Patagonian Squash

The members of the squash tribe are readily fertilized, as illustrated in earlier pictures of this volume, but the hybrids tend to show extreme variation, and they are very difficult to fix. Mr. Burbank has shown, however, that it is not impossible to fix new varieties by careful selective breeding. The squash here shown was developed from seed sent from South America. It has almost the solidity and weight of a cannon ball.

Fixing Good Traits

How to Hold a Result Once Achieved

IT IS traditional that you cannot teach an old dog new tricks. The maxim applies with full force to old plants. You may bend the twig and make a permanent twist in the future tree; but the hardened stock of the matured branch will return persistently if bent, and will break rather than change its form.

Now there is something like the same difference in flexibility between young and old races of plants. Here is a variety of plant that has been developed in the orchard or garden, under man's influence, in the course of the past few generations. It tends to vary, and its progeny may be made to adapt themselves to different conditions; by selection, they may be developed into divers and sundry new races.

But yonder palm tree has no such propensity to vary. Its ancestors have remained substantially

unchanged, true to their racial type, generation after generation, for untold centuries. It represents an old, fixed, conservative stock. No one knows how to make it change, except within the narrowest of limits.

There is a very essential time element, then, that is instrumental in determining the fixity or variability of a race of plants. A plant that has been bred true to a given type for long periods of time, as is the case with the generality of wild plants, will breed substantially true from seed, and as a rule will maintain its racial type even if transplanted to new surroundings.

But, on the other hand, the generality of cultivated plants are of mixed ancestry. Man has attempted within recent generations, to change them and adapt them to his needs. He has constantly been hybridizing them, or placing them under conditions that resulted in their hybridization through the visits of bees; and he has selected and cultivated the individual specimens that tended to vary, and thus has fostered the habit of variability rather than that of fixity of character.

In the case of most orchard fruits, as we have had occasion to observe more than once, so many strains are blended that propagation from seeds is quite out of the question; unless, indeed, it be

desired to secure seedlings of varying qualities in the interests of experimentation, or in the attempt to develop still other varieties.

One might plant a thousand acres with seeds of the Baldwin apple, without perhaps producing a single plant that would precisely duplicate the qualities of the fruit from which the seeds were taken. And the same thing is true in greater or less measure of the majority not merely of orchard fruits but of cultivated plants in general.

The notable exceptions are annual plants that are habitually grown from seed, such as melons and peas in the garden, and the great tribe of cereals represented by wheat, oats, rye, and barley. The reason why all of these breed true from seed is that they are necessarily propagated in this way alone, and it has been essential that fixed races should be developed.

Mankind depends largely upon the cereals for food, and his existence would be altogether precarious could he not have reasonable assurance that when he sows grain of a certain quality, he will secure a crop of grain of similar quality.

The fixity of character of the cereals and various other plants, including peas, and beans, is enhanced and assured by the fact that the flowers of these plants are habitually self-fertilized. If you examine a head of wheat at

the right stage, you will find that you must pull open the little bracts in which the flowers are encased, in order to make the stamens and pistils visible. Under ordinary circumstances, insects cannot find access to them. The wind has no influence over them. Their normal habit is to fertilize the pistil of each individual flower with pollen from the stamens that grow within the same closed receptacle.

This is inbreeding of the closest and most intimate character, and there is obviously no ordinary opportunity to introduce the element of variability which, as we have seen illustrated over and over, cross-fertilization brings.

So the essential qualities that make wheat valuable have been aggregated in a few fixed combinations, and the resulting varieties of wheat, differing not very widely from one another, are never crossed, unless by artificial means to meet the special needs of the plant developer.

They remain fixed because they are of pure lineage.

Mixed Ancestry and Inbreeding

The case of the wheat is typical. Its development furnishes an illustration of the method through which many specialized races of animals and plants under domestication have been developed. Indeed, it might almost be said that the

one rule that has actuated the developer of special races has been to apply the principle of inbreeding. When an individual appeared in a herd or flock that showed certain peculiarities that the owner thought desirable, the natural and obvious way of perpetuating these was to breed from that individual; and then persistently, for a time, to inbreed the progeny in order to accentuate the desired trait.

The result has often been all that could be expected. Take, for instance, the case of the trotting-horse.

It is, I believe, a matter of record that practically the entire stock of trotters, as developed in America in the past hundred years, descended from a single ancestor, the celebrated "Messenger." This individual horse chanced through some accidental mixture of ancestral strains to combine in its organization the particular qualities of nerve and muscle that adapted it for rapid progress by trotting instead of by the more natural method of running.

And as regards this quality or combination of qualities, the horse proved amazingly prepotent.

Its descendants soon constituted a race of trotters. Pedigrees were kept; the best individuals of the new race were selected as breeders; closely related animals were mated; and the character-

istics that make for speed at the trotting gait were in a few generations so fixed that a new race of horse was produced.

The principle thus illustrated applies with equal force to the breeding of plants. Indeed, it is possible here to hold even more rigidly to the idea of inbreeding, inasmuch as the individual flowers may be self-fertilized. We have just seen this illustrated in the case of the wheat and allied cereals.

There is no question whatever that any given characteristic of a plant, once it appears, can be accentuated and fixed, first in individuals, and finally indelibly in the heredity of the descendants of the plant by systematic inbreeding.

But, unfortunately, there are complications in the case of most experiments that the originator of new plants is called upon to undertake, that robs the method of its simplicity. The complications arise from the fact that the would-be originator of new races of fruit or flowers is usually seeking to develop not merely a single quality, but a number of qualities. And this alters the case fundamentally.

In the case of the trotting-horse, the one all-essential quality desired is speed.

The capacity to trot a full mile at high speed does, indeed, imply the possession of stamina and

courage, as well as capacity for rapid action of the legs. These are qualities that are necessarily linked with the capacity for the right kind of muscular action.

But beyond this there are very few qualities upon which the breeder must insist. It does not greatly matter whether the speedy animal is small or large; its color is mostly a matter of entire indifference; and it is taken as a matter of course that the record-breaking animal will be nervous in temperament, tender as a hothouse plant, and requiring such care and attention as would be only wasted upon a more plebeian animal.

In a word, the breeder of trotting-horses fixes attention principally on the single quality of speed.

But it is rare indeed that the would-be developer of a new plant can thus fix attention upon any single quality to the disregard of other qualities. On the contrary, as a rule, the plant experimenter, while he may have in mind one most important quality, must consider at the same time six or eight or ten or a dozen other qualities that are only a degree less essential. We have seen this illustrated again and again, and we shall have occasion to recall some of the specific characters involved in the course of the present discussion.

In reality, the task of the experimenter who would develop a new and really valuable variety of plum or cherry or apple or spineless cactus, is to be compared not with the task of breeding trotting-horses as they are, but rather to the task that would confront the breeder were he to attempt to develop a race of trotting-horses which should retain the capacity to trot a mile in less than two minutes, yet at the same time should be big and powerful enough to serve on occasion as draught horses; should be always of some predetermined color, say bright bay; and should be as hardy and require as little attention as the toughest broncho.

It requires no great amount of imagination to see that the task of breeding race horses would be quite different from what it is, were the specifications such as these.

Yet I repeat that the qualities that the plant experimenter usually seeks to combine in his new variety of flower or fruit are at least as varied and as difficult to fix in combination as the qualities just suggested for the supposititious new breed of race horses.

The Shasta on the Witness Stand

Let us by way of illustration recall the case of the Shasta daisy which, the reader will remember, was developed by the union of three different

Rose Cuttings—Developed by Selective Breeding

A new variety of rose—developed by selective breeding—may be propagated by merely cutting the branches into sections, and planting them in the way illustrated on page 135. It is of course necessary to have at least one bud, and preferably two or three, on each cutting. Mr. Burbank has developed some very remarkable new varieties of roses, including one that received a gold medal at the St. Louis International Exposition in 1904.

species of flowers, coming respectively from Europe, America, and Japan.

It will be further recalled, that the ideal daisy that I had in mind for years before it became an actuality, showed in superlative degree a considerable variety of qualities that were not found in combination in any one of its ancestors. Indeed, the Shasta daisy, as ultimately developed, reveals a number of very conspicuous and important qualities that are not shown at all in any one of its known progenitors.

To make the illustration specific, we may cite, among the qualities that are assembled in the finished product, the following: (1) extreme size, (2) dazzling whiteness, (3) broad rays, (4) double rays, (5) gracefully drooping rays, (6) keeping quality of flower, (7) smooth stem, (8) early and persistent blooming, (9) hardiness, (10) constant bearing.

The perfected Shasta daisy manifests these qualities in supreme degree. As regards each and every one of them, it surpasses any of the parental forms from which it sprang; indeed, as to some of them, such as double and drooping rays, it shows an entire departure from all of its observed ancestors, harking back to the remoter forms of past ages.

But to assemble these qualities in a single

flower required about fifteen years of persistent effort, and the handling of probably not less than half a million individual seedlings.

Generation after generation the plants were cross-pollenized and selected over and over, always with an eye not merely to a single quality, but to the ensemble of qualities.

And always we were confronted with the difficulty that in reaching out to bring in some new quality, we were disturbing the balance of qualities already attained, and endangering the entire structure.

When, for example, the final cross was made with the Japanese daisy, to secure if possible the element of whiteness shown pre-eminently by that flower, and add it to our mosaic, we, of necessity, brought in also from the Japanese parent, along with the quality of whiteness, such undesired qualities as crude, ungraceful stems and flowers.

It was necessary to select and interbreed, and select again, for successive generations from among a multitude of the progeny of this cross, before a plant was finally secured that presented the desirable combination of qualities, retaining the whiteness of the Japanese parent, but rejecting its undesired characteristics of leaf and stem, and departing utterly from that particular parent in point of size.

But, although an individual was at last found that did combine all the desired qualities, the very fact that this individual had been built up by putting together *this* quality brought from one parent and *that* quality from another, with the rejection of antagonistic qualities in each case, makes it inevitable that the perfected Shasta should contain latent in its system a whole coterie of tendencies which are fighting for recognition, and which will make themselves felt in subsequent generations.

Hence it is that when seeds are gathered from the perfected Shasta they will not give us a crop of flowers like their parent. On the contrary, they will show the utmost diversity of form and size and color, making tangible thus the persistent force of the hereditary tendencies that had been transmitted from divers ancestors, but which were submerged or made latent, simply because they were momentarily subordinated to opposing qualities, in the case of the perfect Shasta.

The Shasta daisy, then, while individually almost a perfect embodiment of the ideal at which I aimed, is when reproduced, from seed, anything but a fixed type. Had it not been possible to propagate the plant by division and then by an unending series of successive divisions to produce an indefinite number of individuals, each precisely

like the original because they were in a sense a part of it, my entire series of experiments in developing the new daisy would have been unavailing except for still further selection. But as the case stands, it was possible rapidly to develop an entire race of Shasta daisies by root-division, and thanks to this method the descendants, or, to speak somewhat more accurately, the *sisters* of the original Shasta daisy have become an enormously populous race, scattered to the remotest parts of the earth.

Several other types of Shastas have been developed by new breeding experiments from the original stock, but to this day the race of Shasta daisies must be propagated from the root, and not grown from seed, unless one desires a conglomerate progeny, departing in many ways from the form and quality of the immediate ancestor.

Fixing a Type

In all this, it must be recalled, the Shasta daisy does not differ from a large number of long-established cultivated plants that are everywhere recognized as being "fixed" races.

One does not produce apples or pears or cherries or plums or blackberries or potatoes or sugar cane or horse radish, to say nothing of roses, ornamental shrubs and a great number of flowering plants, from seed.

Wild Grapes

There are a good many species of wild grapes, and Mr. Burbank has utilized several of these in his experiments. His chief work with this species has been done, however, with the common European cultivated grape, which has developed a large number of varieties through being selected for various purposes during past centuries. In particular some of his most important new varieties are descended from a "bud sport,"—that is, a variation that appeared "spontaneously" in a branch growing on an ordinary grape vine.

They are propagated by grafting or budding, or by rooting the stem or dividing the roots or planting the tuber. And the reason in each case is the same. The perfected variety originated from a single individual that combined a large number of desirable qualities, and the entire company of individual representatives of that variety, though they be numbered in millions, are not really descendants, but offshoots, of the original individual.

Each cion or bud from a given tree will produce fruit precisely like that from the tree from which it is taken, because it is itself a part of the tree. And however widely new cions and buds from the first cion may be disseminated, they carry the same traits, because, rightly considered, they are a part of the same individual organism. The Seckel pear tree that grows in your dooryard is, from the standpoint of heredity, a tree of the same generation with untold thousands of other Seckel pear trees that have grown here and there across the hemispheres for more than a hundred years—or since the first one appeared in the orchard of the Pennsylvanian whose name they bear.

Were it not for the contradiction of terms, one might say that all Seckel pear trees constitute a single tree.

All these Seckel pear trees are essentially alike; they bear fruit that may vary in size and lusciousness with varying conditions, but that is everywhere essentially identical in flavor and in the characteristic qualities of texture and color. But if you plant the seeds of one of these pears you do not secure Seckel pears, unless by the merest chance, among the progeny. You secure instead, representatives of a galaxy of ancestors, no one of them individually just like the Seckel, although *collectively* they represent all the qualities of that fruit, plus almost numberless undesirable qualities.

Pairs of Qualities

The fact that our most familiar and best prized fruits and flowers show this lack of fixity, suggests that the inherent difficulties in the way of fixing the type of these plants so that they will breed true from seed are very great. Otherwise some one would long ago have remedied the defect, for the advantages of being able to grow these useful plants from seed are obvious.

Nevertheless it should not be assumed that the task of fixing the type of a newly developed race of fruit or flowers is of necessity a hopeless one.

The truth is that it would be possible to fix the type of almost any variety of plant, provided time enough and patience enough were devoted to the

task, and the experiment were conducted on a wide enough scale. Indeed, nothing more would be necessary than to continue for an additional number of generations the same line of experimentation through which the new varieties were produced; attending carefully at all stages to the analysis of the different qualities that prove to be mutually antagonistic.

To this end, the new terminology which endeavors to analyze the qualities of a given plant into complementary pairs of unit characters may prove very helpful, particularly to the inexperienced investigator.

Such an analysis has always been made, tacitly at any rate, by the successful plant experimenter. No one can think of the development of an *early*-fruiting cherry or prune without having in mind the quality of *late*-fruiting. To speak of a prune with *high* sugar content implies one with *low* sugar content.

In a word, the desired quality of fruit or flower at which one aims is always balanced against the opposing quality—sweet fruit against sour, hardiness against tenderness, resistance to disease against susceptibility to disease, profuse bearing against scant bearing, thorny brier against smooth brier, black fruit against white fruit, and so on down the list.

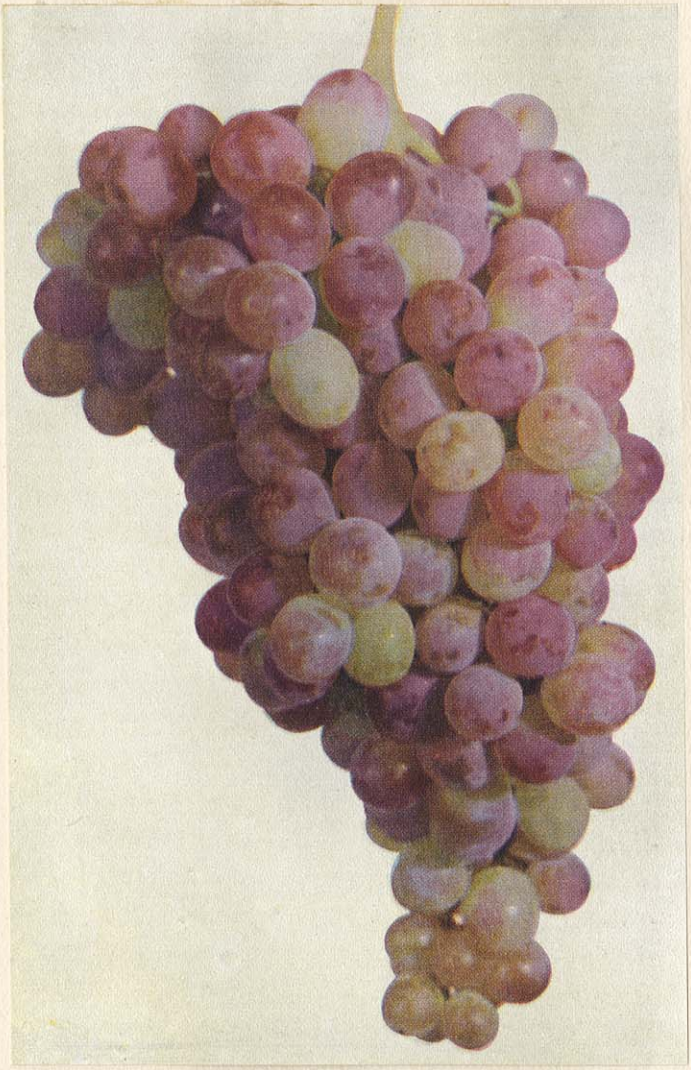
It is only by constantly bearing these divergent pairs of qualities in mind that any experimenter can hope to advance toward the production of an ideal fruit or flower or vine. And it has always been so.

Old Wine in New Bottles

But there can be no question that the new terminology, as used by present day biologists, serves to give precision to the ideas of the plant experimenter, and enables him to analyze the results of his experiments in more precise terms than have hitherto been available.

It will be convenient, therefore, and probably helpful to the reader, in making precise reference to some of the experiments in plant breeding already detailed, with special reference to the possibility of fixing the type of new races, if we discuss the matter in the new terminology.

It will at once appear that when a plant developer attempts to fix a certain type, he is fundamentally changing his point of view. Hitherto he has been concerned to make plants vary, in order that he might seize on new forms, and use them as material for developing the type at which he aims. And his success in developing a new race is largely dependent upon the extent to which he has been able to induce the plants with which he experiments to vary.



Seedless Grapes

This shows one of Mr. Burbank's choicest varieties of new seedless grapes. They have been developed by selection, and are of delicious quality, with an added attractiveness due to the entire absence of seeds. Of course a fruit thus developed must be propagated by cuttings, and is not susceptible of further improvement, unless there should be a reversion to the seed-bearing condition.

So now, when he attempts to restore fixity to something that he has purposely made unstable, he is at once confronted with the danger of undoing much that he has accomplished. The measure of success that he can hope to attain will depend very largely upon the particular kind of unit characters that he has combined in the product that he now wishes to make stable.

We have seen that, as between the opposing members of any pair of unit characters, it is usually discovered that one has prepotency or dominancy over the other. When blackberries of normal color, for example, are crossed with the white blackberry, the progeny are all black, because this color is the dominant member, and white the recessive or negative member of the pair of unit characters. But we saw also that the recessive trait will reappear in the succeeding generation, and that when it does reappear, it will, within certain limits, thereafter breed true.

So, when in the second generation we again produce a white blackberry, we have a type which is fixed as regards the particular character of whiteness. In other words, our white blackberry, even though both its parents, and one grandparent, were black, may be considered a berry of pure white strain. From the moment of its appearance it is a fixed type as to color.

But, unfortunately, it is not sufficient that the white blackberry should breed true as regards the quality of whiteness alone. There are other qualities of size and flavor that are equally essential. And these, it would appear, include sundry other pairs of unit characters—sweetness versus sourness, large size versus small size, profuse bearing versus scant bearing, and the like—that are represented in our berry by mixed factors.

In the Mendelian view, it will be recalled, there are always two factors representing any pair of unit characters.

In the case of our white blackberry, in the Mendelian view, both factors for the unit character blackness-versus-whiteness are of the white order; or in the technical phrase, the berry is "homozygous" for that pair of factors.

But as regards, let us say, the factor for the unit character bigness-versus-smallness the case is different; for this character may chance to be represented by one factor of each type. In other words, resorting again to the technical language, the berry may be "heterozygous" as regards that character.

In this particular generation, the quality of bigness prevails, because bigness is dominant to smallness. But the factor for smallness must have a hearing in the next generation.

Until we can produce a white blackberry that is "homozygous" for size-factors as well as for color-factors, we shall not obtain a fruit that will breed true to size as well as color.

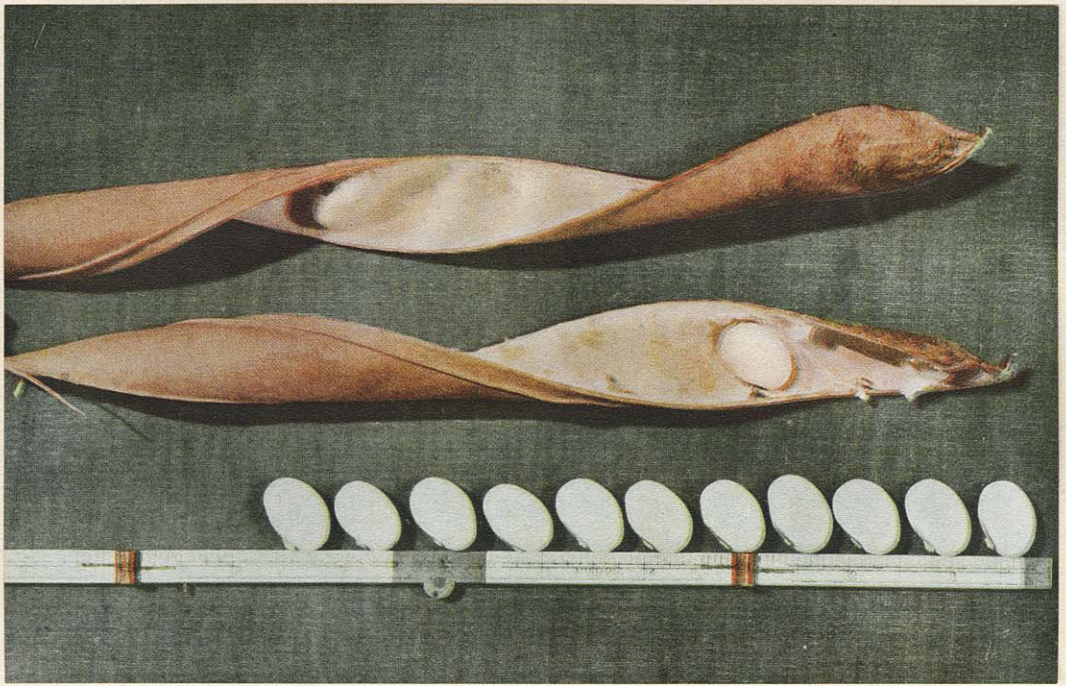
A similar analysis might be applied to the various other pairs of unit characters that are represented in any given fruit or flower. And the essential principle, stated in Mendelian terms, to be aimed at by the experimenter who would fix a newly developed type of plant so that it will breed true from seed, must be to render the plant "homozygous" for the factors of each pair of unit characters involved. If that can be done, the plant will breed true; if that cannot be done, the plant will not breed true.

In the olden phrasing, this would be spoken of as "line" breeding—a method long familiar to every breeder of plants or animals.

Fixing a Type in the Second Generation

In actual practice, where only two or three unit characters are involved, it may be possible to produce a new type that breeds true, or is fixed, in the second generation. In such a case the time element may be ignored.

Take, by way of illustration, Professor Castle's guinea pigs, to which reference has more than once been made. Suppose we have as parent stock a black guinea pig with a smooth coat, and



New Chilian Beans

Mr. Burbank for many years had a trusted collector in Chili, from whom he received numerous interesting new plants. This bean has been developed by selective breeding until it produces large seeds of extraordinary uniformity of size and shape. Hybridizing this bean with cultivated varieties will probably produce interesting variations.

a white guinea pig with a rough coat. Now we have already seen that blackness is dominant to whiteness as regards the coat of the guinea pig, and we must further understand that roughness of coat is known to be dominant to smoothness.

We must expect, then (according to Professor Castle), that when a cross is made, the guinea pigs of the first filial generation will, unlike either parent, be black in color and rough as to coat.

But, in the succeeding generation, the black, rough-coated guinea pigs being interbred, there will be a certain number of offspring that combine the dominant characters of blackness and roughness of coat, and will breed true to these; a certain number will be black and rough-coated, but will bear the latent characters of smoothness and whiteness of coat which will reappear in their progeny; and, finally, there will appear individuals combining the two recessive traits of whiteness and smoothness of coat.

These white, smooth-coated individuals are obviously different from their parents, and different also from either of their grandparents. They constitute a new race, sprung into being in a single generation, and a race that will necessarily breed true as to the character of smooth coat and white coat, because they are "homozygous" as to the factors for both these recessive characters.

Their progeny cannot be black because their germ-plasm contains no hereditary factor for blackness; nor can their progeny be rough-coated, because their germ-plasm contains no hereditary factors for rough-coatedness.

Yet side by side with this new fixed race of smooth-coated white guinea pigs, there are, as we have seen, twins of the same fraternity that instead of being white and smooth in color, are black and rough. And these also constitute a new race that will breed true because they contain, as regards the unit character for color and for condition of hair, only the dominant factors of blackness and roughness. They also are "homozygotes," but they are of the opposite type—dominants instead of recessives.

Meantime, we must not overlook the other members of the fraternity, twin brethren of these new races, which are individually black and rough, but which are "heterozygotes" as regards the unit characters under consideration, and hence will show progeny of variously mixed characteristics as to roughness or smoothness of coat, and as to black or white color.

This illustration, perhaps, gives as tangible an impression as can well be gained, of the complexities that confront the experimenter when he attempts to fix a new type of animal or plant.

Even where only two unit characters are involved, the progeny of the second generation, as we have just seen, may break up into numerous races, some fixed and others variable. And, as we have previously pointed out, the complications thus introduced increase at a startling ratio when more characters are under consideration.

Moreover, the matter is rendered increasingly difficult for the plant experimenter by the fact that he must often wait, particularly in the case of orchard fruits, for a term of years before he can know the result of any single breeding experiment. To sort out the pure types from the mixed ones of any given generation under these circumstances becomes a matter of enormous complexity.

It could be done, by inbreeding representatives of the new type and carefully selecting the progeny for a series of generations.

But in the end, all that would have been accomplished, in the case say of a Shasta daisy or of a stoneless plum or a sugar prune, would be the production of seed that could be used to disseminate the new variety. And in most cases we are justified in feeling that this would represent an undue expenditure of time and energy for a comparatively insignificant result.

For, as the case stands, even though the new form will not breed true from seed, it may be

propagated indefinitely from roots or from the grafting of cions; so that in practice the failure to breed true from seed has little significance.

Probably it is the fact of the relative unimportance that our cultivated plants should breed true from seed that chiefly explains the failure of plant breeders in the past to fix the type of the best known fruits and vegetables and flowers.

The same reasoning obviously applies to the newly developed varieties. While so much work remains to be done in the way of developing new types of fruit and flower, the most practiced experimenters will probably feel that they have not time and energy to spare for the fixing of the new races already developed.

We shall have occasion to call attention to various exceptions to this rule in the course of our subsequent studies; particularly with reference to certain annual plants. Here by "line" breeding for a few generations we may fix the new traits almost as firmly as the old traits are fixed in wild species. Again we shall learn in due course of new hybrid fruits like the sunberry, the primus berry, and the phenomenal berry that are fixed as to their chief properties from the very first hybrid generation. But as regards most of the new forms of fruit and flower that we have hitherto described, the rule holds with full force.