5	X	2	5	Protanope
70S	12	3	5	35	2	17	21	X	X	X	X	X	X	5	45	2	5	Protanope
301	12	8(3)	5	55(35)	2	17	21	X	X	16	X	X	X	5	45	*42*	5	Protanope or protanomalous
109	12	8	5	33(88)	2	17	21	X	X	X	X	X	X	5	45	*62*	35	Protanomalous
200	12	8	6	87	5	15	X	2	X	45	5	7	X	5	45	*42*	35	Protanomalous or normal
4	12	3	5	85(35)	2	17	21	X	X	X	X	X	X	5	46(45)	4	3	Deuteranope
134	12	3	5	35	2	17	21	X	X	X	X	X	X	5	45	X	3	Deuteranope
4S,50S 208,304	12	3	5	35	2	17	21	X	X	X	X	X	X	5	45	4	3	Deuteranope
209	12	8	5	55	2	17	21	X	X	X	X	X	X	5	45	4	8	Deuteranope
11S	12	8	5	55	2	17	21	X	X	X	X	X	X	5	25	4	3	Deuteranope
432	12	3	5	35	8	15	21	X	X	X	X	X	X	5	45	*42*	*33*	Deuteranomalous or deuteranope
140	12	3(8)	8(6)	37	8(2)	17	21	2	6	X	X	X	X	3(5)	26(15)	42	38(35)	Deuteranomalous
445	12	8	5	34(33)	12	15	21	X	X	X	X	X	X	5	25	48(42)	*35*	Deuteranomalous
90S	12	3	5	35	8	15	81	X	X	X	X	7	10(16)	5	45	*42*	35	Deuteranomalous
255	12	8	6	57	3	15	21	X	6	15	X	7	16	5	45	42	35	Mildly deuteranomalous?
307	12	8	6	57	5	15	21	2	6	45	X	X	X	5	45	42	35	Mildly deuteranomalous?
360	12	8	6	57	5	15	21	X	X	X	5	7	16	5	X	62(42)	35	Mildly deuteranomalous?

N.B. In columns 16 and 17 the italic figure was the one read more clearly.

Table 8. Subclassification of the twenty-six abnormals; X indicates no number read (Orissa)

	Normal		Abnormal	
	♂	♀	♂	♀
Hindus				
Sudras	164	112	16	0
Brāhmans	78	121	5	1
Kshatriyas	13	8	0	0
Komatis	4	4	1	0
Harijans	4	5	0	0
Christians	4	19	0	0
Muslims	3	2	0	0
Totals	270	271	22	1

Table 9. Classification of school children in Andhra Pradesh according to their caste and colour vision.

	No. tested	Colour blind	Colour blind (%)
Hindus			
Brāhmans	186	8	4.3
Kshatriyas	20	0	0
Vaisyas	7	0	0
Sudras — Khandayats	106	5	4.7
Sudras — Karans	56	2	3.6
Sudras — Other Sudras	120	9	7.5
Tribals	5	1	20.0
Christian	1	0	0
Muslims	3	0	0
Totals	504	25	4.96

Table 10. Classification of 504 Oriyas.

Plate no.	Normal reading	Person with red-green deficiencies				
1	12	12				
2	8	3				
3	6	5				
4	57	35				
5	5	2				
6	15	17				
7	74	21				
8	2	x				
9	6	x				
10	45	x				
11	5	x				
12	7	x				
13	16	x				
14	x	5				
15	x	45				
		Protan			Deutan	
		Strong	Mild		Strong	Mild
16	42	2	(4) 2		4	4 (2)
17	35	5	(3) 5		3	3 (5)

Table 11. Readings of normal and colour blind persons on Ishihara Plates (1959). Figures in brackets can be read but are comparatively unclear. x means no number is read.

Sex	No. tested	No. colour blind	Colour blind (%)
♂	577	26	4.6
♀	608	1	0.16

Table 12. Frequency of colour blindness in Bhubaneswar, Orissa.

Plate no.	Colour blind answer		Neither colour blind nor normal answer	
	♂	♀	♂	♀
1	0	0	0	0
2	1	1	0	0
3	0	0	0	1
4	0	0	12	23
5	0	0	6	10
6	0	1	0	1
7	14	0	70	95
8	4	0	24	71
9	2	0	0	6
10	7	0	26	70
11	3	0	1	3
12	1	0	0	1
13	1	0	2	0
14	94	20	39	39
15	78	18	118	62
16	0	0	0	1
17	0	0	2	0

Table 13. Number of normals who gave abnormal answers on each of seventeen Ishihara Plates.

	Sex	No. tested	Read 5 on Plate 15	Read 45 on Plate 15	Read both	Read one or both
Normal	♂	551	94 (17.1)	78 (14.2)	38 (6.9)	172 (31.2)
	♀	607	20 (3.3)	18 (2.9)	9 (1.5)	38 (6.3)
Colour blind	♂	26	25 (96.1)	20 (76.9)	19 (73.1)	26 (100.0)
	♀	1	1	1	1	1

Table 14. Figures in parentheses refer to percentages.

Sex	No. giving normal answers	Total	Percentages
♂	219 (300)	577	37.9 (41.9)
♀	344 (384)	608	56.6 (63.1)

Table 15. Figures in parentheses refer to normals who gave abnormal answers on Plates 14 and 15.

Population	No. tested ♂	No. tested ♀	Frequency ♂	Frequency ♀	S	Author
School children in Andhra Pradesh (caste Hindus)	569	272	.065	.004	.004	Dronamraju, 1961, 1963
Tribal people of Andhra Pradesh Koya Dora	966		.025		.0006	Dronamraju, 1963
Konda Reddi	61		0		0	"
Sugali	51		.019		.0003	"
Koya Kammara	44		.045		.002	"
Pandava Nayaka	24		0		0	"
Konda Raju	6		.166		-	"
Musara	3		0		0	"
Orissa (Oriya caste Hindus)	504	608	.049	.002	.002	Dronamraju, 1963
" Nepalis	17		.059		-	"
" Bengalis	34		0		-	"
Six endogamous groups in Bombay						
VNB	100		.100		.01	Sanghvi, 1949
DRB	100		.030		.0009	"
DYB Brahmins	100		.030		.0009	"
KB	100		.050		.002	"
CKP	100		.010		.0001	"
M	200		.020		.0004	"
Brahmins (Madras)	153		0		-	Sirsat, 1956
Brahmins (Banares)	86		.012		.0001	Sirsat, 1956
Six Gujarati groups						
Brahmins, ABS	100		.090		.008	Vyas, 1958
Tribesmen, TD	106		.028		.0007	"
Other castes; KV	100		.050		.002	"
BHS	100		.010		.0001	"
CL	100		.060		.003	"
IPC	100		.030		.0003	"
Six Gujarati tribes						
Koli	67	63	.090	0	.008	Vyas, unpublished
Naika	36	46	.028	0	.0007	"
Dhodia	45	40	0	0	-	"
Gamit	147	54	.027	0	.0007	"
Bhil	142	27	.007	0	.00004	"
Dhanka	111	102	.018	0	.0003	"
Tamils (Madras)	282	78	.045	0	.002	Ananthanarayana Iyer, 1956
Tamils (Pondicherry)	973		.042		.001	Olivier, unpublished
Eight endogamous groups in Bombay						
Brahmins, GSB	100	100	.050	0	.002	Varde, 1961, unpublished
Other castes, SKP	100	100	.030	0	.0009	"
AG	100	89	.010	0	.0001	"
CH	111	96	.036	0	.001	"
DK	83	51	.012	0	.0001	"
MH	93	99	.022	0	.0004	"
LP	100	100	.020	0	.0004	"
LG	155	48	.026	0	.0006	"

Table 16. India (S = Expected frequency in females)

Population	No. tested ♂	No. tested ♀	Frequency ♂	Frequency ♀	S	Author
Chinese, Peiping	1164	1132	.069	.017	.004	Chang, 1932
Chengtu,	1115		.063		.003	Kilborn, 1934
Chengtu, students	7542	3519	.050	.007	.002	Chen, 1950
Philippinos	959	977	.042	.002	.001	Nolasco, 1949
Persians, Tabriz	949		.045		.002	Plattner, 1959
Japanese						
Hiroshima	809		.049		.002	Schull, 1962
Nagasaki	1157		.048		.002	Schull, 1962
Tokyo	1524		.051		.002	Nakajima, 1960
Sado, north	1338	1314	.031	.002	.0009	Nagasima, 1949
" central	3547	3235	.035	.002	.001	"
" south	1671	1582	.074	.010	.005	"
Shisuoka	1524	1509	.050	.003	.002	Majima, 1960
Hokkaido	9689	5980	.039	.003	.001	Sato, 1935
Gumma	5977	4835	.039	.006	.001	"
Ishikawa	12115	11018	.043	.006	.001	"
Kumamoto	18385	12344	.040	.006	.001	"
Kagoshima	8366	7982	.040	.007	.001	"
Japanese in Brazil	62		.029		.0008	Kalmus, 1957

Table 17. Other Asian Countries.

Population	No. tested ♂	No. tested ♀	Frequency ♂	Frequency ♀	S	Author
Bechuanas	407	574	.030	.004	.0009	Squires, 1942
Bugandas	537		.019		.0003	Simon, 1951
Batutsis	1000		.025		.0006	Hiernaux, 1953
Bahutus	1000		.027		.0007	"
Belgian Congo	929		.017		.0002	Appelmans, 1953

Table 18. Africa

Population	No. tested ♂	No. tested ♀	Frequency ♂	Frequency ♀	S	Author
Norwegians, Oslo	2005	2200	.101	.009	.01	Schiotz, 1922
" "	9047	9072	.080	.004	.006	Waaler, 1927
Swiss, Basel	2000	3000	.080	.004	.006	von Planta, 1928
Germany	6863	5604	.078	.004	.006	Schmidt, 1936
France	6635	6990	.089	.050	.007	Kherumian, 1959
London	6000		.068		.004	Vernon, 1943
England, East coast	6000		.070		.005	"
" North central	6000		.074		.005	"
" South west	6000		.095		.009	"
" Northeast	6000		.054		.002	"
West of Scotland	6000		.077		.005	"
Glasgow	989	676	.078	.006	.006	Pickford, 1951
Russians	1373		.067		.004	Serebrovskaiä, 1930
Polish	103		.107		.01	"
Bulgarians	93		.065		.004	"
Finns of Leningrad	245		.057		.003	"
Tartars	755		.072		.005	"
Komi, S.S.R.	1019		.047		.002	Cheboxarov, 1936
Australia, Whites	558	327	.073	.006	.005	Mann, 1956
Australia, half-castes	181	273	.033	0	.001	"
" aborigines	4455	3201	.019	.003	.0003	"
Fiji islanders	608	99	.008	0	.00006	Geddes, 1946

Table 19. Europe & Australia

Population	No. tested ♂	No. tested ♀	Frequency ♂	Frequency ♀	S	Author
Eskimo, full bloods	297	273	.025	.004	.0006	Skeller, 1954
Navajo Indians	535	456	.011	.007	.0001	Garth, 1933
Ramah Navajo	163	197	.025	.010	.0006	Spuhler, 1951
North American Indian, full bloods (several groups pooled)	392		.020		.0004	Clements, 1930
" " plus Sioux	562	337	.025	0	.0006	Garth, 1933
Brazilian Indians	230	129	0	0	-	Mattos, 1958
" Caingangs (Paraná)	164	135	.043	0	.001	Salzans, 1961
" Caingangs (Paraná)	43		.070		.004	Fernandes, 1957
" Carajas (Goyaz)	35		.057		.003	Junqueira, 1957
Mexicans in Mexico City	571	494	.023	.006	.0005	Garth, 1933
" in Colorado	523	469	.025	.009	.0006	"
Brazilians: Negroes and Mulattoes, mixed	250		.088		.007	Kalmus, 1957
American Negroes:						
Virginia	2019	722	.039	.001	.001	Crooks, 1936
North Carolina and Tennessee	538	496	.039	.008	.001	Garth, 1933
Connecticut (full blood)	205		.034		.001	Clements, 1930
" (mixed blood)	118		.042		.001	"
Colorado	254	165	.028	0	.0007	Garth, 1933
American Whites:						
Stanford University	1286	436	.082	.009	.006	Miles, 1929
Nex Mexico	346	390	.038	.008	.001	Garth, 1933
Denver, Colorado	795	232	.084	.013	.007	"
Baltimore, Maryland	448	487	.078	.016	.006	Haupt, 1922
Philadelphia, Penna.	379		.065		.004	Dronamraju, unpublished

Table 20. North & South America

Population	No. tested ♂	No. tested ♀	Frequency ♂	Frequency ♀	S	Author
Jewish students at N.Y.U.	529		.076		.005	Schuey, 1936
Jews of Israel						
Ashkenazim (from northeast central Europe)	568		.095		.009	Kalmus, 1961
Sephardim (from southeast Europe)	140		.064		.004	"
North Africa	318		.066		.004	"
Kurdistan & Turkey	495		.065		.004	"
Iraq and Iran	742		.044		.001	"
Yamen and Aden	404		.052		.002	"
Palestine-born	143		.063		.003	"
Mixed, Middle-East	191		.059		.003	"

Table 21. Jewish Communities

Population	No. tested (all male)	Frequency Deutans	Protans	Total	Author
Caingangs (Paraná)	43	.047	.023	.070	Fernandes
N.A. Indians, mixed	392	.015	.005	.020	Clements
N.A. Indians, several groups with White admixture	232	.008	.004	.012	"
American Negroes, Connecticut	205	.025	.010	.035	"
American Negroes, with white admixture	118	.034	.008	.042	"
American Negroes Virginia	2019	.029	.010	.039	Crooks
Brazilian Negroes and Mulattoes (mixed)	250	.068	.020	.088	Kalmus
Arabs	337	.077	.021	.098	"
Japanese in Brazil	62	.097	.032	.129	"
Jews in Israel & Middle East					
Ashkenazöm	568	.062	.030	.092	"
Sephardim	140	.021	.029	.050	"
Kurdistan & Turkey	495	.044	.018	.062	"
Iraq and Iran	742	.032	.010	.042	"
Yemen and Aden	404	.025	.022	.047	"
Middle East, Mixed	191	.032	.022	.054	"
North Africa	318	.044	.019	.063	"
Palestine	143	.049	.014	.063	"
Persians, Tabriz	949	.039	.006	.045	Plattner
Indians					
Hindus of Andhra Pradesh	569	.048	.015	.064	Dronamraju
Tribals of Andhra Pradesh	1155	.020	.004	.024	"
Hindus of Orissa	504	.028	.022	.050	"
Belgians	1243	.062	.024	.086	François
English	1338	.063	.025	.088	Nelson
S.W. Scotland	989	.050	.028	.078	Pickford
Norwegians, Oslo	9047	.061	.019	.080	Waaler
Swiss, Basel	2000	.058	.022	.080	von Planta
Whites in Brazil					
Rdi de Janeiro	147	.054	.020	.074	Kalmus
Rural	247	.053	.016	.069	"
Whites in Philadelphia	379	.060	.005	.065	Dronamraju

Table 22. Incidence of deuteranopic and protanopic defects shown separately (all males).

ABO BLOOD GROUPS AND GENE FREQUENCIES

The blood group data recorded during the years 1955-1960 at the blood bank of the King George Hospital in Visakhapatnam were extracted and analyzed to calculate the frequencies of the genes A, B and O (p, q and r). The results are presented in Table I (Dronamraju, Meera Khan and Narayana Murty, 1962).

Table I

The Frequencies of Phenotypes and Genes of the ABO System in Different Population Groups of Andhra Pradesh

	O	A	B	AB	Totals	p	q	r	D
Hindus	1526	628	1040	147	3341	.1239	.1974	.6787	+ .0035
Christians	142	62	83	17	304	.1395	.1805	.6800	- .0041
Moslems	58	33	65	8	164	.1350	.2572	.6078	+ .0162
Totals	1726	723	1188	172	3809	.1256	.1985	.6759	+ .0033

The most frequent blood group among the Hindus and Christians is O, whereas among Moslems it is B. The Christian frequencies do not differ significantly from the Hindu ones ($\chi_3^2 = 2.74$). The Muslim frequencies differ very significantly ($\chi_3^2 = 74.65$). The expectation for Christians and Muslims had their frequencies been the same as Hindus is given in Table II.

Table II

	O	A	B	AB
Christians	138.9	57.1	94.6	13.4
Muslims	74.9	30.8	51.1	7.2

The similarity in this respect between the Hindus and Christians is compatible with the historical evidence that the Christians are

descendants of converts made among the Hindus. Since their settlement the Moslems have made fewer converts and have remained largely endogamous in this region of India. However, the origin of the Moslems remains uncertain since many Hindus, as well as Moslems in the northern Indian states, have more than 20 percent of the B gene (Mourant, et al., 1958). These populations, unlike those of Andhra Pradesh, have undergone various turmoils, first by foreign invasions and later by religious riots which must have resulted in gene exchange among various communities.

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SUMMARY AND CONCLUSIONS

The high frequency of consanguineous marriages recorded in Andhra Pradesh suggests that the population of the coastal districts in this state is probably the most highly inbred community in the world. The population is thus best suited for large scale investigations of the genetic effects of inbreeding. The present work also suggests that the children of consanguineous marriages may more often be susceptible to infectious diseases such as pulmonary tuberculosis than those of non-consanguineous marriages. Consanguinity may also cause more abortions and offspring with congenital malformations, and the females in such unions may remain sterile more often than those of non-consanguineous marriages. These observations, however, need further confirmation, and it is important to continue this study as soon as possible because the frequency of consanguineous marriages has been declining, especially since 1950, and infectious diseases are becoming rarer. The present study has been useful in recording the high frequencies of consanguineous marriages for the first time and in suggesting some fruitful lines of research for the future.

A new colour vision anomaly of high incidence and of probable X-linked inheritance is reported. This anomaly can be used in the mapping of the human X-chromosome.

The gene frequency of inherited colour vision anomalies among the caste Hindus of Andhra Pradesh and Orissa are in general agreement with the data on the settled populations of Europe though the proportion of Protanopes is higher in India. The significantly lower frequencies of colour vision anomalies in the tribals of Andhra Pradesh agrees with those reported in the Australian aborigines, some African populations such as the Bahutus and Bechuanas, and the Indians of North and South America. It is suggested that

natural selection against the colour blind gene has been and probably is still intense in aboriginal and tribal populations who live, hunt and gather food in a primitive environment. Such selection is relaxed as a population becomes more civilized and settled to live in pastoral-agricultural habitat. The gene has not completely disappeared in the primitive environment due to some factors not known at present, i.e. due to what is called a "balanced polymorphic system" in the terminology of population genetics. It is also possible that in highly industrialized and wealthy countries as in the United States there is selection against colour blindness owing to increase in fatal automobile accidents made by colour blind motorists.

The study of hypertrichosis pinnae auris in West Bengal, Orissa, Andhra Pradesh and Ceylon suggests that this trait, which is characterized by long hairs on the helix of ears and which is popularly known as "hairy ears", could be used as an anthropological marker in studying the affinities and differences between human populations. The inheritance of this trait is shown to be due to genes on the Y chromosome which also bears genes controlling the development of male sex. This is the first known example of Y-linked inheritance in man.

The higher incidence of blood group "B" in Muslims and the agreement between the frequencies of A, B and O in Hindus and Christians confirms the historical record that Christians are descendants of Hindus converted to Christianity while Muslims are descendants of some external population.

The work reported in this dissertation thus revealed several interesting features of the Andhra Pradesh population which should be exploited in the near future to answer some basic questions of population genetics before such factors as consanguineous marriages become rare.

S U P P O R T I N G W O R K

NON-GENETIC POLYMORPHISM IN BAUHINIA ACUMINATA L

Introduction

In the year 1958 Professor J. B. S. Haldane suggested that I should look for heterostylism in Indian plant species where it has not previously been observed. I found a condition resembling it on a bush of Bauhinia acuminata L. This however differs from the heterostylism so far reported in three respects. First, long and short styled flowers are found on the same plant; secondly the lengths of the filaments of the two flower types are not negatively correlated with the style lenght; and thirdly, most, if not all of the short styled flowers, are female sterile. I began measuring the styles on this bush in the middle of the flowering season, and the results encouraged me to measure them on four other bushes of the same species. A bush can produce up to 50 flowers in a day, so it was possible to compare the results on different bushes, and on the same bush at different times.

Material

The members of the species Bauhinia acuminata L are leguminous plants belonging to the subfamily Caesalpineae. They have woody upright stems growing to a height of 12 feet. The leaves consist of 2 leaflets joined to form a single leaf with two lobes at the apex. The flowers are white and solitary, and very conspicuous, making the bush attractive in a garden. The 5 petals are slightly unequal in size. The stamens number 10, but those of the inner whorl are usually smaller and sterile (Fig. 1 a,b). The pods are thin and flat, and contain 10-14 flat seeds.

Two bushes (Nos. I & II) of B. acuminata L growing in the compound of 202 Barrackpore Trunk Road, of the Indian Statistical Institute, and three (Nos. III, IV & V) growing in 204 Barrackpore Trunk Road, were numbered in

the order in which collections were started. All the opened flowers produced on each bush were picked daily between 08.30 and 09.30 hours in the morning, and the styles were measured while the flowers remained fresh. The periods during which these daily collections were made are shown in Table 1 and include the last days of the flowering season. After removing the petals and stamens the flower was placed horizontally on a millimetre scale; and the distance between the end of the ovary where this is seen to narrow and the stigmatic expansion was measured. The length was recorded to the nearest millimetre. The style was straightened fully on the scale before reading the measurement. In flowers where the style was much distorted or bent, a thread was also used to aid in the measurement. In 1960 a few petals and stamens were also measured in the same way.

The flowers are grouped according to their style lengths as shown in Table 2, and the bimodality demonstrated in Fig.2. There were no flowers at 11 mm, and the division into long and short styled flowers is based on this observation. This is further supported by the occurrence of very few flowers of style lengths around 11 mm. Thus the total numbers of flowers obtained from all the five bushes were 1, 4, 3 and 1 for style lengths 13 mm, 12 mm, 10 mm, and 9 mm, respectively.

Bushes I and II flowered for about 115 days from the date they were first examined, and produced 1683 and 1042 flowers respectively. They thus provided enough data for an analysis of the variation on the same bush and between the two bushes. The flowering period was divided into groups of ten days; and the mean maximum and minimum temperatures, the mean rainfall and the two mean style lengths of the two sorts of flowers were calculated for each period (Table 3). Similar analysis of data has been made for bushes III, IV and V, but is not published and is less meaningful because of the smaller numbers of flowers measured. The proportion of long styled flowers altered much

through the season (Fig. 3) and on bushes IV and V no short styled flowers were produced for periods of ten to twelve days consecutively. The lowest percentage of long styled flowers was found on bush I, and the highest on bush V (Table 2). When all the five bushes are compared over the same period plants I, III and IV do not differ significantly, but II and V differ from the rest and from one another significantly. The mode for the lenghts of long styles is at 20 mm in all the five bushes (Fig. 2). The mode for short styles is at 5 mm in I and II. In III this is at 4 mm, in IV at 3 mm and V at 7 mm and 4 mm (Fig. 2). This deviation of the modes for short styles in bushes III, IV and V from those of I and II is possibly because very small numbers of flowers were obtained from them. This is partly due to the fewer days of flowering period observed and partly to the difference in the fraction of short styled flowers produced by the plants. The mean lengths of the long styles in all the five bushes rose at first and later fell to a minimum at the season's end (Fig. 4). In I, II and V the highest mean corresponds to the hottest period in that part of the flowering season observed. The mean lengths of the short styles in all the five bushes fluctuated a good deal through the period of observation. No relation was noticed between the rainfall and the mean style length and its variance. No order has yet been recognized in the position of the two types of flowers on any of the five bushes.

As the season progressed the mean length of long styles shows a slight rise and later a fall which shifted the distribution nearer to the mean lengths of short styles. If we consider bush No. I (Fig. 5), there were 115 flowers at 20 mm and 8 flowers at 17 mm for the first 20 days of the flowering period observed. But in the last 20 days there were 49 flowers at 17 mm and only 10 flowers at 20 mm.

Further Comparison of the Two Kinds of Flowers

It had seemed that other parts of short styled flowers were also relatively smaller than those of long styled flowers; so in 1960 I made a few measurements of petals and stamens (Table 4). The length of a petal was measured along its midrib. The breadth was measured on a line perpendicular to the midrib, passing through its mid point. The filament length was measured after removing the anthers. Table 4 gives the means of these measurements for 5 short styled and 5 long styled flowers. There is very little variation between the different parts of a single flower, and some of this must be due to details of their detachment and separation; also measuring to the nearest mm is too coarse a grouping for statistical analysis to be meaningful. For example the 21 measurements made on the flower with the largest range of petal lengths are given in Table 5. In every flower there were 5 long filaments (i.e. over 19 mm) in an outer whorl and 5 short (i.e. under 19 mm) filaments in an inner whorl. This is not comparable to the style dimorphism as there were 5 belonging to each class in both long and short styled flowers. From Table 4 it is clear that both the petals and the filaments of short styled flowers are smaller than those of long styled flowers. Thus there is no suggestion of an inverse relation between style and filament lengths such as is characteristic of heterostylic flowers.

The stigmas of short styled flowers were narrow and unexpanded in contrast to those of long styled flowers, and no short styled flower was ever noticed to set seed on the plants. Forty-two were tested systematically, about half by simple bagging of the flowers and about half by bagging after emasculation followed by artificial pollination using pollen from both kinds of flowers. None of these experimental flowers set seed. However, among the short styled flowers dissected for measurement a few had a more developed

ovary than usual, leading me to suspect that an occasional fertile short styled flower may yet be recorded. Also because measured flowers cannot be subsequently tested for fertility it is not known whether the functional difference coincides completely with the qualitative division based on style lengths, i.e. whether some flowers with style lengths of 12, 13, and 14 mm may also be sterile, and conversely whether flowers with style lengths of 10, 9, or 8 mm may sometimes set seed, and may be more likely to do so than flowers with shorter styles. One long styled flower on bush I yielded seed when fertilized by the pollen from a short styled flower of the same plant. Bagged long styled flowers yielded seed.

DISCUSSION

Variation in the number of fertile stamens has been recorded in a number of Bauhinia species, such as B. purpurea L. and B. variegata L. The extreme case of reduction in the number of fertile stamens is seen in B. monandra Kutz which is characterised by having only one fertile stamen in each of its flowers. But so far as I know, there is no previous record of the variation in the gynoecium in the genus. Hooker (1879) gives the length of the style in B. acuminata L as 0.5 inch (12.7 mm) with no estimate of variation. Since I have found only one with a style of 13 mm and only four of 12 mm among 3,427 flowers, it is possible that Hooker gave an average length of a few short and long styles. Such an unexplained average hinders the use of his description for identification, because this description implicitly denies a conspicuous (and physiologically important) difference between flowers on the same tree.

Roy (1959) studied the variation of petal numbers in the flowers of Nyctanthes arbortristis. This work is very similar to this on Bauhinia, as

both were concerned with the collection of data regarding the variation in a certain organ of the plant with time. However, the present study includes measuring as well as counting, whereas Roy's work was concerned with counting only. Price-Jones (1933) found that the red blood cell diameters in patients with pernicious anaemia were not only large but also more variable than in normal people. Attfield (1951) made a similar study on mice and showed that red cell diameters were more variable in anaemics than in normals in stocks segregating for two of the dominant spotting genotypes. In Roy's data the variance was shown to increase at the end of the season. Though I found that the lengths of the functional styles decreased at the end of the season, no increase of variance was observed. Because of their part in fertilization, styles are more important sexual organs than petals which are the organs of sexual display; therefore this is a possible reason why styles should be more rigidly canalized (Waddington, 1957) in their development than petals, if indeed this is a general rule.

There is no evidence that the variation in style length in Bauhinia acuminata L will have any evolutionary future. It may be merely a failure of developmental homeostasis which is common among horticultural plants and domestic animals. However, in perennial plants with no mechanism for wide dispersal of seeds there may be selection pressure in favour of devoting more of the available materials to forming pollen, because the pollen will to some extent compete with pollen from other plants, while the seeds will do so to a much less extent. Such selection is to be expected especially in species like Bauhinia acuminata L which have seeds with large food reserves that germinate under the parent plant and therefore compete with it.

Such variations must however have been essential steps in the evolution of both diclinous populations and dioecious populations from hermaphrodite

populations. A reduction in the function of the stamens in long styled flowers would be a step towards dicliny. The advantages, if any, of dicliny are not very obvious to me unless there are very few flowers to a plant and the sexes tend to flower at different times.

In any species where heterozygosity is an advantage, the failure of one sexual attribute of a flower will facilitate cross-pollination, provided other flowers provide a sufficient supply of the reciprocal gametes. Though the condition of B. acuminata L here described provides only a trifling facilitation would be greatly increased. This will become genetically more and more effective as the two kinds of incomplete flowers are associated with different genotypes as would be expected if they are themselves genetically determined. Such variation in the degree of development of male parts is indeed characteristic of the genus Bauhinia (Hooker, 1879) though not yet reported in B. acuminata L. It is difficult to think that the tendency of a plant to produce incomplete flowers is not due to its genotype, and also the proportions of two or more types of flowers are not dependent on the genetic milieux and therefore sensitive to selection. Though I have not discovered what determines whether a given style is canalized as long or short it is unlikely from previous experience that this is due to somatic mutation in a wide sense.

If heterozygosity is as important as modern results and ideas lead one to believe, it is surprising that dioecy is not as common among plants as bisexuality is among animals. Spurway and Callan (1960) suggested that plants have been unable to evolve whole populations of genomes which maximise the hybrid vigour for which they are responsible when heterozygous, but can be inadequate when homozygous because plant genes while in the haploid person have to control some developmental processes, whereas among animals no epigenetic functioning seems to be demanded of the genomes when these are hemizygous, except for genes on differentiated sex chromosomes.

Alternatively, the very fact that some genes are functional in the haploid generation has made possible the evolution by plants of several different mechanisms which prevent self-fertilization as completely as dioecy, and are more subtle than the bisexuality of animals, in that they also selectively sterilize the matings of close relatives. It is very interesting that sex determining mechanisms comparable to s^1, s^2, s^3..incompatibility allelic systems have evolved in Hymenoptera (Whiting, 1943; Mackensen, 1951) a group where the males are haploid, and therefore their development and physiology must bear a relation to their genotypes comparable to that of a pollen tube to its genotype.

SUMMARY

The lengths of 3,427 styles from five bushes of Bauhinia acuminata L ranged from 2 mm to 27 mm with modes at 5 and 20 millimetres. No flower had a style of 11 mm in length and only 26 flowers had style lengths between 8 mm and 10 mm. The fractions of short styled flowers obtained from the 5 bushes were 24.2%, 11.4%, 22.6%, 21.9%, and 6.1%. No order has yet been recognised in the position of the two types of flowers on any of the five bushes.

The mean lengths of the long styles on the first two plants show a significant rise and later a decrease as the day temperature rose and fell during the season. The periods of flowering of the latter three were insufficient for such comparison.

The short styled flowers are female sterile, therefore such a variation could play some part in the evolution of both dioecy and dicliny.

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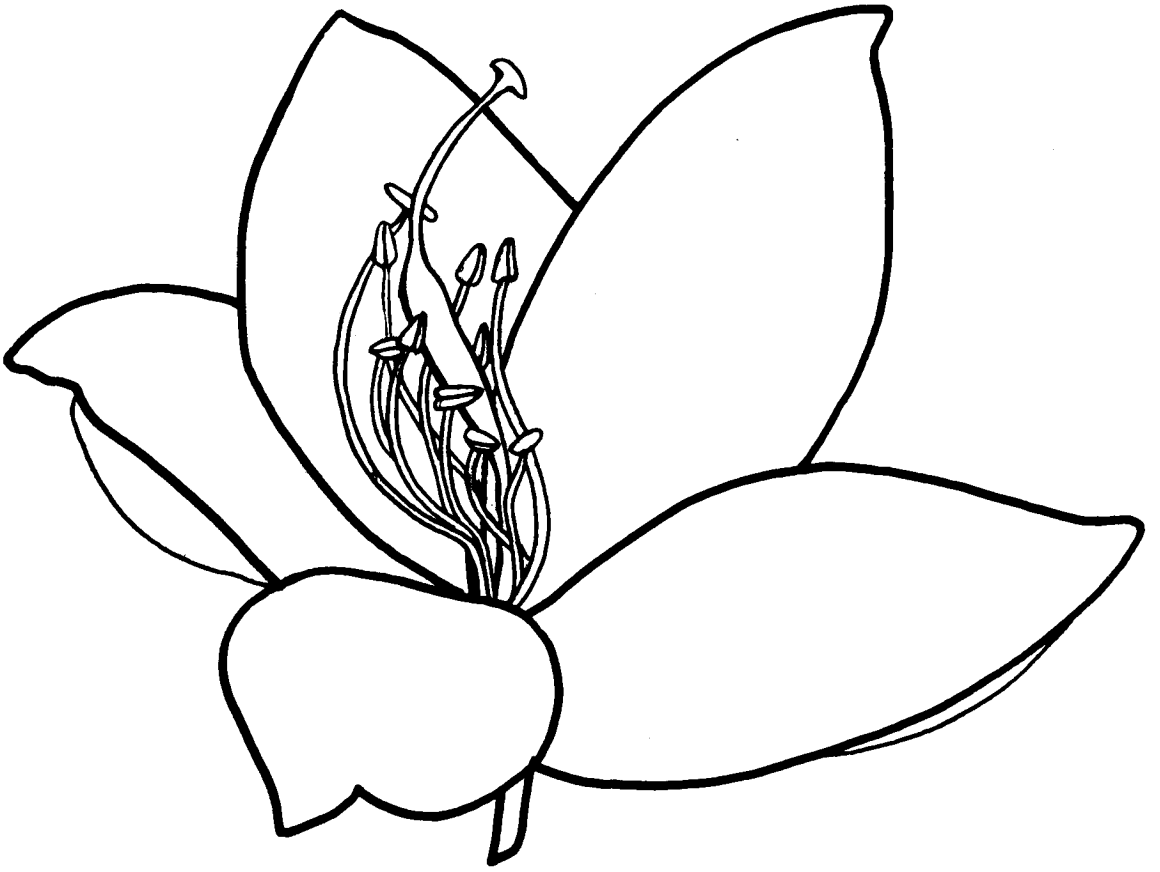
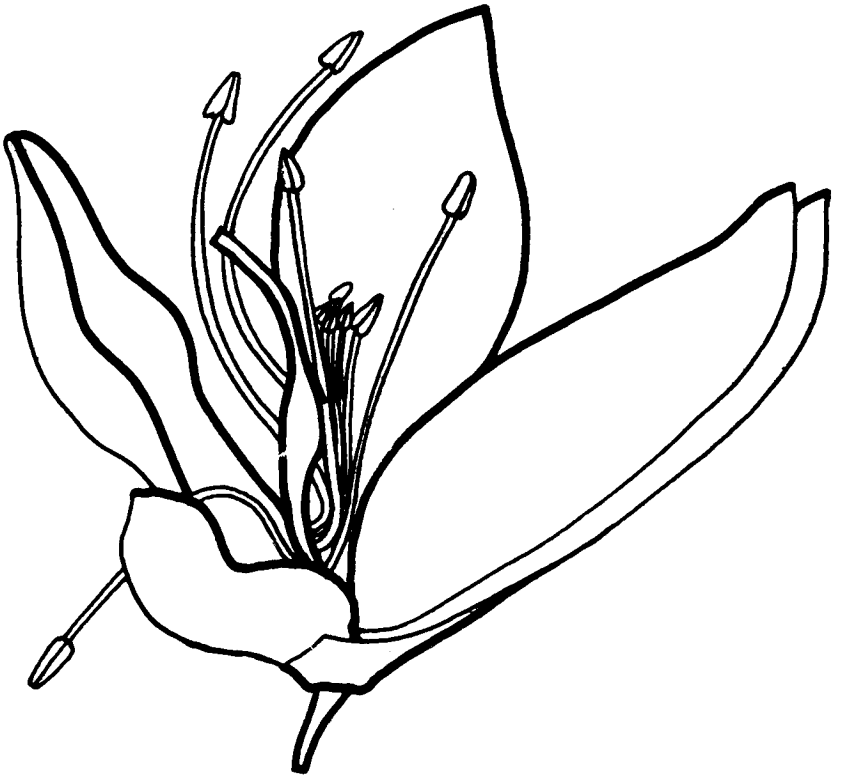
*not seen in original

Fig. 1. Bauhinia acuminata L.



(a) LONG STYLED FLOWER



(b) SHORT STYLED FLOWER

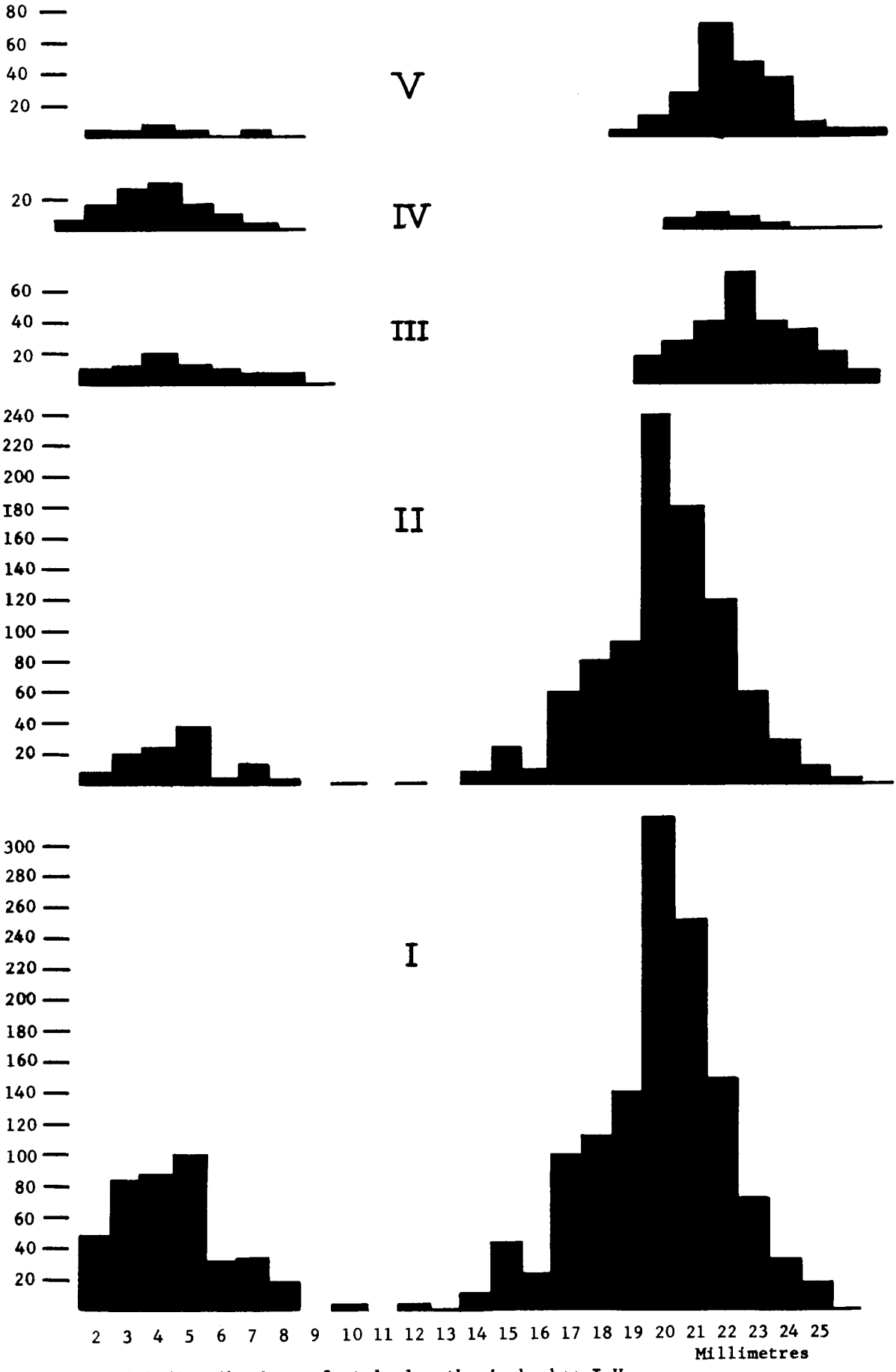


Fig. 2. Bimodal distributions of style lengths in bushes I-V.

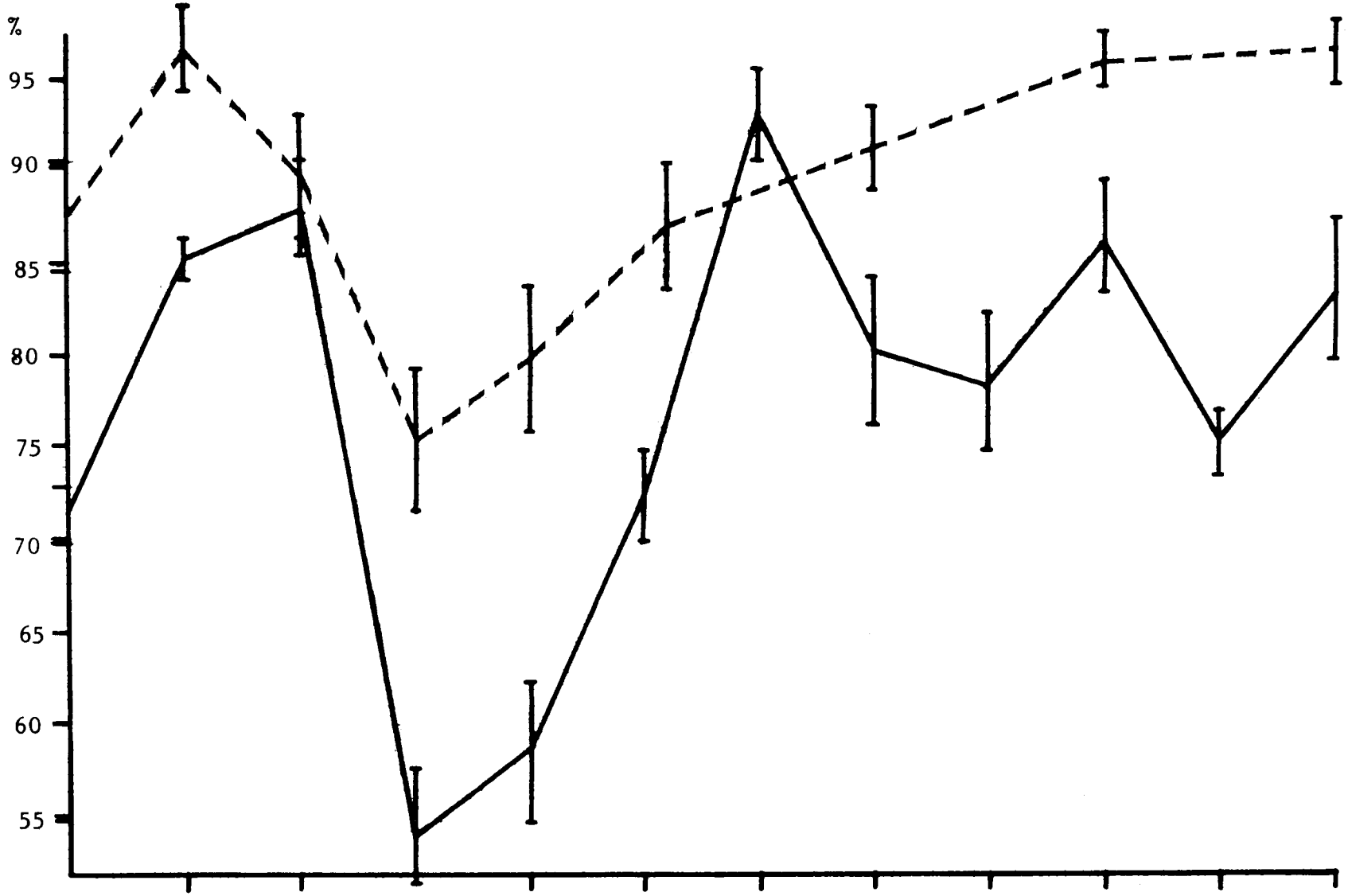


Fig. 3. Percentages of long styled flowers in 10-day periods. Bushes I (——) and II (---) compared.

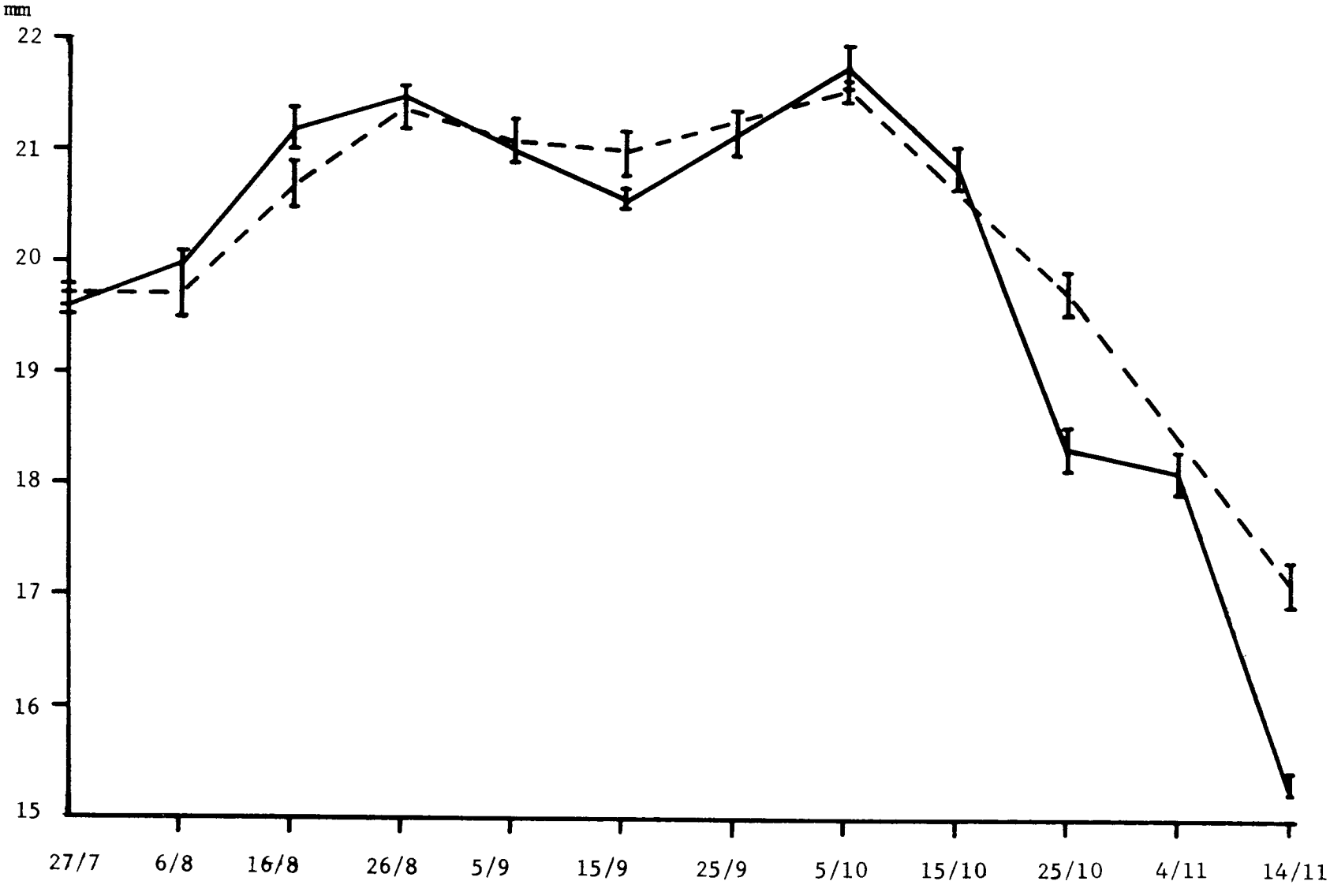


Fig. 4. Mean lengths of long styled flowers in 10-day periods. Bushes I (——) and II (---) compared.

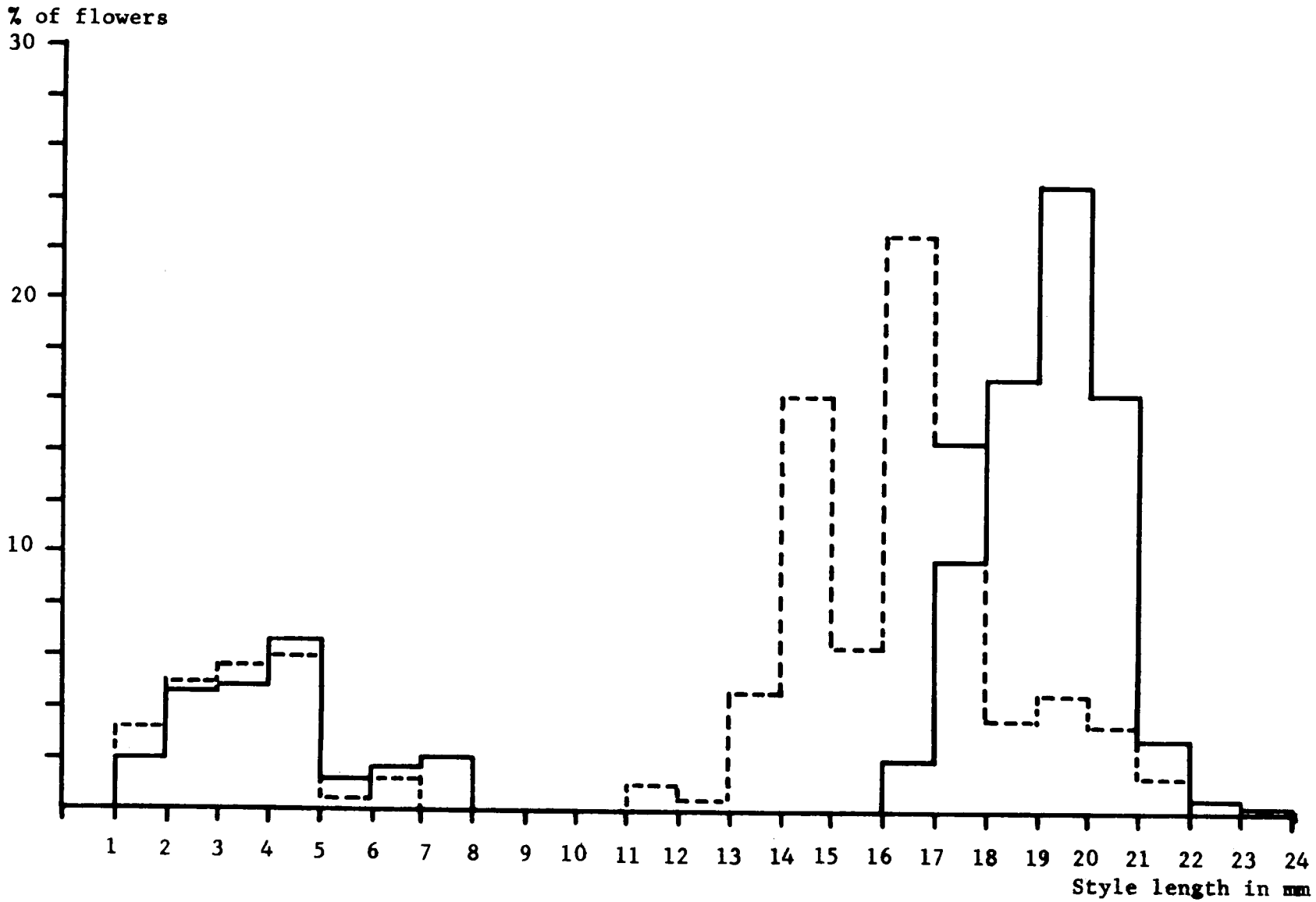


Fig. 5. Bimodal distributions of style lengths in bush I, at the beginning and the end of the flowering period observed.
——24. 7. 58 to 15. 8. 58 - - - - 4. 11. 58 to 23.11.58

Tree Number	I	II	III	IV	V
Date 1st examined	27.7	27.7	11.8	13.8	14.8
No. of days examined	115	115	69	39	79

Table 1

Style length in millimeters	Number of Flowers on I	II	III	IV	V
27	0	1	0	0	0
26	1	4	0	0	0
25	17	14	0	0	3
24	33	29	6	1	3
23	72	61	20	3	8
22	151	120	35	10	38
21	254	180	40	17	47
20	316	242	71	31	72
19	141	93	39	28	29
18	112	82	25	18	13
17	100	56	17	6	2
16	24	12	0	0	0
15	41	25	0	0	0
14	10	7	0	0	0
13	1	0	0	0	0
12	3	1	0	0	0
Total with long styles	1276	927	253	114	215
mm					
11	0	0	0	0	0
10	2	1	0	0	0
9	0	0	1	0	0
8	18	4	5	1	1
7	35	15	5	1	3
6	33	3	7	1	1
5	100	37	12	4	2
4	87	25	21	9	3
3	83	20	13	10	2
2	49	10	10	6	2
Total with short styles	407	115	74	32	14
Percentage with short styles	24.2±1.2	11.04±0.97	22.6±2.3	21.9±3.4	6.1±1.6

Table 2. The distribution of flowers from the five Bauhinia bushes according to the style lengths.

Period	Temperature C° Max.	Temperature C° Min.	Rainfall in mm	Style length from 27mm to 12mm: No. of flowers I	No. of flowers II	Mean I	Mean II	Style length from 10mm to 2mm: No. of flowers I	No. of flowers II	Mean I	Mean II	Percentage of short styled flowers I	Percentage of short styled flowers II
27.7 to 5.8	31·6	26·1	81·0	153	111	19·569±0·077	19·695± ·082	62	16	4·64±0·18	4·19±0·33	28·8±1·5	12·6±2·9
6.8 to 15.8	32·0	26·4	4·2	155	54	19·96 ±0·11	19·68 ±0·17	27	2	4·30±0·40	4·0 ±1·0	14·8±1·2	3·6±2·5
16.8 to 25.8	32·8	26·3	24·9	102	78	21·16 ±0·15	20·74 ±0·18	14	9	4·71±0·54	4·89±0·74	12·1±2·7	10·3±3·3
26.8 to 4.9	32·7	26·0	40·4	102	95	21·53 ±0·14	21·38 ±0·15	87	31	5·05±0·19	5·03±0·26	46·0±3·6	24·6±3·8
5.9 to 14.9	32·9	26·6	53·6	100	87	20·97 ±0·13	21·13 ±0·18	71	22	3·72±0·17	4·09±0·25	41·5±3·8	20·2±3·8
15.9 to 24.9	32·6	26·0	16·9	99	87	20·58 ±0·14	21·00 ±0·18	38	13	3·90±0·20	4·85±0·42	27·7±2·5	13·0±3·4
25.9 to 4.10	32·3	25·6	27·1	95 } 155		21·22 ±0·17	21·57 ±0·14	7	15	4·71±0·64	4·60±0·48	6·9±2·5	8·8±2·2
5.10 to 14.10	33·8	26·1	9·0	97 }		21·75 ±0·17		24		3·88±0·28		19·8±3·9	
15.10 to 24.10	31·0	25·2	43·1	98 } 143		20·82 ±0·16	19·78 ±0·16	27	6	5·04±0·31	4·3 ±1·2	21·6±3·7	4·0±1·6
25.10 to 3.11	31·5	22·2	14·7	109 }		18·38 ±0·17		17		4·41±0·40		13·5±3·0	
4.11 to 13.11	30·6	21·8	2·2	95 } 114		18·15 ±0·16	17·20	31	4	4·13±0·22	4·50±0·96	24·6±1·8	3·4±1·7
14.11 to 23.11	29·3	18·2	0	77 }		15·43 ±0·14		15		3·47±0·34		16·3±3·9	

Table 3 (*Bushes I and II*)

Style length in mm	Means in millimeters of: petal lengths	petal breadths	filament length long	filament length short
21	38.2	24.2	22.4	13.4
20	36.4	23.8	22.4	12.8
20	37.0	24.0	21.8	12.0
20	34.6	24.4	22.2	13.0
20	34.6	24.6	22.6	14.0
Total	36.16	24.20	22.28	13.04
5	31.6	20.4	19.6	11.2
4	35.8	21.4	21.6	12.6
3	30.0	21.2	21.0	11.4
3	32.2	20.6	20.8	10.6
2	31.6	18.8	21.6	11.6
Total	32.24	20.48	20.92	11.48

Table 4 (Bush I): Measurements of petals and stamen filaments.

Style length mm	Petal length mm	Petal breadth mm	Filament length long mm	Filament length short mm
20	35	23	22	11
	38	24	20	11
	38	24	20	10
	37	24	24	14
	37	25	23	12

Table 5 (Bush I): Variation within a flower.

SELECTIVE VISITS OF BUTTERFLIES TO FLOWERS: A POSSIBLE FACTOR IN SYMPATRIC SPECIATION

Since Aristotle it has been known that bees of a particular colony showed a constancy to one species of flower until the local population of this was exhausted of its nectar. Recent discussions (e.g. Ribbands, 1953; Butler, 1954) are agreed that a few workers of a hive scout for adequate sources, and inform their comrades, who exploit these sources to exhaustion before turning their attention to newly discovered supplies. Mather (1947) has shown that in the genus Antirrhinum at least, this constancy is species specific.

While working in a small experimental garden consisting of three plants each of two colour varieties of the primarily South American species Lantana camara L. I observed that the different varieties were preferentially visited by different species of butterflies (Dronamraju, 1958). The two varieties of Lantana are those which are overwhelmingly preponderant among the feral population around Calcutta. In one called pink the newly opened florets are white except for the yellow honey guides, but the unopened buds and the ageing florets at the periphery of the inflorescence are pink. In the other variety called orange the buds and ageing florets are orange and the young florets yellow. Both forms set seed, and the specimens in the garden were collected as seedlings. I began watching the garden again in the spring of 1959 and spent 46.75 hours all tolled attempting to note all visits of all species of insects. Among these were 9 species of Papilionoidea. I have also casually observed other species of butterflies at other times and seasons, in other places, on the same varieties, and on other varieties, (and perhaps species), of Lantana.

Table 1 shows the data collected for the six most frequent visitors (Dronamraju, 1960). The unit counted is the insertion of the proboscis into a floret, from now on to be called a feed. The movements of normally feeding

butterflies are sufficiently slow for these feeds to be counted. Only in the counts of Baoris mathias is it believed that the movements were so rapid that any large number of feeds were unnoted. Such an underestimate would increase the significance of the preference for pink shown by this butterfly. Smaller data on other species showed statistically significant preferences, but because they were collected during too short a period of time they may only record individual preferences, or temporary constancies such as are known for Apis mellifera, and were observed during this same series of observations for A. florea.

On the totals it is clear that 5 species have a distinct preference for one colour variety rather than the other. The length of the periods during which the observations were made, and in some species the use of individuals which were sexually dimorphic, or marked by injury, or paint, makes it clear that several individuals of each species were observed. We cannot assume that all these individuals either had indistinguishable experiences, or alternatively were influenced by some previously unsuspected social reaction to a variety first visited by one individual. Therefore I think that these data make it most unlikely that an individual butterfly of these species emerges from its pupa indifferent to which colour of Lantana it feeds upon, and becomes conditioned by its own individual experience.

Danais chrysippus judged by the totals given in Table 1 has no preference. However the data are highly heterogeneous. Statistical estimation cannot be made because so many observation periods included only one or two feeds.

Therefore I give (Table 2) the number of feeds during the two hours when most visits of this species were recorded. Both were between 8 and 9 a.m.

Formally such counts resemble those that are obtained by watching a colony of bees visiting a mixed crop, but before I postulate that Danais chrysippus

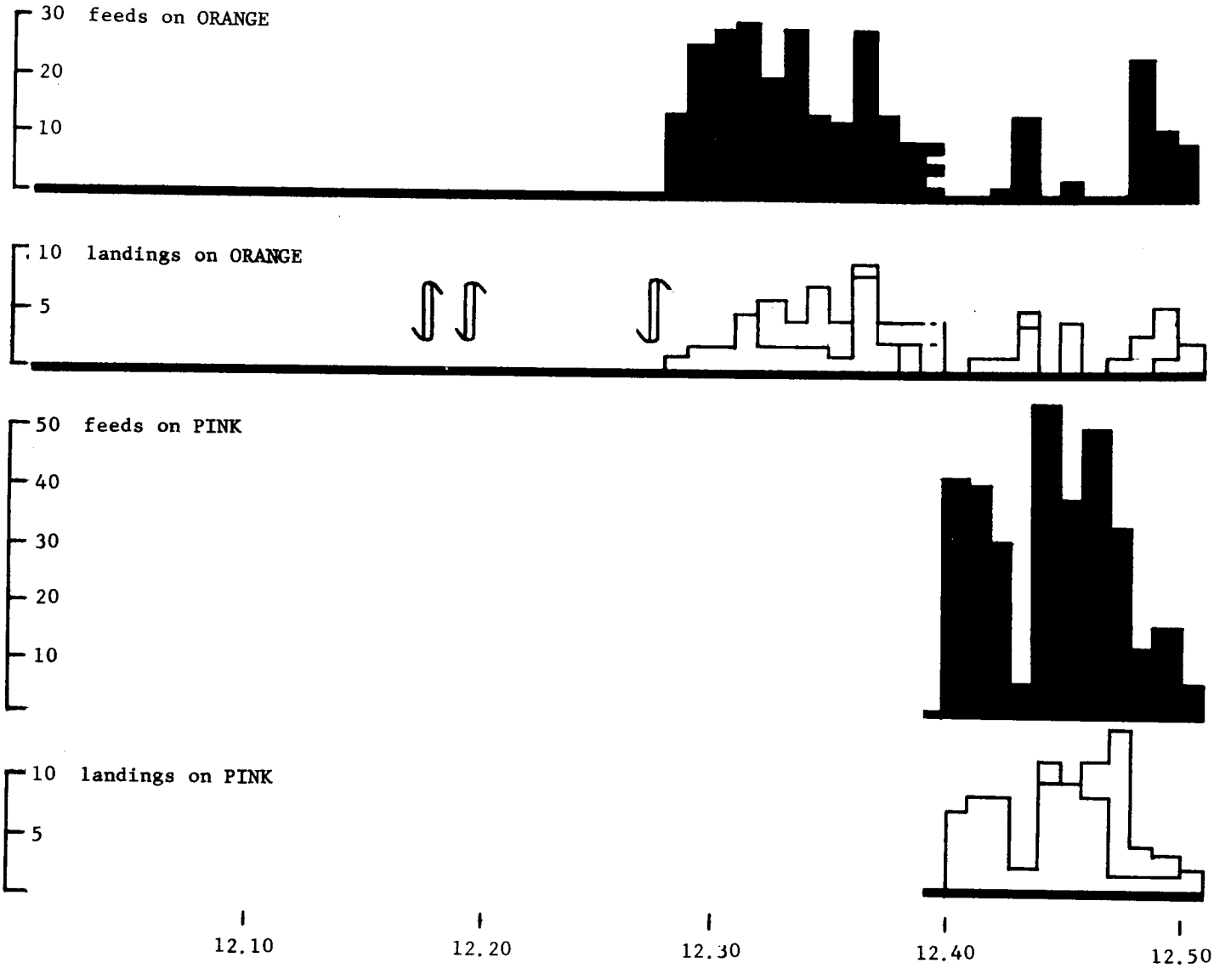


Fig. 1.

Papilio demoleus ♀3 feeding on Lantana camara 24-8-1959.

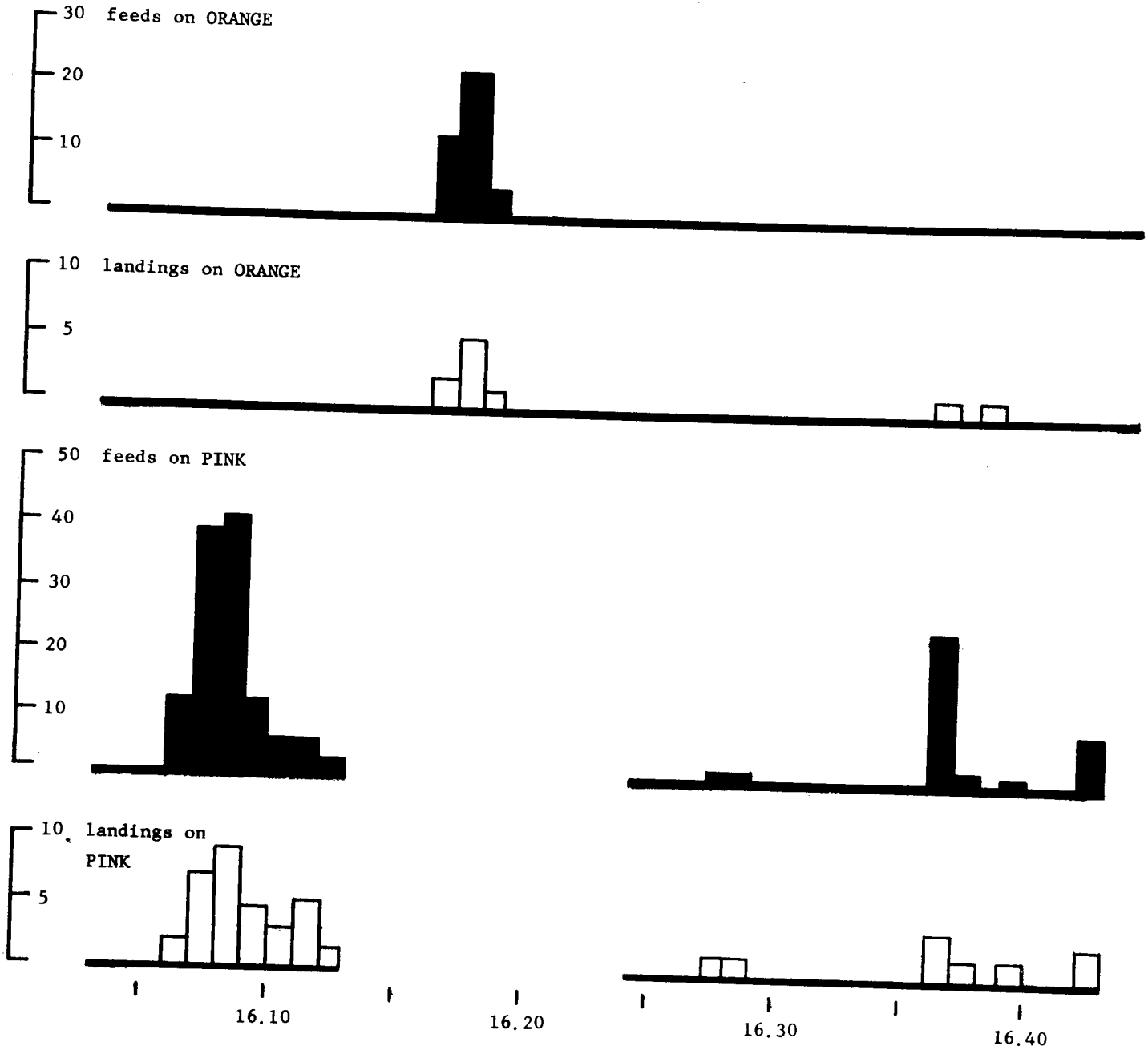


Fig. 2.

Papilio demoleus ♂7 feeding on Lantana camara 28-8-1959.

has a social organisation I will discuss my observations on the first feeding behaviour of twelve individuals of Papilio demoleus that emerged from their pupae in the laboratory.

This species is the only one of those observed of which we have obtained larvae to experiment upon. Professor B. Rensch suggested that these preferences might be due to the butterflies becoming imprinted to flowers of the colour of their first feed (Rensch, 1959, Personal communication to Professor J. B. S. Haldane). Therefore, because wild P. demoleus showed a significant but not extreme preference for pink, I exposed ten of these twelve animals to orange flowers alone, including holding them on to the inflorescences if they did not alight voluntarily. After at least half an hour if they did not feed, or after at least 40 feeds if they accepted orange, pink was presented. The other two butterflies were offered a choice. One (♂ 4) always flew away when held on inflorescences of either colour during the hour's observation period, though he inserted his proboscis once into an inflorescence. This was a pink inflorescence on which he had been placed and on which he subsequently remained unfeeding for 17 minutes, only leaving when disturbed. Next day he was not offered a choice and refused orange for half an hour but then accepted pink. The record of the other animal offered a choice (♂ 7) is graphed in Fig. 2.

Any number from 4 to 40 inflorescences of one colour were offered on cut stems and care was taken to match the specimens of the two colours in number and condition to human eyes. Also note was taken as to whether the flowers were freshly gathered, previously used that day for butterfly feeding experiments, or the present mature florets had opened in the laboratory sheltered from any insect visits. We have only tenuous evidence that our florets were ever exhausted enough for their interest to decrease for a butterfly.

At first the experiments were performed in a large room with windows in

three walls. One butterfly fed on orange and was immediately eaten by a gecko; another refused orange for 2 hours and 40 minutes and then walked through a draining hole - and instead of flying away fell from four storeys and was recovered (she was marked) with a fractured costa! The third produced clear results and was observed on 6 consecutive days. All other animals were observed in a small wire and wood cage 2.1 x 1.5 x 2 cu. m. in volume. No sugar water had been given before the experiments to be described.

Table 3 sums up my conclusions, and Figs. 1 and 2 graph two experiments to demonstrate the behaviour which I categorise as "feeds on orange; prefers pink". In both the figures the horizontal axis represents time, and there are four distinct vertical axes. The black histograms represent separately the number of feeds on orange and pink, and the white histograms the number of landings, i.e. the number of times the butterfly alighted and stood on an inflorescence. I have never seen a Papilio demoleus feed without landing, but these butterflies often land without feeding. The horizontal lines represent the period of time when flowers of that colour were present. Pink was only presented to ♀ 3 (Fig. 1) at 12.39 hours, after the animal had fed upon orange; pink was removed from ♂ 7 (Fig. 2) at 16.14 hours, after it had been fed upon, and returned at 16.24; orange was present throughout both experiments. In the experiment with ♀ 3 two vases of both colours were presented and the histograms of landings are divided into two parts to indicate when she flew from one vase to another. When all four vases were presented they were arranged alternately in a row so that a vase of another colour had to be flown over with every change. In Fig. 1 the arrows indicate when the animal was forcibly held on to the flowers. She always flew away when released. The dotted histograms represent feeds and landings uncounted because I was occupied in introducing the vases of pink flowers. It will be seen that both these animals did feed on orange, but were

reluctant to do so especially in the presence of pink. The second supply of pink offered to ♂ 7 consisted of only four inflorescences which had been ardently fed upon (194 feeds) five hours before. Nevertheless they held his attention from the four orange to which he only had had access, and on which he had only fed 36 times (Dronamraju and Spurway, 1960).

The series of experiments summarised in table 3 support the theory that most individuals of P. demoleus emerge from their pupa with a preference for feeding on pink Lantana rather than orange and that this is not altered by receiving their first food from orange flowers. The three animals who continued to feed on orange after pink was made available were a mother, one son, and one daughter. The father and another son and daughter were tested and preferred pink. Thus a minority of P. demoleus prefer orange in the sense of behaving thus in our experimental conditions. If this difference is genetically determined it is a behavioural polymorphism, and a similar polymorphism present in Danais chrysippus would explain the observations on wild animals in Table 2. A similar heterogeneity can be discerned in the data on wild P. demoleus, but the individual observations are too few for this to be demonstrated as significant.

I have been able to find only one previous recording of a similar phenomenon. Eltringham (1933) observed specimens of Vanessa urticae (an orange Nymphalid not unlike Precis almana) visiting a bed of asters (Compositae) of which white, purple, and pink flowers were in the approximate proportions 7:9:12. However, out of 427 visits 47 were to white, 245 were to purple, and only 135 were to pink (from discussion by Ford, 1945, who gives more details). These observations raised the question of whether the animals distinguished by colour vision, and led to the establishment of the fact of colour vision in butterflies (discussed by Ford, loc. cit.). However its relevance to these

flower preferences was not established, and the same question must be asked about my own observations. Because a pink-preferring butterfly does in my experiments feed on pink, white, and heliotrope flowers of other nectar-bearing species, while ignoring nectar-bearing orange and yellow flowers, I believe that these animals are reacting to colour and not to some other stimuli correlated with it in these Lantana stocks. However I do not want to stress this belief yet, as the flowers presented were very heterogeneous in structure, and not every species with pink flowers was visited.

Whatever the nature of the stimulus, such preferences will exert a selection pressure on the plant population comparable to that exerted by sexual selection in animals. A learnt preference will exert much less selection; a bee changes its behaviour to accommodate, or to adapt to, every change in the source of nectar. An instinctive preference will either sterilize a new mutant because few or no pollinators visit it; or preserve the phenotype because it is pollinated by animals who rarely mix its pollen with that of the unchanged parental population, i.e. whose behaviour favours homogamy. So if a new mutant is recessive the butterflies' behaviour will maintain homozygosity once a few homozygotes have segregated in a population; if the mutant is a dominant so that the first unusual phenotype is a heterozygote this will be self-pollinated by the pollinators and so produce homozygotes which will be maintained by the same behaviour. The two phenotypes will be more or less isolated sexually, and thus have the possibility to become further differentiated. In short is this an insect capacity which could make possible in a plant population the initiation of sympatric speciation by a single gene mutation? Mayr (1947) considered and rejected the possibility of sexual isolation arising by a mutation producing a change in a preference. The butterflies I have described have established preferences and it is these which could exercise selection pressure on any mutants that altered relevant stimuli.

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Species	Family	Date of		Number of days observed	Number of feeds	
		1st observation	last observation		on orange	on pink
Precis almana ..	Nymphalidae ..	29-5-58	21-4-59	16	218	13
Danais chrysippus ..	Danaidae ..	19-3-59	22-5-59	18	142	152
Papilio polytes ..	Papilionidae ..	19-3-59	4-4-59	4	15	31
Papilio demoleus ..	Papilionidae ..	19-3-59	19-5-59	13	42	98
Catopsilia pyranthe ..	Pieridae ..	29-5-58	22-5-59	27	40	603
Baoris mathias ..	Hesperiidae ..	19-3-59	19-5-59	12	1	108

Table 1

Date	Orange	Pink
22-3-59	0	46
7-5-59	50	7

Table 2

		Prefers Orange	Prefers Pink	?
Feeds on Orange	..	3	3	1
Does NOT feed on Orange	..	..	4	1

Table 3

Papilio demoleus

First feeds in captivity