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10th June, 1932.

Dear Dr. Fisher,

I suppose you will have seen that the battle of words is being continued.

I am enclosing herewith a complete copy of the correspondence ending with the draft of a letter which I have made in reply to the contribution of Mr. Edwards and Dr. Wishart in this week's NATURE.

I hesitate to bother you further in this matter but I would be greatly obliged if you could cast your eye over this last letter and let me know, specially whether the contention contained in the third paragraph is valid.

With apologies for troubling you,

Yours sincerely,

J.D. Buchanan Smith

Dr. R.A. Fisher,
Rothamsted Experimental Station,
Harpenden,
HERTS.

If the statistical part of the correspondence is prolonged I fear I shall get right out of my depth.

(*Reprinted from* NATURE, *January 30, 1932.*)

INHERITANCE OF MILKING CAPACITY

A STUDY of the milk yields of the progeny of 728 bulls of the Red Danish breed has been made with a view to determine—first, the ability of each bull to transmit the different degrees of milking capacity; and secondly, having thus obtained an index of this ability, to determine the extent to which it was influenced by the various animals in his pedigree. The average number of daughters to each bull was 18. The figures were taken from the annual reports of the Milk Recording Societies throughout Denmark for 1918–1931. The daughters' yields were mainly calculated on the average of the first two lactations and corrected to the third lactation. The records of the dams and grandams were based on as many lactations as possible, from three to ten, and averaging 5·5. The average of these uncorrected lactations was taken as an indication of the milking capacity of the dam or grandams.

To measure the genetic aspect of the ability of bulls to transmit milking capacity, correlations were made of the average yields of the daughters of these

		Total Yield of Milk.			Total Yield of Butter-fat.		
x	y	N	r	R^x_y	$\sigma y/\sigma x$	r	R^x_y	$\sigma y/\sigma x$
Bulls to Sires		555	0·255	0·291	0·577	0·224	0·288	0·634
,, to Dams		725	0·173	0·117	1·47	0·182	0·141	1·30
,, to Paternal G'sires		478	0·202	0·263	0·767	0·193	0·267	0·723
,, to Maternal G'sires		503	0·194	0·208	0·932	0·258	0·221	0·685
,, to Paternal G'dams		721	0·020	0·018	1·45	0·061	0·055	1·10
,, to Maternal G'dams		715	0·112	0·077	1·40	0·170	0·134	1·27

The standard error of 'r' ranges from $\pm 0{\cdot}02$ to $\pm 0{\cdot}04$.
R = Regression.
Bulls (a) mean total yield of milk = 4403 kgm., σ = 440.
,, ,, ,, of butter-fat = 172·64 kgm., σ = 20·48.

bulls to the average yields of the daughters of their sires, and to the actual yields of their dams and grandams. Thus the milking capacity of the bulls (as measured by the yields of their daughters) has been correlated to the milking capacity of the sires and grandsires (similarly measured) and to the dams and grandams (as measured by actual production). These correlations are as shown in the accompanying table.

It is to be noted that the genotypes of the bulls

have been compared to the *genotypes* of their male ancestors but to the *phenotypes* of their female ancestors. Hence the correlation figures to the male ancestry cannot be directly compared with those to the female ancestry.

It will be seen that as regards milk yield the paternal grandsire has an effect equal with the maternal grandsire, though as regards butter-fat yields the maternal grandsire is of slightly greater importance. This can be accounted for by the methods employed by the breeders, who for the past fifteen years have, through an intelligent appreciation of the value of the progeny test, paid almost exclusive attention to the male line. From a study of the records of the progeny of the two grandsires and the deviation of the yields of their daughters, it was found that the more highly selected bulls which appeared as paternal grandsires were distinctly more homozygous for the factors affecting the transmission of milking capacity than were the less highly selected maternal grandsires.

There is, however, a highly significant difference between the correlation figures to the two grandams. The correlation to the paternal grandam is practically nil, while that to the maternal grandam is significant.

Smith, Scott, and Fowler,[1] working with correlations of Ayrshire *cows* to their ancestors, found a significantly lower correlation to the paternal than to the maternal grandsire, and from this deduced the possibility that sex-linked factors might be involved. In the present study, the correlation to the two grandsires is approximately the same, but a difference is found between the correlations to the two grandams. The present study is of *bulls* and their ancestry. A character inherited in a sex-linked manner cannot be transmitted to a bull from his paternal grandam. (But a paternal grandam can transmit sex-linked factors to her granddaughters.) Accordingly, in the present work the test as to whether sex-linked factors are involved in the transmission of milking capacity depends on whether or not there is in this respect a difference between the correlations of the bull to his two grandams. This has been found to be the case. Thus, while from these figures it can be demonstrated that autosomal factors are concerned in the transmission of milking capacity, it is also clearly shown that this capacity is to no small extent conditioned by factors inherited in a sex-linked manner.

KARL MADSEN.

Institute of Animal Genetics,
The University of Edinburgh.

[1] Smith, A. D. Buchanan, Scott, F. J., and Fowler, A. B. "The Inheritance of Milk Yield in Ayrshire Cows", *J. Dairy Research*, 1, 174-179; 1930.

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Extract from NATURE, March 19th, 1932, 129: 437.

Inheritance of Milking Capacity.

Mr. Madsen's letter in NATURE of Jan. 30 contains much interesting information, based, as it is, upon data unusually numerous and comprehensive. It is with regard to his conclusion concerning the evidence of transmission of some factors for milk-inheritance in a sex-linked manner, based upon the difference in the correlations of the sires to their paternal granddams (0·026) and their maternal granddams (0·112), that I should like to make two points.

(1) The small correlation to the paternal granddam (0·026) might be explained by the choice of the sires by genotypic rather than by phenotypic methods; the merits of the progeny test having been for some time widely recognised in Denmark. The insufficiency of a single cow's record (because it is the expression of a phenotype) in foretelling the production of her progeny, has been stressed by many investigators, and it is doubtful if one should expect to find a significant difference in the correlations of two such records diluted through three generations.

(2) The difference between the correlation coefficients 0·026 and 0·112, is not significant. From the data tabulated, it appears that such a difference would be likely to occur by chance once in ten times. The odds are, therefore, not great enough to warrant the postulation of sex-linkage for some factors, from the data used.

J. Edwards.

School of Agriculture,
University of Cambridge, Feb. 5.

(*Reprinted from* NATURE, *May 7, 1932.*)

INHERITANCE OF MILKING CAPACITY

I SUBMIT that on the evidence available Mr. Madsen[1] was justified in reaching the tentative conclusion, that some of the genetic factors governing milking capacity are transmitted in a sex-linked manner, and that the points mentioned by Mr. Edwards[2] in his letter are based upon a misapprehension of the subject. Mr. Edwards states two objections, but if his first one be analysed it will be seen to contain three different points, so that all Mr. Edwards's objections to the conclusion reached by Mr. Madsen may be summarised as follows:

1. That the sires are selected by genotype, rather than phenotype.
2. That the record of a single cow is insufficient in foretelling the production of her progeny.
3. ". . . it is doubtful if one should expect to find a significant difference in the correlations of two such records diluted through three generations."
4. That the difference between the two correlation coefficients is not significant, and that such a difference would be likely to occur by chance once in ten times.

The logic on which the first objection is based is not clear. How does the method employed in the selection of the sires affect the grandams? Would Mr. Edwards argue that those cows which are mated to bulls selected by genotype are of a different order from cows mated to bulls selected on phenotype? Or would he argue that since the sires of the bulls involved are selected on their genotypes, therefore their dams are of a different order from the maternal grandams of the bulls in question? In any event, when the full paper is published, Mr. Madsen will show that the majority of the sires involved have not been selected on genotype, but on appearance plus pedigree.

As to the second objection, Mr. Edwards should know that dairy cattle are extremely heterozygous for the factors governing the transmission of milking capacity; and further, that it is the exception for the genotype of a cow to be assessed in respect of milk

yield, because her offspring are few and seldom all sired by the same bull. It is not to be expected that the records of a single cow will be of great value in foretelling the production of her progeny by another bull. I would point out that a statistical study is based on the average of a large number.

Mr. Madsen in his letter was particularly careful to stress the fact that the *genotypes* of the male, but the *phenotypes* of the female, ancestors were being compared to the genotypes of their sons and grandsons, and that consequently correlations to the female ancestry were in a category by themselves. Both of Mr. Edwards's objections seem to be based on a misunderstanding of Mr. Madsen's statements.

The third objection is based on the speculation that, with the material used by Mr. Madsen, no correlation to the grandams was to be expected. Incidentally, this was also my own expectation. But Mr. Madsen has shown that this is not so. Despite the inevitable drawbacks of his method, he has given good reason to believe that there is a small but significant correlation to the maternal grandam, while the slight positive correlation to the paternal grandam is insignificant. Mr. Edwards is scarcely justified in upholding speculation against ascertained fact.

The last objection refers to the value of the standard error. If the study were to be contained within reasonable limits, an error of such value was unavoidable. Actually more than 100,000 lactations had been analysed and classified. Mr. Madsen's conclusions are based not merely on his own work, but also on the material contained in the paper by myself, Scott and Fowler,[3] which he quotes, and, by implication, on the work of Gowen, to which reference is made in our paper. Mr. Madsen was also acquainted with other papers dealing with this subject, including the most recent one from this Institute,[4] which presents a case for the possibility that certain of the genetic factors controlling milk production are inherited in a sex-linked manner. Any one of these several investigations alone might be insufficient for drawing such a deduction, but when what Mr. Edwards calls one chance in ten recurs repeatedly, it is surely not illogical to presume that it has some significance, and to try to interpret the facts. Of all possible explanations, sex-linkage is not only the simplest, but also the most reasonable.

I should like also to correct an error on the part of Mr. Edwards. If he will re-calculate the figures carefully, remembering that he is dealing with a *standard* error of $\pm 0{\cdot}03$, he will find that the results would be

likely to occur by chance, not once in ten times, as he states, but once in twenty. I leave it to others to determine whether this difference is significant.

Finally, I may take this opportunity of congratulating Mr. Madsen on his study, which is in some respects the most comprehensive of this nature that has as yet been made. His material is unique and his results give considerable food for thought. It is to be regretted that funds for such research, both in Britain and in Denmark, have been recently curtailed, so that the publication of the full paper has been considerably delayed.

A. D. Buchanan Smith.

Institute of Animal Genetics,
University of Edinburgh,
April 16.

[1] Nature, Jan. 30, p. 165.
[2] Nature, March 19, p. 437.
[3] *J. Dairy Research*, 1, pp. 174-179; 1930.
[4] Smith, A. D. Buchanan, and Robison, O. J., "The Inheritance of Milk Yield", Conference Papers, International Dairy Congress, Copenhagen, 1st Session, pp. 127-140; 1931.

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Inheritance of Milking Capacity.

In replying to Mr. Buchanan Smith's remarks (1) concerning my discussion (2) of Mr. Madsen's letter (3), I shall deal with them in the order set out by him.

(1) I suggested that the small correlation to the paternal granddam might be explained by the selection of the sires of bulls studied as prepotent on the basis of the progeny test (rather than on their dams' records), a form of reasoning used by Mr. Buchanan Smith for another purpose (4) in discussing a low correlation of daughters' yields to their paternal granddams' yields when he states "...this...may probably be explained by the fact that up till quite recently in the Ayrshire breed the bull was selected onot on the performance of his dam so much as on the showyard record of his sire". In each case the principle is obviously the same - the bull being selected with little reference to his dam's record. Mr. Buchanan Smith's statement that "when the full paper is published Mr. Madsen will show that the majority of sires involved have not been selected on genotype but on appearance plus pedigree" is difficult to reconcile with Mr. Madsen's own statement about "... breeders who for the past 15 years have, through an intelligent appreciation of the progeny test, paid almost exclusive attention to the male line".

(2) Rather than to the contrary we find ourselves in agreement on the second point; I stated that a cow's record is insufficient in foretelling the production of her progeny because it is the expression of a phenotype and Mr. Buchanan Smith allows that rarely is the cow's genotype capable of assessment because of the small numbers of her progeny. This is a state of affairs in no way improved upon by any increase in the number of daughter-dam pairs, and as in discerning inheritance it is essential to distinguish transmitting ability from actual production, it is difficult to see why two small correlations to phenotypes far removed can be expected to reveal anything. Actually the correlations amongst genotypes in Mr. Madsen's data should more reasonably be expected to yield a clue, as the X-chromosome which the bulls receive comes as often from the maternal grandsire as from the maternal granddam, though never from the paternal grandsire. Mr. Madsen finds that to the latter parent $r = 0.202$, while to the maternal grandsire $r = 0.194$, which would indicate that the presence or absence of the X-chromosome makes no difference.

The method of direct correlation employed leaves much to be desired. To a daughter's inheritance the sire and dam each contribute and yet in the daughter-dam correlations the sire's part is completely left out of account. This omission is not made good by/

by an increase in the number of daughter-dam pairs studied. (3) and (4) That the suggestion of inaccuracy in the calculation of the odds as one in ten is unfortunate is shown by Dr. J. Wishart in a letter contributed below.

I agree with Mr. Buchanan Smith that Mr. Madsen's investigation is particularly exhaustive and it is the very thoroughness with which he has prosecuted it which makes the likelihood of significant sex-linkage even more uncertain.

J. Edwards.

School of Agriculture,
University of Cambridge.

1. Nature 129, 688, May 7, 1932.
2. Nature 129, 437, March 19, 1932
3. Nature 129, 165, Jan 30, 1932.
4. Smith, A.D. Buchanan and Robison, O.J., "The Inheritance of Milk Yield". Conference Papers, Internat. Dairy Cong., Copehhagen, 1st section, pp. 127-140; 1931.

The standard errors of the correlation coefficients 0.026 from 721 pairs and 0.112 and from 715 pairs are almost exactly equal, at 0.037. Thus the difference 0.086 is 1.64 times its standard error, and treating this as a normal deviate it appears that the difference of this size, or greater, would occur in random samples from equally correlated populations just once in ten times on the average. Mr. Edwards used the more exact z-transformation of R.A. Fisher, but the small size of the correlations and the large numbers on which they are based, lead to exactly the same result by both methods. The observed coefficients are thus compatible with the hypothesis that the correlations with paternal and maternal granddam are equal. The best value for the joint correlation afforded by the data is 0.07, so that the relationship at best is very slight.

J. Wishart.

School of Agriculture,
University of Cambridge.