SCIENCE

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GENETICS AND BREEDING[1]

ONE of the primary purposes for which the American Breeders' Association was founded was to bring together on a common ground those who were approaching the problem of the improvement of plants and animals by breeding, on the one hand, from the side of practical breeding, and, on the other hand, from the side of the scientific study of heredity. One of these groups stands as the representative of the art or craft of breeding, and the other as the representative of the science of genetics. That each of these two bodies of men has something to learn from the other there is no doubt. Even with the continued and prosperous existence of such an association as this it is certain that actually there is far from being anything like as extensive a mutual interchange of knowledge and opinion between science and practise in breeding as would appear from every point of view to be desirable.

It will have been perceived by all who have followed my remarks so far that they have been commonplace to the point of utter banality. They constitute a thoroughly bromidic introduction to a conventional treatment of that time-stained and battle-scarred old theme of compulsory oratory, the relation of science and practise. Every one can foresee, with a moment's reflection, just what ought to come next, and next, and on to the end. At the outstart should be set forth the great achievements

[1] Papers from the Biological Laboratory of the Maine Agricultural Experiment Station, No. 44.
Address of the retiring chairman of the Animal Section of the American Breeders' Association at its Columbia, S. C., meeting in January, 1913.

of the science of genetics; then the tremendous possibilities thus opened out to the practical breeder, who in the near future will be able to soar from this scientific foundation to realms of wealth and power in the community hitherto possible only to the predatory classes; nevertheless, in a meek and humble spirit of gratitude engendered by the blessings which have been poured at his feet, he in turn contributes to the great cause of science by placing at the disposal of the geneticist the wonderful stores of experience he has accumulated; at the end should come an impassioned plea for "getting together" for the good of agriculture, humanity and sundry other things, which should, if well done, so titillate the emotions as to send everybody home uplifted, and, in general, determined to lead a better life.

I have sketched this little picture, which, if necessarily impressionistic, is essentially true, only to bring into sharp relief the intellectual junction point, at which we shall alight and change cars. Just because there has been so much perfervid oratory, loose thinking and cheap advertising of the achievements of men and institutions based on the ideal or assumed mutual interrelationship of the science of genetics and the breeders' art, it seems worth while to make a careful objective analysis of the actually existing relations between these adjoining fields of human endeavor. Such an analysis will be attempted in what follows. Specifically the question to which attention is invited is: What essential and fundamental contributions has genetics made to the *practise* of the breeders' art? Or, to put the matter in another way, what particular things does the most highly successful practical animal breeder do now which he did not do, or performed differently, before Mendelism was rediscovered or Darwin wrote?

It is generally agreed that during the past fifteen years there has been a great advance in our knowledge of the fundamental laws of heredity. Indeed, it may fairly be said that more has been gained in this regard within this period than in the entire previous history of this field of knowledge. The new method of investigating heredity which was given by Mendel's work has for the first time made a real analysis of genetic phenomena possible. It was a truly imposing array of organisms and characters which Major Hurst was able to list at the meeting in commemoration of Mendel at Brunn, as comprising those attributes of organisms about the inheritance of which something *definite* is *known*.

There is a very widespread assumption that coincident with this advance in our knowledge of the fundamental laws of inheritance there has been an equal advance in the practical art of breeding. This has perhaps resulted from the somewhat over-enthusiastic prophecies of the early Mendelian workers. Many will remember the glittering possibilities set forth to the practical breeders in the early meetings of this association. They were told in effect that at last the key to the genetic riddle had been found; that by the application of these simple Mendelian laws existing races of animals could be brought up to desired ideals with more certainty and despatch than had hitherto been possible, and that new races could be created which would surpass in usefulness anything now existing. There was, of course, an element of truth in all this. But it raised unwarranted hopes in the minds of many laymen. The apparent failure of these prophecies to be realized has probably done real harm to the cause of science in the minds of some practical men—representatives of the class to which in last analysis science must look for its material support—and very generally has led animal breeders to under-rate the real value of Mendelian investigations.

It is permissible to think that the fundamental error involved was in the assumption we are all inclined to make that any distinct advance in science necessarily means an equally marked and immediate advance in the practise of the associated art or craft. It is extremely difficult for the man of the laboratory or the study, as he takes a broad view of the history of the industrial arts, and sees that great progress there has rested upon fundamental scientific discoveries, to realize that the art of breeding differs essentially in this respect from the industrial arts. The breeding of animals by man for more or less definite purposes goes back to prehistoric times. Practically as soon as primitive man began the domestication of animals he must perforce have begun, in greater or less degree, to control their breeding. Having started thus early, the craft of breeding had attained a relatively high degree of development centuries before any attempt was made to formulate the scientific principles of genetics. As an example may be mentioned the breeding of horses in England. It is customary to think of "stallion laws," aimed at the improvement of the horses of a state, as very modern and American, and an indication of the influence of the science of breeding on the practical craft. But three hundred and seventy odd years ago, in the reign of Henry VIII., there was passed a "bill for the breed of horses," which in its preamble stated that:

> Forasmuch as the generation and breed of good strong horses within this realm extendeth not only to a great help and defence of the same, but also is a great commodity and profit to the inhabitants thereof, which is now much decayed and diminished by reason that, in forests, chases, moors and waste grounds within this realm, little stoned horses and nags of small stature and of little value be not only suffered to pasture thereupon, but also to cover mares feeding there, whereof cometh in manner no profit or commodity.

In order to prevent the multiplication of poor specimens section 2 of this law provided that no uncastrated stallion two years or more old which was under 15 "handfulls" high should be allowed to graze on common or waste land in certain counties. Further it was provided in section 6 that all forests, chases, commons, etc., were to be "driven" at a stated time in the year (just preceding Michaelmas day) and all horses, mares and colts which were not of good quality, or did not promise to become or to produce serviceable animals, were to be killed.

The fact is that the practise of the art of animal breeding, so far from languishing, for want of instruction from the science of genetics, is actually immeasurably in advance of that science. The geneticist who is disposed to think otherwise should visit a great horse, or cattle, or even poultry show, and then permit himself to consider candidly the question whether with all his science he could himself breed, or tell any one else how to produce, *finer* specimens than he will see there. Yet by hypothesis that is exactly what he ought to be able to do, if genetics is to set up as a teacher and guide to the best practical methods of live-stock breeding.

It is capable of abundant historical proof that many years ago, before the beginning of the world movement towards agricultural education, experimentation and the grounding of a science of agriculture in general, there were in existence individual animals (even flocks and herds), and strains of seeds or farm crops which were probably intrinsically as fine, as productive, and generally as excellent as any that we know to-day. Given as intelligent care and feeding as our prize-winning animals and plants now get, there is every reason to believe that they would have equalled or surpassed our finest specimens of to-day. Some specific examples may be cited. Mr. Geo. A. Scott,[2] of Nashville, Tenn., had in 1863 "a common scrub cow" which produced in one year 1,447½ gallons of milk. Taking the weight of one quart of milk at 2.15 lbs. as sufficiently close for practical purposes, this gives a record of 12,448.5 lbs. of milk for the year. This is a respectable figure even for present standards. Going back a half century earlier we have the record of a Sussex cow[3]: "a cow not of either of the highest improved English breeds—long horns or short horns; but of the proper old Sussex breed." The following record is of her production in five successive years beginning in 1805. I have transposed quarts to pounds by the use of the factor given above—2.15.

	Weeks in Milk	Lbs. of Milk	Lbs. of Butter
First year	48	10,580.2	540
Second year	45½	8,894.6	450
Third year	51½	12,366.8	675
Fourth year	42½	9,070.9	466
Fifth year	48	11,543.4	594

Facts of the same sort are at hand for crops. Justin Ely, Esq., of West Springfield, Mass., in 1816, raised 50 bushels of wheat to the acre. Col. Jas. Valentine, of Hopkinton, raised 128 bushels of "Indian corn" to the acre. Payson Williams, Esq., of Fitchburg, raised 614 bushels of potatoes to the acre, and James Whitton, Esq., of Lee, raised 85 bushels of oats to the acre. The average yield of oats to-day is approximately 36 bushels to the acre. The Maine Agricultural Experiment Station, in its tests of the best commercial varieties of oats procurable in this country and Europe, has never been able to obtain a yield per acre of more than 76 bushels.

I have elsewhere discussed records of egg production in poultry in this connection. From 1836 there is an authentic record of crested Polish fowls producing an average of 175 eggs each per year. This was long before the trapnest had been discovered.

Too much stress, of course, should not be laid on such examples as these. They do not indicate that there has been no advance made by the breeder in the qualities of domesticated animals and plants during the last century. The *average* quality of live stock and of crop plants is constantly improving, not only as a result of breeding, but also because of better and more widely disseminated knowledge of how to provide the food and environmental conditions best suited to bring to full expression the potential hereditary capabilities[4] of the individual. I think that such records, however, do fairly indicate that in the practise of the art of breeding there has been no such marked fundamental advance in recent years as there has been in the science of genetics. By empirical methods man has been steadily improving the quality of live stock for centuries past, and long ago a *relatively* high level was reached by the most skillful breeders.

Purely empirical methods are wasteful and slow in operation, but they may attain excellent results. When they are successful it is obviously because at just that point the practise was, by chance, in exact conformity with the underlying principle or law concerned. More generally it may be said that all progressive success of em-

[2] *The Cultivator and Country Gentleman*, Vol. 28, p. 401, 1866.

[3] *Massachusetts Agricultural Repository and Journal*, Vol. IV., No. 4. Cf. also *New England Farmer*, Vol. III., p. 305, 1825.

[4] Consider in this connection the practises of the real expert in making world's records for milk and butter fat production in the seven- and thirty-day advanced registry tests of the Holstein-Friesian breed.

pirical methods depends on a gradual elimination of those operations or practises which do not accord with basic natural laws. In the consideration of the science and practise of breeding this has sometimes been forgotten. It is difficult to remember always that a law of nature may be presumed to have been in operation before its discovery. If Mendel's law represents a real and fundamental law of nature, as certainly appears to be the case in the light of present evidence, it is quite certain that it did not begin operation in A.D. 1900. Whatever of success has been attained during centuries past in the breeding of improved strains of animals and plants, must have been attained by methods and practises which were not violently in discord with Mendelian principles. A nomad Arab may never have heard of the principle of segregation, but none the less he had to reckon with the phenomenon in breeding his horses.

Looking at the matter in this way, the reason is clear why the rediscovery of Mendel's work and the brilliant genetic researches which have followed did not and could not have had any profound revolutionary effect on the *practise* of the animal breeders' art. By years—even centuries—of "trial and error" methods, breeding practise has been brought into rather close conformity with the basic laws of heredity. The discovery of some of these laws by the geneticist could not radically change the breeder's way of attaining results.

What then has the rapidly developing science of genetics done for the breeder and what can it do? Still looking at the matter from the standpoint of the practical animal breeder, it must be agreed, I think, that the chief contribution of recent discoveries in the field of inheritance is that they have brought to light and fairly established certain general principles which enable him in greatly increased measure to understand and interpret his methods and his results.[5] This may seem too mild a statement of the practical value of genetic science to the animal breeder. It undeniably does lack the grandeur of the vision sometimes opened out by the extension lecturer in his zeal to inspire the farmers to better things, and at the same time pave the way to increased appropriations for his institution. But to help one to understand and to interpret is, after all, no mean achievement. It signifies that, with much economy of effort, the successful breeder may dispense with the merely trivial and unessential in his empirical methods, and more directly and uniformly attain the same or a greater measure of success than before. To his less successful brother and the beginner, it means a surer and more rapid guide than the old tradition based on empiricism. It is certain that the young man starting out to-day to be a breeder of fine cattle, of fine horses, of fine chickens, will attain his goal much sooner if he thoroughly understands the meaning of those laws of inheritance associated with the name of Mendel.

The most important general principles which the scientific study of genetics has firmly grounded are, it seems to me, these:

(*a*) That the fundamental basis of all inheritance is to be found in the germinal constitution of the individual rather than

[5] This is of course to be understood as a general statement. There are now a few specific instances, and in time there will be more, where the geneticist has been able to show the breeder precisely how to attain a particular result in breeding commercially for a particular quality, which result he had only hitherto been able to obtain by chance. In no such case, however, so far as I am aware, has the new method been so essentially different from former practise as to be fairly regarded as "revolutionary."

in the body or soma. Those qualities alone are inherited, which are innate in the germ cells, the ova and the spermatozoa. Here only can the breeder find the means with which to accomplish his ends. However interesting theoretically may be those rare and still doubtful cases in which extraordinary influences acting upon the body under the controlled and special conditions of the laboratory may perhaps influence the germ cells through the soma, they have no bearing on the practical conduct of the breeders' craft. Genetics has demonstrated that he may cast aside, for once and all, that mass of tradition and superstition which assumes that influences specifically affecting the body will specifically modify subsequent generations. Has not genetics done breeding a service of great value in freeing it of the sinister influence of "telegony," "saturation," "maternal impressions" and similar sorts of nonsense?

(*b*) That specific characters or groups of characters, in the great majority of cases and perhaps all, are inherited as discrete and definite units. If one mates a pea-combed fowl with a single-combed, all the offspring will have pea-combs. This result occurs whether the pea-combed parent is a Game or a Brahma; whether it is a male or a female; whether it is a strong, vigorous individual, or the sickliest, weakest scrub in the flock. In other words the *kind of bird* it is whose germ cells carry the potentiality to make pea-combs develop in the offspring, so far as we now know has nothing to do with the *specific* result (*i. e.*, the production of a *pea* comb, rather than a single, a rose, or any other kind). Comb form is inherited as a discrete unit uninfluenced by the individual's other attributes. This discovery that characters are inherited as separate units—and no principle of genetics is more firmly grounded than this—gives the breeder a totally new concept of the meaning of "purity" of blood in breeding. We see now that properly (*i. e.*, biologically) one can only speak of an animal as being "pure-bred" when he specifies the particular *character* to which he refers. A chick may be the veriest mongrel in all other respects and yet carry in the germ cells only that potentiality in respect to comb form which leads to the development of a pea-comb. Then however much of a mongrel it may be in respect to all other characters, it is "pure" and "pure-bred" so far as concerns comb. Is it not a contribution of moment to the breeder to have demonstrated that in his breeding operations he may safely and surely deal with individual characters, and groups of correlated characters as units?

(*c*) That in a very great range of cases, perhaps in all—the number of known cases daily grows larger—the Mendelian law of segregation and recombination of characters operates. In the formation of the germ-cells of an individual there is a sorting out or segregation of the hereditary characteristics contributed by the father and the mother and a readjustment of these into all of the combinations, both old and new, which are mathematically possible. What may be the precise cellular mechanism or basis of this wonderful process is not altogether certain, but the phenomenon itself is as certain as the phenomenon of gravitation. It operates as well in regard to the minutest heritable differences in the pedigreed specimens of the same sub-breed as in the wide differences of true hybridization. Properly understood, it enables the breeder to interpret and weigh the results of his breeding operations, and so intelligently to plan the next steps with a certainty and precision hitherto unattainable. Is not this a real contribution of science to practise?

(*d*) That the germinal bases of heritable unit characters can be changed or altered in any respect, only with the greatest difficulty, if at all. It is, I believe, fair to say that there is at present no critical, unchallenged evidence that any alteration can be produced. This matter has recently been discussed in a most able manner by East.[6] The weight of evidence at present indicates that selection does not act in the manner it was long supposed to, in accordance with Darwin's interpretation. It appears that selection, however stringent or long continued, is powerless to alter in any way the original potentialities of the germinal basis of a unit character. Selection appears to be essentially a process of sorting out from a mixture of heritable variations what is already there, and not a germinally creative or germinally additive process.

So far this discussion has been approached from the standpoint solely of animal breeding. It is perhaps allowable, even before this animal section, to digress for a little and discuss plant breeding. The ultimate objective point of the animal breeder is the same as that of the plant breeder, namely the greatest possible improvement of animals and plants and their adaptation to the needs of man. The practical method of working towards this goal is, however, somewhat different in the two fields. The animal breeder almost exclusively works towards the amelioration of existing fixed and "pure" breeds. Especially among the larger domestic animals such a thing as a *new* breed is brought forward by the breeder only on very rare occasions. Almost all of our existing breeds of horses, cattle, sheep and swine have long histories as "pure breeds," and no new ones are being added now. With smaller animals such as poultry the case is of course somewhat different. There we have no registered pedigrees and, with some difficulty, new breeds may be launched.

[6] *American Naturalist*, 1912.

The plant breeder, on the other hand, makes nearly all of his improvements by the production of new varieties. This he does either by hybridization, actually building up a new type, or by isolation of superior pure-breeding forms from already existing mixtures. He is not hampered by a body of tradition that only the "pure bred" is of any particular value. Almost if not quite every one of the most valuable strains of agricultural plants to-day carries the "bar sinister." To the animal breeder they would be "grades" or "crosses" however gametically pure and only with the greatest difficulty would ever have gained a chance to show their worth.

No one would deny that the systems of registry for live-stock and the exploitation of the "pure-bred" have been of great value in the development of the animal industry of the world. They certainly have; and every day the economic importance of the system becomes greater, for obvious reasons. All systems of pedigree registration operate economically precisely like a monopoly. As such a plan of developing the live-stock industry of a country grows, the more difficult does it become for a *new* creation of the breeder to get a foothold. If it is new, it is by definition not "pure-bred," because if it were "pure-bred" it must belong to one or another of the established breeds. But anything not "pure-bred" has no recognized standing, or market value. Without regard to the merits of the individual the mere fact of pedigree registration adds a definite and not inconsiderable amount to the monetary value of an animal. In last analysis this fact is to-day one of the strongest arguments which can be made to the farmer in favor of keeping "pure-bred" animals.

What has just been said is not intended in any way to criticise, or belittle the importance and value of the "pure-bred" registry system of developing the live-stock industry of the world. I merely wish to point out that when he adopted the system, the animal breeder took upon himself along with the advantages certain very real restrictions to the freedom of his breeding operations, which the plant breeder has escaped. The animal-breeding industry of the world has developed as a system of pedigreed aristocracy. The plant-breeding industry is developing as a democracy. The "social position" of a horse or a cow is primarily determined on the basis of whether it had a grandfather or not. A variety of oats takes its place in the world by virtue of its own inherent qualities, with no questions asked about forebears or the orthodoxy of their marital relations. Both aristocracies and democracies have their advantages and their disadvantages as social systems. These merits and defects are just as real and effective in their operation whether the ultimate vital unit of the system be a man, a cow or an oat plant.

Owing to the essentially different conditions and methods of work which obtain in plant breeding, this field is able to reap more direct benefits of a practical character from the advances which have been made in the science of genetics, than is animal breeding. In the creation of new races by hybridization the plant breeder can and does take Mendelian principles as a direct and immediate guide. He has made Mendelism a working tool of his craft.

To conclude: What I have tried to do in this paper is to discuss the relation between the science of genetics and the practical art of breeding as they actually have developed and now exist. Your attention has been directed to the obvious fact that animal breeding has, without the aid of genetic science, attained an extremely high level of achievement. Empirical methods can only have been successful when they were fundamentally in accord with natural laws, and it is therefore not to be considered surprising that the recent discoveries of world-old genetic laws have not radically modified the successful animal breeders' methods. In pointing out that a scientifically trained geneticist is not as yet an absolutely indispensable necessity on a successful animal breeding farm I have no thought or desire to belittle the importance of the science of genetics. My zeal and enthusiasm for the advance of knowledge in this field know no bounds. This attitude, however, furnishes no reason that the geneticist should delude himself, or by rash statements hold out false hopes to the breeder, as to the immediate practical importance of some of the recent developments in the science of genetics. All knowledge is potentially useful, but the fundamental reason for undertaking and encouraging research in genetics, or anything else, is not because what one gets may be useful, but because it is *knowledge*.

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THE METAMORPHOSIS OF THE CARNEGIE FOUNDATION

THAT part—a relatively small part—of the new annual report of the Carnegie Foundation which deals with the affairs of the foundation itself, is significant chiefly as showing that the president of the foundation, at least, has already abandoned most of those principles which at the outset were generally understood to govern the foundation's policy with respect to retiring allowances. It is worth while to recall what some of those principles were.

1. The primary purpose of the pension system was to be, not to relieve deserving and necessitous college teachers in their old age, but to better the profession as a whole, "to attract into it increasing numbers of strong