THE FERMENTATION OF CACAO AND OF COFFEE.[1]

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THE FERMENTATION OF CACAO.

Although much has been written about the fermentation of cacao, there still exists a great difference of opinion in regard to the process, its purpose and necessity, and the kind of action involved in it.

Herbert Wright, in his exhaustive work on cacao[2] mentions yeast cells[3] as the most important organisms causing the fermentation, while other authors attribute the fermentation to unorganized ferments, others again to bacteria, and even the changes due to germination were supposed to play a rôle in it.

According to George Watt, in his Dictionary of the Economic Products of India[4]—

> The coolie dexterously strips all the beans off the center pulp. The pods are then thrown round the trees and act as manure, while the beans are removed to the fermenting cistern. It takes from five to nine days to properly ferment the cacao and it is then ready for working. It is trampled first, as in coffee, with the feet and then removed in baskets and carefully hand-washed.[5] * * * I have no doubt that before long some means less expensive will be found for washing. * * * The prices obtained for it will depend in the much greater measure on the careful attention of the curing than in the case of coffee.

Safford, writing on cacao in Guam,[6] says:

> Cacao beans are sometimes kept in jars and allowed to "sweat," or undergo a sort of fermentation which improves their flavor, but this custom is not universal. Many families, after having dried the beans in the sun, keep them until required for use, when they toast them as we do coffee, grind them, and make them into chocolate. Chocolate made from the newly ground bean is especially rich and aromatic.

[1] From the annual report of the Porto Rico Agricultural Experiment Station for 1907.

[2] Theobroma cacao or cocoa. Colombo, 1907, p. 108.

[3] According to A. Preyer (Tropenpflanzer, 5 (1901), pp. 157–173), a special kind of yeast, which he named Saccharomyces theobromae, effects the best fermentation in Ceylon.

[4] London, 1893, vol. 6, part 4, p. 44.

[5] Such methods are followed in India, but not in America.

[6] Useful Plants of Guam. U. S. Nat. Mus., Contrib. Nat. Herbarium, 9 (1905), p. 387.

Hinchley Hart[7] writes:

> The prime object of sweating or fermentation appears to be to change the inside portion of the bean by absorbing into it products obtained from the fermenting pulp, and where this is not fully accomplished by any of the methods the bean is classed as unfermented, and the product is generally of lower value.

The changes brought about by the fermentation have been minutely examined by J. B. Harrison, chemist in British Guiana. Some of the changes observed, as, for example, the decrease of protein in the seed and the increase of amido compounds, are only incidental and not of any importance, since they do not affect the color, which is simply due to the action of a proteolytic enzyme in the seed.

The principal conclusions reached by Harrison[8] are that the process of "fermentation or sweating in cacao consists in an alcoholic fermentation of the sugars in the pulp of the fruit accompanied by a loss of some of the albuminoid and indeterminate nitrogenous constituents of the beans, * * * and some parts of the carbohydrates other than the sugars undergo hydrolysis and either escape in the runnings from the boxes in the form of glucose or undergo in turn the alcoholic and acetic fermentations." Further he declares, "During this change some of the astringent matters, to which the somewhat acrid taste of the raw beans is due, are also hydrolyzed, and thus a marked improvement in flavor is gained." Finally he adds, "This work has necessarily only resulted in a partial and incomplete study of the results of the fermentation." The so-called fermentation is carried out either by heaping the fresh seeds, after separating them from the shell, on the floor or in receptacles and covering them with banana leaves or with cloth. The floor or the receptacles slope so that the watery products can escape during the fermentation. A period of two to six days, according to circumstances, is usually allowed for fermentation. The height of the heaped seed measures 1 to 1.5 meters and over. In some countries the highest temperature allowed for fermentation is 45° C., in others, 50° C. According to Hart[9] there is "danger in allowing (the temperature) to rise above 140° F. (60° C.), as the character of the product is sure to suffer."

An apparatus has been recently devised by M. Schulte in which a constant temperature of 60° C. is maintained. In this case the yeast is fully excluded and bacteria with few exceptions also, and the necessary changes are brought on mainly by the heat, but this method has been considered too tedious and of little value to cacao planters, as is shown by Maurice Montet[10] in his criticism of the apparatus.

The rise of temperature amounts to about 5° C. in twenty-four hours,

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[7] Cacao, Trinidad, 1900, 2d ed., p. 38.

[8] Proc. Agr. Soc. Trinidad, 2 (1896–97), p. 250, Hart, Cacao. Trinidad 1900, 2d ed., pp. 106, 107.

[9] Cacao, Trinidad, 1900, 2d ed., p. 42.

[10] Jour. Agr. Trop., 5 (1905), No. 52, p. 297.

PLATE I.

and after four days the fermenting beans show generally an elevation of 18° to 20° C. above the temperature of the surrounding atmosphere. The more or less rapid rise of temperature in the fermenting pile depends, of course, upon the height of the pile and upon the temperature of the surrounding air.

The cacao fruit resembles a cucumber in shape, but the form is subject to certain variations. The shell is of violet, red, or yellow color, sometimes even nearly white, 15 to 25 centimeters long and 6 to 10 centimeters thick. The shape of the seed is more or less round, often laterally compressed or flattened, when it resembles the bean of Phaseolus; its length varies from 2 to 2.5 centimeters, the diameter from 0.8 to 1.8 centimeters. Between the fleshy and corrugate cotyledons, showing convolutions on the surface, lies the bitter purple embryo with its white chalaza. The cotyledons of one variety are white in color. There may exist in one fruit as many as fifty seeds. The loose parenchymatous slimy tissue (pulp) surrounding the testa of the seed appears to be of similar nature to the tissue forming the soft inner layer of the hard fruit shell. The structure of the entire fruit is somewhat complicated, and nature has evidently taken much pains to protect the embryo by four different envelopes.

The chief purposes of the fermentation process are:

(1) Removal or contraction of the pulp surrounding the seeds.

(2) Loosening of the connection between the seed and its testa.

(3) Development of color and improvement of taste.

Some authors hold that the heat of the fermentation is required to harden the interior of the bean, and also to pass it to a second fermentation; further, that another change consists in the hardening or toughening of the testa of the bean, whereby brittleness is avoided during drying, and thus the seeds are better protected against the entrance of mold fungi.[11] Various authors also ascribe to the fermentation a great influence upon the development of the aroma.

As regards the first of the above-named purposes, namely, the removal of the slime layer attached to the seed coat, a somewhat similar process occurs in the fermentation of coffee. The first step is the development of numerous yeast cells, which find ample nutrients in the sweet juice oozing from the pulp. The yeasts are chiefly *Saccharomyces ellipsoideus* and a certain amount of *S. apiculatus* which develop rapidly. These organisms occur on fruits, as well as in the dust of the air and on the surface of the soil, together with numerous bacteria. The alcohol fermentation of the sugar by these yeasts destroys the superficial strata of the pulp or slime tissue, and as its juice passes freely to the outside, nourishment is given to innumerable bacteria, among them the widely distributed acetic bacillus. The respiration of these organisms and the

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[11] Hart, Cacao, Trinidad, 1900, 2d ed., pp. 35, 49.

fermentative activity generate heat and gradually a considerable elevation of temperature is reached.

The juice on the surface now assumes a strong acid reaction, due to the oxidation of alcohol to acetic acid, and this suffices to destroy the remaining cells of the slime layer, causing thereby a considerable shrinkage of it, and also a further discharge of juice, as the cytoplasm of the dying cells becomes permeable to the interior juice. Thus a considerable amount of liquid gathers at the bottom of the receptacles and, since this liquor has an agreeable sour smell and taste, it is used in some factories as vinegar. By the bacterial action the attached pulp is further loosened from the testa to some extent and can be washed away, as is done in Ceylon. In many parts of Central America, however, the shrunken pulp is dried with the beans, which are shipped in this condition to other countries.

The fermented and well-washed cacao beans show a uniform yellowish or brownish coloration of their testa. The testa of unwashed fermented beans do not show a uniform coloration on account of the adhering films of fermented and shrunken pulp, which has turned from the original colorless condition to violet brown color, and which is reduced from the original thickness of 0.1 to 0.2 centimeter to a mere film. An advantage of removing the remaining films by washing consists doubtless in the greater rapidity of drying, whereby the danger of attack by mold fungi is diminished. E. Lange [12] holds that the extra trouble is not compensated by the additional price obtained for washed cacao. Nevertheless the washing of the cacao has been recently introduced in Trinidad.

When the pulped cacao is not fermented, but simply dried in the sun, the slimy layer around the testa shrinks considerably, but not to such insignificant thin films as after fermentation. When the entire juice of the slimy layer is simply dried up instead of being removed, a hygroscopic condition of the product results, which in moist weather becomes sticky and might support fungus growth. Hence, fermentation is preferable to a simple drying process, and after washing yields a much cleaner product.

In the fermentation of coffee the slimy layer to be removed from the testa (parchment envelope) is much thinner that of the cacao seed. Hence the fermentation of coffee is of much shorter duration than that of cacao.

In regard to the second purpose above-mentioned, namely, loosening the connection between the seed and its testa, it must be mentioned that by the death of the seed, caused by the elevation of temperature of the fermentation to 40° to 45° C., some contraction takes place and the seed recedes somewhat from its walls. Later on, in the manufacture of cacao from the fermented and dried beans, they are roasted and some further contraction of the seed is caused. The testa having lost its

[12] Agr. Record (Trinidad), 4 (1891), pp. 105–107.

hygroscopic water by the heat, now can be easily separated, especially while still warm and brittle.

An important change also due to the fermentation process is the production of a fine brown color. The effect of the fermentation in this direction is, however, not a direct, as supposed by many, but an indirect one, and may be secured by simply drying the bean. Sun-dried beans are uniformly deep brown. When the fresh seed is cut, the surface thus opened will turn from the original violet to a deep brown color within a short time, while boiled seed thus treated will not show any change of color, even after many hours' exposure to the air. This is in full analogy with similar phenomena observed very frequently with plants, and is due to the presence of oxidases or oxidizing enzymes. When cells are killed by being cut open or in any other way that will not injure the oxidases, these will, upon the death of the protoplasm in which they were stored up, be liberated and commence at once their activity, easily recognized by the early appearance of a brown, black, or red color. These colors are generally due to the oxidation of various kinds of tannins originally present in the juice or cell sap.[13] If, however, the death of the protoplasm is produced by strong acids or boiling temperature,[14] the oxidases will also be killed and no color change will be noticed, as the tannins and other readily oxidizable matters in the juices can not easily take up the atmospheric oxygen without the assistance of oxidases.

A further control experiment was made in which the pulped cacao (seed with testa and attached slime layer) was boiled for about twenty minutes with dilute sulphuric acid of 2 per cent. The slimy tissue contracted and together with the swollen testa was easily separated from the seed. These seeds showed a pure red coloration on the outside, while the interior was violet, and no trace of brown color appeared even after many hours' exposure to the air, since the oxidizing enzyme (oxidase) had been killed, together with the living matter (the protoplasm of cells).

The seeds commence to die when the entire fruit is kept for several days at 40° to 45° C., and the browning can be observed progressing from the surface of the seed toward the interior. By becoming overripe, the soft interior strata of the fruit shell, as well as the slime tissue around the seeds, contract more or less and a hollow space is formed between the fruit shell and the seeds with their adhering slime tissue. Air diffuses into this space and the reason for the brown color produced by oxidation within the fruit becomes apparent. During the fermentation process the browning does not often go farther than this, and the interior of the

[13] Such a case is observed in the curing of tobacco, whereby a fine brown color is produced.

[14] The killing temperature for oxidases is 20° to 30° C. higher than that for protoplasm or living matter.

seed often continues to show the original violet coloration. It is then that the subsequent drying process, which admits air abundantly by diffusion through the testa, completely finishes the browning process. Some further darkening can take place during the roasting process when powdered cacao and chocolate are made from the fermented beans.

The color change of the cacao seed is no doubt similar to the color change in the preparation of black tea, for which it has been positively proved [15] that an oxidizing enzyme acting on a specific tannin is the real cause of the blackening of the leaves. When the oxidizing enzyme of the tea leaves is killed by steam, the leaves retain their green color and never turn black (green tea).

Tea leaves contain 7 per cent tannin and over, and the production of a black color from this tannin commences as soon as the leaves die, which takes place when they are kept in heaps after picking and are deprived of sunlight (death by starvation). Indeed, black tea contains less tannin than green tea. In order to increase the black coloration the leaves are rolled, which brings their juice to the surface, and the access of air accelerates the blackening process.

A case in which tannin is changed by partial oxidation for the sake of removing the astringent taste is observed in the curing of the fruit of certain varieties of persimmon (kaki) in Japan. By the curing process, which consists in keeping the fruits in vapor of alcohol or in subjecting them to slow desiccation in the sun, the tannin is changed, in contact with an oxidizing enzyme and oxygen, to a brown, tasteless substance.[16] The fruit thus acquires an agreeable taste.

Since a moderate brown color is also produced in white "nibs," free of cacao red, it follows that the brown coloration is not due exclusively to a change of cacao red. If the production of the color is due to an incomplete oxidation of the tannin, then there will be less tannin found in the cured cacao than in the fresh cacao. This agrees, indeed, with some analytical determinations of J. B. Harrison, published by Hart.[17] The fat content is assumed not to change during the curing process, and this is in all probability the case. The data compiled under this condition is as follows for Calabacillo cacao:

Analyses of Calabacillo cacao.

Constituents.	Fresh (per cent).	Cured (per cent).	Constituents.	Fresh (per cent).	Cured (per cent).
Fat	29.25	29.25	Glucose	0.99	0.60
Tannin	5.00	3.61	Hemicelluloses	5.11	3.74
Cacao red	2.95	1.89	Woody fiber	3.03	2.78
Theobromin	1.35	1.00	Protein	6.69	4.42
Caffein	.11	.03	Amido compounds	.53	2.06
Starch	3.76	3.22			

[15] K. Aso. Bul. Agr. Tokyo, Imp. Univ., 4 (1900–1902), p. 255.

[16] S. Sawamura, *ibid.*, 5 (1902–3), p. 237.

[17] Cacao, Trinidad, 1900, 2d ed., p. 100.

A part of the changes brought about by curing is probably due to the action of the living cells in the seed, before they are killed by the rising temperature. This would account for the decrease of starch, glucose, and hemicelluloses, which may be consumed by the respiration process, but the other changes are due to several enzymes. A proteolytic enzyme brings on the decrease of protein and the corresponding increase of amido compounds, while oxidizing enzymes, generally liberated from the protoplasm upon its death, cause the decrease of tannin and cacao red and their change to other compounds. The most conspicuous changes are, therefore, only possible after the death of the protoplasm, which is a desirable factor. Hence it is a mistaken idea of Zipperer that the changes are due to a germination process of the seeds. He has even attributed the rise of temperature of the fermenting pulp cacao to this process, considering it analogous to the behavior of barley on the malting floor. This error can only be explained by the fact that he never witnessed the fermentations of cacao or coffee, for germination changes are not in the least apparent.

Another result is the change of flavor. In the fresh state the seeds have a raw, bitter, and astringent flavor, while after fermentation and drying the bitter and disagreeable taste has entirely disappeared. This change is doubtless due in a certain measure to the decrease of tannin, that is, to its change by oxidation to a brown substance, as in the case of the persimmon fruits, mentioned above.[18] The flavor of the fermented beans is still far different from that of the prepared cacao product, which is produced by roasting the fermenting beans; hence a part of the taste must be due to changes caused by the heat of the roasting process.

The presence of oxidizing enzymes in the seeds of cacao can be proved by the usual reaction. Upon moistening a freshly cut section of cacao seed with tincture of guaiacum resin, just after taking the seed from the ripe fruit, a blue color is rapidly produced, first and most intensely in the chalaza of the embryo and gradually spreading over the entire seed tissue; also, the placenta shows soon an intense blue color. When a cross section through the whole fruit is moistened with guaiacum tincture, the chalaza of the embryo and the interior soft stratum of the fruit shell become rapidly and intensely blue, then follow in order the coloration of the convolutions of the cotyledons of the seed and the tissue of the hard outer shell. Finally the whole surface of the section of the seed and the exposed tissue of the testa become blue, but the slime tissue or pulp around the testa remains perfectly colorless, presenting a most striking contrast.

If the tissue of the seed is crushed with some water in a mortar, the filtered liquid will show no blue coloration on addition of guaiacum tincture, and shaking with air, while the unfiltered liquid will become

[18] The opinion of Harrison, mentioned above, that the decrease of the astringent taste is due to a hydrolysis is erroneous and would be without analogy.

blue very soon. This shows an exceptional case, namely, that the oxidase (laccase) is present in an insoluble state and perhaps held in combination with an insoluble protein.[19] Upon standing, the blue color, obtained with the unfiltered liquid, will gradually disappear, except on the surface, but on adding a few more drops of the reagent, and shaking, the intense blue color reappears. This phenomenon is due to the presence of a reducing compound in the juice.

In testing for a second oxidizing enzyme, the peroxidase, the tissue of the seed, crushed with a little water, was heated for five minutes to 75° C., and one portion of this liquid was filtered; the other not. The test with guaiacum tincture yielded no blue reaction in either liquid, proving that the oxidase was killed, while on addition of a little peroxid of hydrogen the unfiltered juice gave an intense blue reaction and the filtered juice showed only a trace. This difference proves that the peroxidase, like the oxidase, was present, but retained as an insoluble compound—an exceptional case.

Reactions with guaiacol were also tried. This substance produced no coloration when applied by itself, but in conjunction with hydrogen peroxid a red color turning to brown was soon produced in both the hard as well as the soft layer of the fruit shell. Later, in the testa and the seed in general, as well as in the slime tissue covering the testa, only a weak, reddish coloration was produced. This peroxidase reaction agrees also with that just mentioned, in so far as the slime tissue gave only an exceptionally weak reaction compared with all other parts of the fruit. The slime tissue of the coffee fruit is also poorer in oxidase and peroxidase than the other tissues.

The further generation of the characteristic aroma of cacao is of great importance. Is this process due to the action of an oxidizing enzyme or to that of a hydrolizing enzyme, and does the fermentation influence the generation of aroma only indirectly by the development of heat or directly by furnishing some compound? Or, is the roasting of the fermented cacao beans alone responsible for the aroma? The investigations thus far made do not solve this problem satisfactorily. It may be mentioned, however, that Hart[20] agrees with Chittenden,[21] who declared that after a certain stage of the fermentation "the cotyledons are found separated, and the vinous liquor of the pulp, which passes through the membranous covering, occupies this space as well as the cavities between the convolutions. * * * This it is which has so marked a physiological influence and affects its flavor, the bean being, as may be said, 'stewed in its own juice.' "

According to the laws of osmosis, some acetic acid and some alcohol from the fermenting liquor will doubtless enter through the testa and

[19] This recalls the existence of a soluble and insoluble form of catalase.

[20] Cacao, Trinidad, 1900, 2d ed., p. 38.

[21] Agr. Record, Trinidad, 2 (1890), p. 110.

come in contact with the cotyledons, which thereby may be killed, if the temperature of the fermenting mass has not already accomplished this. The reaction of the cotyledons after drying the fermented beans is acid, but whether this is wholly due to the entering acetic acid may be doubtful since the reaction is weakly acid in the fresh state. A stronger acid reaction is shown in the slime tissue.

The expression, "stewed in its own juice," used by Chittenden can hardly be admitted, since the juice of the pulp, after being entirely decomposed by yeast and bacteria, is certainly not the "own juice" of the cotyledons. Still, that author attributes to it the generation of the flavor.

The opinion of J. B. Harrison (see p. 352) that the decrease of tannin during the fermentation process stands in relation to the development of aroma (see p. 356) is certainly far from the mark, as tannin can not produce ethereal oils by any oxidation or fermenting process. Only color and taste stand in this relation to the tannin content.

Several experiments were made by the writer with an aqueous solution of 1 to 4 per cent acetic acid containing from 3 to 5 per cent of alcohol in order to imitate the composition of the fermenting pulp juice. After twenty to thirty hours' digestion of pulped cacao at 40° to 44° C., it was observed that the pulp had died and shrunk to skinny masses, partly separating in small pieces, but mostly still firmly adhering to the testa. It appears that for bringing about an easy separation of the dead pulp from the testa a bacterial enzyme is necessary, as in the case of coffee fermentation. It was further observed that the amount of acetic acid, which entered by osmosis through the testa to the cotyledons, was not sufficient to kill the oxidizing enzyme, since the freshly cut surface of these seeds rapidly turned brown on exposure to the air. On the other hand, it was observed that when the freshly cut surface of the seeds so treated was moistened with 4 per cent acetic acid no further change by oxidation took place. In this case the oxidizing enzyme was killed.

It is stated by Hart[22] that "of late years there has been a large amount of inquiry for cacao which is but slightly fermented or not fermented at all."[23] This renders it very probable that the decomposed juice of the slime tissue is not required for the generation of the aroma, as was supposed. Indeed, the true odor of cacao is faint before roasting the fermented beans. The case is, therefore, similar to that of coffee, and is different from that of tea. With tea the aroma is the result of the action of a hydrolizing enzyme, yielding the volatile tea oil, as was shown by Katayama.

That the aroma of the cacao is chiefly produced during the gentle roasting process is the opinion of the manufacturers of chocolate from

[22] Cacao, Trinidad, 1900, 2d ed., p. 33.

[23] Compare the quotation in the introductory remarks to this article.

the fermented beans. The fermentation seems, indeed, to have nothing at all to do with the production of aroma. Seeds simply dried in the sun and then gently roasted may yield an especially rich and aromatic chocolate, as Safford has also indicated. Hart says:

No adulteration * * * is equal to the flavor of the virgin cacao, provided the essential oil has not been destroyed during the process of roasting, during which process it appears to be developed.[24]

The question now arises, which compound yields the aroma in the cautious roasting of the fermented cacao beans? It is certainly not a glucosid, for neither the testa nor the cotyledons of the beans develop anything like a cacao flavor upon being boiled for some time with dilute sulphuric acid (3 to 6 per cent). The same negative result was obtained by boiling those materials with moderately concentrated solution of caustic potash. It seems also probable that it is a certain concomitant of the fat which causes the production of the flavor, after being moderately oxidized during the drying of the beans. Only seeds in which the oxidizing enzymes have produced changes can yield the true aroma by roasting—not the fresh beans.[25]

In the manufacture of the cacao powder of commerce the fat of the cacao is removed more or less, since a suitable powder can not otherwise be obtained, but in the direct manufacture of chocolate this removal of the cacao fat can not be justified. It is claimed that cacao fat or cacao butter is difficult of digestion, but in reality cacao butter is as easily digested as cow's butter. Besides, the removal of fat also diminishes the aroma of the chocolate. In the manufacture of chocolate in Porto Rico, fermented cacao seeds are placed in a small baker's oven for about one hour until the testa have become very brittle and can be easily removed.

This roasting temperature is kept considerably lower than that required for baking bread. The cacao butter is not removed in Porto Rico, and therefore the chocolate manufactured there has an exquisitely fine aroma.

SUMMARY.

The fermentation process itself is due in the first place to yeast cells which multiply rapidly in the saccharine juice oozing from the pulped cacao and produce alcohol and carbon dioxid. In the second place bacteria participate, which develop rapidly after a certain time, and

[24] Cacao, Trinidad, 1900, 2d ed., p. 111. These words, however, contradict his other opinion, quoted above, in regard to the influence of fermentation on aroma.

[25] Fresh beans were crushed, washed with alcohol, and extracted with ether. Neither the extracted fat nor the seed powder developed on moderate heating any flavor resembling that of cacao, only the alcoholic extract yielded thus a very faint flavor of cacao. On evaporation of the alcoholic extract another aromatic odor is noticed.

change the alcohol formed by the yeast by oxidation, either wholly or partly, into acetic acid. These processes cause a rise of temperature and the death of the cells of seed and slime tissue, whereupon the juice of the slime tissue, more or less altered, collects at the bottom of the receptacles, together with the acetic acid produced.

The chief object of the fermentation is to shrink the slime tissue or pulp attached to the testa of the seed, allowing the remnants either to be washed away, as is done in Ceylon, or dried upon the seed, forming an irregular brown film upon the testa. The advantage of thus changing the voluminous slime tissue lies in the increased facility of quickly drying the seed. In this regard there exists a close analogy to the fermentation of coffee. The loosening of the adhesion between the seed and its envelope and the hardening of this envelope (testa) are claimed as further effects of fermentation.

The fermentation has also an indirect influence on changes going on within the seed, inasmuch as by the temperature produced (40° to 50° C.) the cells of the seeds are killed, thus liberating the oxidizing enzymes, which cause the formation of the brown color, by oxidation of the tannin of the seed. This brown coloring is increased during the drying process and finally by the roasting. The taste of the raw cacao bean is not only altered by the partial oxidation of tannin during the fermentation or sun-drying of the seed, but also by products of roasting.

The action of oxidizing enzymes, as well as the final roasting process, plays a part in the development of the aroma.

THE FERMENTATION OF COFFEE.

The so-called fermentation of coffee has thus far not been investigated, and has been defined sometimes as an "alcoholic fermentation necessary to remove the saccharine matter." [26] Such saccharine matter, however, should be easily removable by simply washing with water. Upon close examination the writer concluded that the aim of the "fermentation" is the removal of a slimy stratum firmly adhering to the parchment envelope of the seeds. The removal of this is necessary because the drying of the seed envelope would otherwise be very much retarded, and because a bad flavor may finally be imparted to the seeds by the partial decay of the slimy stratum during the drying process. The process will be explained by examining the anatomical structure of the fruit. (Pl. II.)

Just below the skin of the fruit and extending between the enveloped seeds is a fibrous tissue containing a sweet juice. This pulp, together with the skin, is easily separated by mechanical means from the seeds, which are enveloped in a hard parchment. Adhering to this parchment is a stratum of very slimy cells, the slime layer.

[26] Cf. Watt, Dictionary of the Economic Products of India. Calcutta, 1889, vol. 2, p. 476.

The preparation of coffee for market requires the following manipulations:

(1) Pulping to secure removal of the skin with the adhering tissue.

(2) Fermentation to separate the slimy layer from the parchment envelope.

(3) Washing away the loosened slime.

(4) Drying the envelope around the seeds, preparing for the necessary brittleness for the next operation.

(5) Hulling or milling, consisting in the removal of the parchment envelope, with subsequent subjection to a fan to blow away particles of parchment envelope and silver skin.

The entire fruit is often called "cherry," from the similarity of form and color. The expression "pulped coffee" signifies seeds in the parchment envelope with slimy layer. "Coffee in parchment" means the product after pulping, fermenting, and drying. The "bean" means the seeds deprived of parchment and silver skin.

Fruits of red or yellow color should be picked for pulping, as only such furnish seeds of the desired bluish-green color. Green unripened fruit containing a hard pulp and little or no sugar should be excluded, but such fruit can not be entirely avoided since some unripened seeds will drop off in gathering the ripened ones.

The fruits are well moistened with water when passing through the pulper, which easily separates the skin and fibrous layer. Attached to the pulper is a conical sieve (separator) placed in a horizontal position, which retains the fruits which have accidentally escaped pulping, and they are carried back to the pulper.[27]

In order to understand the fermentation process, it must be remembered that on the surface of all sweet fruits are a great many yeast cells and bacteria. When by the pulping the sweet juice is forced out and spread all over the separated skin, and over the pulped coffee, it is not surprising that these organisms develop rapidly. The sweet juice not only contains sugar but also some nitrogenous and mineral matters required for the development of organisms.

An examination of the skin with a high magnifying power several hours after pulping shows numerous cells of *Saccharomyces,* which in form resemble chiefly *Saccharomyces ellipsoideus* and sometimes also *S. apiculatus.*

Numerous bacteria are also present. Alcoholic fermentation can soon be detected by the vinous odor, and the fact that the fermentation pro-

[27] It has been proposed to dry the pulp and bring it into commerce as a cheap substitute for coffee. When pressed well to remove the caffein and mixed then with molasses it might serve as a food for hogs. Greshoff holds that the best application is as a manure and gives the following composition in the air-dry state: Caffein, 1.1; carbohydrates, 23.3; albumin, 7.6; cellulose, 16.1; water, 14.9; fat, 3.3; ash, 6.9.

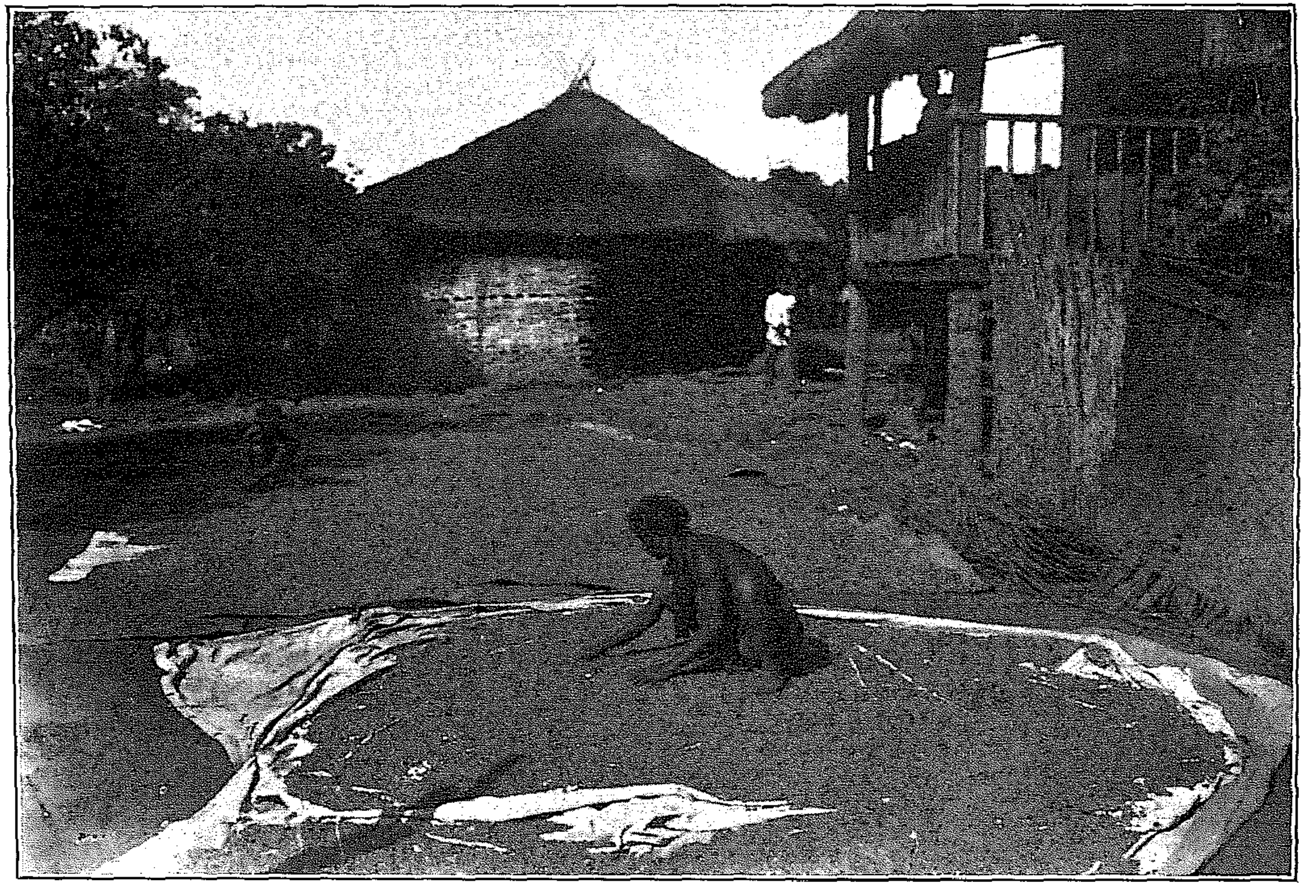

PLATE II.

duces heat explains why the temperature of such a heap of pulp rises considerably after a time. A heap of nearly 30 centimeters in height showed after sixteen hours a temperature of 41° C. at an air temperature of 26° C. Later, acetic acid is formed and the red color of the skin changed to a brownish one.

When the pulped coffee, on the other hand, is examined, a few yeast cells and bacteria are noticed on the slimy stratum after one hour, while after sixteen hours an immense increase has taken place and not only is considerable alcohol formed by the yeast cells but also acetic acid by certain bacteria. Mycoderma and the mycelium of fungi are occasionally seen. Litmus is reddened intensely and the odor of acetic acid is readily discernible. At the same time another volatile product is formed in small quantity, which modifies somewhat the acid odor.

The alcoholic fermentation of the sugar adhering to the slimy stratum, as well as the further oxidation of the alcohol to acetic acid, and finally the respiration process carried on with considerable intensity by all these organisms, cause a rise of temperature, depending upon the depth of the stratum and the temperature of the surrounding air. The heaps of pulped coffee are generally 1 to 2 feet high. In such heaps the temperature was found after fifteen to sixteen hours to range from 34° to 42° C. at an air temperature of 25° to 29° C.

The alcoholic and acetic fermentations proceeding in the heaps of pulped coffee are, however, not the most essential phenomena; the most important point is that the slimy stratum is separated from the parchment envelope. It is by no means dissolved, but merely loses its firm adhesion and is left loosely spread upon the parchment coffee so that it can easily be washed away by a current of water and the parchment coffee dried.

Neither the acetic acid nor the enzyme already present in the slime causes the separation of the slime layer, as tests have shown.

Freshly pulped coffee was kept in dilute acetic acid (about 1 per cent) at 35° to 40° C. and another portion in some water containing a few drops of ether to prevent bacterial growth. In both cases the slimy layer was found still firmly attached to the parchment after twenty-four hours. This leaves no other inference but that a peculiar enzyme dissolving the adhesive substance (a carbohydrate?) between the parchment and the slimy stratum was furnished by the bacterial growth, or, what is less probable, by the yeast cells.

The "fermentation" should not take longer in Porto Rico than fifteen to twenty hours, while in some sections of Central America, as Guatemala, it must be carried on for two days.

Undue prolongation of the fermentation must be avoided, as otherwise a brown coloration of the parchment and of the seeds is produced and the seeds further acquire a disagreeable odor—two circumstances which render the product unfit for the market.

After the fermentation and washing the parchment the coffee is readily dried, either on cement floors exposed to sun and air, or better in rotating cylinders through which warm air passes. At a certain degree of dryness the parchment becomes brittle and breaks easily in the milling process, which thus removes the parchment envelope and silver skin from the seeds. In fact, the milling must be done while the parchment is still warm.

This milling is in many cases done in London, and not in the country where the coffee is produced. Better preservation of shape and color of the bean has been observed when the latter is protected for a time by the parchment envelope. The cost of transportation is in this case a little higher, but it does not come into consideration, as from $2 to $3 more has been realized per hundredweight for coffee thus treated than for that cured in Central America.

In reviewing the so-called fermentation of coffee, the conclusion is inevitable that alcoholic and acetic fermentations are not of direct benefit, but only indirectly, inasmuch as heat is thereby produced which supports the action of a body (enzyme) furnished by the bacteria, which dissolves the adhesive substance between parchment envelope and slimy layer.