SOLAR DRYING OF FOODS: EFFECTS OF DRYING AND TREATMENT METHOD ON VITAMIN RETENTION

A Thesis

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Department of Food Science and Nutrition

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Master of Science

by

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Beans	3	5	2	4	1
Corn	5	3	2	1	4
Grapes	2	4	3	5	1
Tomatoes	2	5	4	3	1
Bananas	5	4	3	2	1
Potatoes	5	2	3	4	1
Banana Squash	2	5	3	1	4
Apples	2	3	5	4	1
Sweet Potatoes	2	5	3	4	1
All Foods	2	5	3	4	1

Key to Dryers:

1. Undried Control
2. Modified Direct Dryer
3. Indirect Dryer
4. Electric Dehydrator
5. Direct Dryer

Underlining indicates that no significant difference was found between the underlined dryers.

Figure 2. Significant differences in ascorbic acid retention between dryers as shown by Duncan's multiple range comparison test.

Beta-Carotene

Beans. There were no significant differences in the amount of beta-carotene (provitamin A) retained between the three treatment methods when all samples were considered. The undried samples did show, however, the steamed samples retained significantly more beta-carotene than either the untreated or the dipped samples.

Drying methods (electric dehydrator and indirect dryer) where the beans were not exposed to the sunlight were significantly better in beta-carotene retention than those methods where the beans were in the sunlight (direct and modified direct dryers). There was no significant difference in beta-carotene retention between the electric dehydrator and the undried samples. There was a significant difference between samples dried on the indirect dryer compared to undried samples. The direct and modified direct dryers showed significantly less beta-carotene retained than the other methods.

Corn. There were no significant differences between treated and untreated samples in corn. When the means of the drying methods were analyzed, the modified direct dryer was significantly more effective in retaining beta-carotene than either the indirect dryer or the electric dehydrator. No other significant differences were found.

Grapes. No significant differences were observed between the treated and untreated samples. Samples from all of the dryers showed significant losses of beta-carotene compared to the undried samples. No significant differences were found in beta-carotene retention between the direct dryer, modified direct dryer and electric dehydrator. The indirect dryer was significantly better in beta-carotene retention than the other three drying methods. Samples from the indirect dryer were significantly lower in beta-carotene retention compared with the undried control sample.

Tomatoes. The steamed and dipped samples retained significantly more beta-carotene than the untreated samples, but there was no significant difference between the two treatments. In the modified direct dryer the steamed and dipped samples were significantly higher in beta-carotene than the untreated samples. In the direct dryer the dipped sample was significantly lower than the untreated and steamed samples.

All dried samples had a significantly lower beta-carotene content compared to the undried control sample. Samples dried on the indirect dryer were significantly lower in beta-carotene retention than samples from the direct dryer and the electric dehydrator but not significantly different from those dried on the modified direct dryer.

Bananas. No significant differences were observed between the untreated and treated samples nor between the treatments. The electric dehydrator was significantly better in retaining beta-carotene than the solar dryers. No significant differences were detected between the solar dryers. All drying methods showed significantly higher levels of beta-carotene than the undried samples.

Potatoes. Potatoes showed no significant differences between treated and untreated samples. Among the drying methods the electric dehydrator and the undried control both showed significantly higher values of beta-carotene than the modified direct dryer. No other significant differences between dryers were observed.

Banana Squash. With respect to beta-carotene retention, no significant differences were observed between the untreated and treated samples. In the modified direct dryer and the direct dryer steamed samples retained significantly less beta-carotene than the untreated or dipped samples. In comparing the drying methods all drying methods showed significantly lower beta-carotene levels than the undried samples. The electric dehydrator was significantly better in beta-carotene retention than any of the solar drying methods. Of the solar methods, the indirect dryer was significantly better than the direct and modified direct methods. No significant difference was observed between the latter two methods.

Apples. No significant differences were found between the treatment methods. The modified direct dryer had a significantly lower beta-carotene content in the steamed sample. The electric dehydrator showed the steamed sample significantly improved in beta-carotene retention. No significant difference was detected between the beta-carotene levels in the undried samples and dried samples from the indirect dryer. Samples from the indirect dryer were significantly better in beta-carotene retention than the samples from the direct, modified direct, and electric dehydrator methods.

Sweet Potatoes. Untreated, steamed, and sodium bisulfite dipped treatments showed no significant differences as a function of treatment. In the modified direct dryer the steamed samples were significantly lower in beta-carotene than the untreated and dipped samples. Untreated samples in the direct dryer were significantly lower than the steamed and dipped samples in beta-carotene retention.

There were no significant differences in beta-carotene levels between the undried samples and the samples dried in the electric dehydrator and the indirect dryer. The indirect dryer was significantly better than the two solar dryers where direct light was involved. The direct drying method was significantly lower in beta-carotene retention than any of the other drying methods.

All Foods. Treated samples (steamed and dipped) were significantly better in beta-carotene retention than the untreated samples. There was no significant difference between steaming and dipping in sodium bisulfite. All drying methods were significantly lower in beta-carotene levels than the undried samples. The electric dehydrator was significantly better in beta-carotene retention than any of the solar drying methods. Of the solar drying methods the indirect was significantly better than either the direct or modified direct methods. The difference between the latter two methods was not significant.

Thiamin

Beans. There was a significant difference between the untreated and the treated samples with treated samples giving lower thiamin concentrations. Sodium bisulfite dipped samples were significantly lower in thiamin than either the steamed or the untreated samples. Dipped samples which were dried also showed significantly lower levels of thiamin.

When the dried were compared to the undried samples, the only significant difference that was found was that the samples dried

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Potatoes	2	5	3	1	4
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Figure 3. Significant differences in beta-carotene retention between dryers as shown by Duncan's multiple range comparison test.

on the modified direct dryer were significantly lower in thiamin than the undried samples.

Corn. A significant difference was observed between the untreated and the treated samples. The treated samples were found to contain less thiamin than the untreated. The treatments were also significantly different with the sodium bisulfite dipped samples retaining more thiamin than the steamed samples. All dried samples except the indirect dryer samples which were sodium bisulfite dipped contained less thiamin than the untreated samples. The steamed samples contained less than either the untreated or the dipped samples. The indirect dryer showed the steamed sample contained the most thiamin with the untreated sample containing the least.

Significant differences were found between all drying methods. Samples from the electric dehydrator retained the most thiamin. Samples from the direct drying method were next in retention. Both of these contained significantly more thiamin than the undried samples. The indirect dried samples retained significantly less thiamin than the undried samples but significantly more than samples from the modified direct dryer.

Grapes. With grapes no significant differences were observed as a function of treatment. The indirect dryer, electric dehydrator, and direct dryer samples along with the undried samples showed that steamed samples retained more thiamin than the dipped samples. When compared by drying methods, the undried control was significantly better in thiamin retention than the direct or modified direct dryers but was not significantly different from the indirect dryer or the electric dehydrator. The electric dehydrator and indirect dryer were significantly better than the direct dryer in retaining thiamin in dried samples.

Tomatoes. Steamed tomatoes retained significantly more thiamin than the sodium bisulfite dipped samples and significantly more than the untreated samples. Dipped samples retained less than the untreated samples.

In the modified direct dryer and the electric dehydrator the steamed samples retained significantly more thiamin while the level of thiamin in the untreated and dipped samples was almost the same. The same was true of the undried samples although the thiamin levels were higher than in the dried samples.

In dipped samples from the indirect dryer, thiamin was only one-fourth of that found in the untreated sample from the same dryer. The dipped samples dried in the direct dryer were significantly lower in thiamin than untreated and steamed samples.

There were no significant differences in thiamin content as a function of drying method but samples from all dryers contained significantly less thiamin compared to the undried samples.

Bananas. There was a significant difference between the steaming and the sodium bisulfite dipping. Dipped samples retained only about one-half the thiamin found in either untreated or steamed samples. Dipped sample levels of thiamin were significantly lower in all dryers and in the undried samples. In the direct dryer the untreated samples retained the most with the steamed samples lower.

The modified direct dryer was significantly better for retention of thiamin than the electric dehydrator. There was also a significant difference in that dried samples in the electric dehydrator showed lower thiamin levels than the undried samples. There were no differences between the undried and the solar dried samples.

Potatoes. A significant difference was found between the untreated and treated samples; however, this difference may be accounted for by the fact that sodium bisulfite dipped samples retained only about one-ninth of that found in the untreated samples.

Samples from the modified direct dryer and electric dehydrator showed the steamed samples to have significantly less thiamin compared to the untreated samples. The dipped samples all showed thiamin levels to be significantly lower.

Samples from the electric dehydrator were found to be significantly lower in thiamin than the undried and the solar dried samples. No other significant differences were observed.

Banana Squash. The sodium bisulfite treatment was significantly detrimental to the thiamin content. Thiamin levels in the sodium bisulfite treated samples were lower than the untreated or the steamed samples. In the undried samples steaming improved thiamin retention significantly. The modified direct dryer, direct dryer and electric dehydrator methods showed steaming to cause significant thiamin losses. Significant losses occurred in all dipped samples.

The undried samples were significantly higher in thiamin than any of the dried samples. The direct dryer and the indirect dryer were both significantly better than the electric dehydrator for retention of thiamin.

Apples. A significant difference between untreated and treated samples was observed with treated samples having less thiamin.

Between treated samples the steaming was superior for thiamin retention while sodium bisulfite dipping reduced thiamin levels by one half those found in untreated samples. A significant drop from thiamin levels in untreated samples was noted in the modified direct and the indirect dryers.

The only significant difference between dryers was found to be that the samples from the direct method of drying contained significantly less thiamin than did the undried control. All other samples were not significantly different from each other or from the control.

Sweet Potatoes. The steam treated sample was significantly different from the untreated samples, reducing thiamin content by one-half. The dipping in sodium bisulfite reduced thiamin to only one-sixth of that found in the untreated samples. This trend was found in all dryers with steaming causing a significant reduction and dipping causing almost complete elimination of thiamin.

In sweet potatoes the direct dryer and the electric dehydrator were significantly higher in thiamin retention than the undried samples, but there were no significant differences among the drying methods.

All Foods. Overall the treatments showed significant differences. Steaming reduced thiamin slightly while dipping in sodium bisulfite caused a reduction of thiamin by about one-half.

Combining values for samples from all drying methods showed dried samples contained significantly less thiamin than the undried samples. No significant differences in thiamin retention were found between the direct dryer, the indirect dryer and the electric

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Figure 4. Significant differences in thiamin retention between dryers as shown by Duncan's multiple range comparison test.

dehydrator. The only significant difference was found between the modified direct method and the direct method where the direct method was found to be significantly superior.

Aesthetic Appearance

Although the nutritional content of a dried food is very important, the appearance and aesthetic appeal is a definite governing factor in whether or not the food will be consumed. The appearance of each of the final dried samples was visually checked and compared to the other samples, both dried and undried, to see the effects of the drying methods and pretreatments.

Beans. The undried fresh and dipped samples both appeared like natural green beans. The beans on the direct dryer dried more slowly than the others and the direct sunlight had a definite effect on the color. The fresh beans dried on the direct dryer became slightly bleached resulting in a dry brown color. Those exposed to the light in the modified direct dryer retained a good green color as did those in the indirect dryer and the electric dehydrator.

The process of blanching caused the steamed samples to darken to a forest-olive green and to become slightly translucent. All of the steamed samples had a translucent-cooked appearance. Those exposed to the light in the direct and modified direct dryers changed color. Those in the direct dryer turned a golden brown color and those in the modified direct dryer changed to a brown color with some turning dark brown. The steamed samples in the indirect dryer retained approximately the same forest green color as the undried samples. The samples in the electric dehydrator turned an olive or khaki shade of green.

Samples dipped in sodium bisulfite when exposed to light in the direct and modified direct dryers bleached to a light dry-grass color. The samples on the direct dryer had some small patches of green remaining, possibly due to incomplete penetration of the sodium bisulfite. The dipped samples in the indirect dryer dried with a good green color but those dried in the electric dehydrator were slightly bleached. Some individual pieces turned a light brown color.

Overall, samples not exposed to the light and dried under low temperatures had the best color. Light and especially direct sunlight caused loss of the green color. Sodium bisulfite seemed to increase the bleaching. Blanching caused a cooked transluscent color but did not stabilize the green color and blanched samples exposed to the light turned brown.

Corn. The corn samples were acceptable in all dryers, and the differences in color were minor. In all cases, including the undried samples, the blanched samples were slightly darker. All of the samples in the electric dehydrator were slightly brighter yellow than the other samples. Color differences in the shade of yellow were only noticeable through a side by side comparison. In both the indirect and the direct dryers some of the embryos in the corn kernals turned a dark brown to black giving a slight mottled appearance. This was not observed in samples from the modified direct dryer or the electric dehydrator.

Grapes. Grapes required the longest of all fruits or vegetables to dry although they were only dried to around 25% moisture. The greatest difference in drying speed was noted in the blanched samples. The waxy cuticle of the grape skin was broken down by blanching and the moisture consequently escaped much more rapidly. The more rapid drying resulted in the blanched samples being lighter in color than those samples which remained for a longer period of time on the dryers. The steamed samples in the direct method became a dark golden-green color when dried. Those in the indirect method and the electric dehydrator were of a gold-green color but of a slightly lighter shade. The steamed samples in the modified direct dryer were brown but much lighter than the untreated or dipped samples. The untreated samples were a dark raisen color in all cases while the dipped samples were dark in the direct, modified direct, and indirect dryers but slightly lighter in the electric dehydrator.

Grapes in all dryers exuded syrup causing them to be slightly sticky. This condition was most extensive in samples dried in the modified direct dryer.

Tomatoes. The color of all the dried tomato samples was a dark, blood-red while the undried control samples were a much lighter red characteristic of ripe tomatoes. The steaming process caused both the dried and undried tomatoes to have a darker cooked color. The samples in the modified direct dryer were generally darker than in the other three dryers.

The greatest problem in appearance occurred in the blanched samples. Blanching caused the tomato slices to become a semiamorphous mass which was difficult to handle. The resulting dried product would not be acceptable for uses other than in soups, etc., where integrity of the product would not be important. Soaking the tomatoes in sodium bisulfite caused the tomato slices to be slightly less turgid and more difficult to handle but not to the extent of the steamed samples.

Bananas. Fresh banana slices began to darken immediately after preparation. The undried bisulfite dipped slices retained their natural color with no perceptible darkening. The undried steamed slices darkened slightly and became very mushy and hard to handle. These slices became darker, more yellow and also acquired a slight translucency.

Untreated samples in all dryers were subject to browning reactions but to differing degrees. The untreated sample dried on the direct dryer became very dark with some of the slices having lighter areas near the outer edges of the slice. These were the darkest of all the untreated samples. The untreated slices in the modified direct dryer were next darkest having dark centers and lighter edges. The slices in the indirect dryer and the electric dehydrator darkened to the point of appearing slightly overripe. The banana slices began darkening in the centers around the seed areas and the color moved from the center to the lighter outer edges.

The steamed samples became a dark brown mass in the direct, modified direct, and indirect dryers with some light spots. The steamed samples in the dehydrator became dark brown but were lighter in color than the steamed samples from the other dryers.

All of the dipped samples retained a good fresh banana color with very little darkening. Darkening which occurred was observed near the center of the slices. Dipped samples in the electric dehydrator had the lightest and most natural color. Dipped samples dried on other dryers had a slightly more yellow cream color.

Potatoes. Initially the undried untreated potato strips were very turgid and white but soon began to turn reddish, then turned brown or grey. Undried steamed samples lost much of their turgidity, becoming flaccid and slightly translucent in appearance. Blanching caused the surface starch, liberated by rupturing of the cells during preparation, to gelatinize and the steamed samples were quite gummy. The color changed to a light yellow in the blanched samples. Sodium bisulfite dipped samples were identical in appearance to the fresh samples immediately after cutting.

Untreated samples dried in the direct dryer were very dark brown-black. Samples in the indirect dryer were slightly lighter in color. The untreated samples in the modified direct dryer were grey but not as dark as the other two samples. The samples in the dehydrator darkened only slightly to a light brown color.

Steamed samples turned a golden brown translucent color. The dryers where the samples were exposed to the light produced the darkest samples with the modified direct dryer showing the darkest samples and the direct dryer producing a slightly lighter product. The indirect dryer produced a light golden brown sample and the electric dehydrator produced the lightest color of all steamed samples.

All of the dipped samples remained either white or turned a very light cream color. The dipped samples exposed to the light remained white while those in the indirect dryer and the electric dehydrator turned a very light creamy yellow with the indirect dryer producing the darker product.

The texture of the untreated and dipped samples in all cases was a soft brittle to crumbly texture. The dried steamed samples were very hard and brittle.

Banana Squash. The undried untreated and bisulfite dipped samples both appeared as fresh squash with a good yellow-orange color. The steamed samples acquired a translucent cooked appearance with a darker and more orange hue.

The color of the dried untreated samples in the direct and modified direct dryers changed considerably. The side exposed to the sun turned white or light grey while the underside remained yellow-orange which was lighter than the fresh squash. The untreated samples in the indirect dryer and in the electric dehydrator showed no change in color and were not bleached.

In all cases steamed samples retained the darker orange translucent color and did not bleach when exposed to light. However, samples in the direct dryer exposed to direct sunlight became lighter in color. Those samples in the indirect dryer became slightly darker orange in color.

The sodium bisulfite dipped samples reacted similarly to the untreated samples. The upper sides of the samples were bleached to a white color in the modified direct dryer and to a light grey in the direct dryer. Except for the upper surface the rest of the sample retained a good yellow-orange color. The dipped samples in the dehydrator remained equal in color quality to the untreated undried sample; however, in the indirect dryer the sodium bisulfite served to bring out the color. Compared to the fresh sample, the dipped sample turned a brighter orange.

Apples. Undried, untreated and dipped samples had a good white apple color although the untreated sample began to turn brown quite rapidly. The undried steamed sample acquired a translucent cooked color with a more yellow hue than the other samples.

Untreated samples in the direct and modified direct dryers turned a medium intensity red-brown on the upper side exposed to the sun with the underside turning brown. The underside of the samples in the modified direct dryer were light brown or white. Untreated samples in the indirect dryer turned a golden brown color with the same color uniformly distributed on both top and bottom of the slices. In the electric dehydrator the untreated slices remained white but showed slight browning beginning near the core area of some slices.

Steamed samples showed some browning in the direct and modified direct dryers, but to a lesser extent than the undried samples. The direct dryer produced a slightly darker product than the modified direct dryer. The top of the slices were slightly reddish brown. The rest of the sample showed no evidence of browning other than a light golden appearance. Both the indirect dryer and the electric dehydrator produced products with a translucent cooked appearance but these showed no evidence of browning.

All of the sodium bisulfite dipped slices retained a natural white apple color. Samples in the direct and modified direct dryers were a slight red-brown on the side exposed to sunlight.

Sweet Potatoes. Undried untreated and sodium bisulfite dipped samples had a light yellow color while the steamed sample became darker yellow with a slight green tinge.

The untreated sample from the direct dryer turned grey-white and was the darkest of all untreated samples. The modified direct dryer also produced a grey-white product, but the light creamy color was also evident. The indirect dryer produced an off-white product while the untreated samples from the electric dehydrator were light cream in color with a bit of grey and were the lightest, most natural looking of the untreated samples.

Steamed samples were translucent in appearance and had a golden yellow color although the intensity of the color varied. The indirect dryer and electric dehydrator produced the lightest products although these samples still were darker than the undried sample but lighter than the samples in the modified direct dryer. The samples from the direct dryer were the darkest being a dark golden brown with an olive or khaki green tint.

Dipped samples from all dryers retained a fairly natural yellow-white color. Samples from the direct dryer were a slight grey in appearance.

Storage

The appearance of the untreated banana, apple, and potato samples was checked after storage at -25^0 C for six months. Even under refrigeration the browning reaction continued when not stopped by some type of treatment. The effect was most pronounced in the banana samples where the color changed from a light brown (when removed from the dryer) to a dark brown after storage. The treated samples did not change color appreciably.

DISCUSSION

The quality of dried food is determined by the nutrient content and the aesthetic appeal of the food. Many factors affected the vitamin retention and appearance of the food during the drying process. The main factors are the pretreatment (i.e. steaming, dipping in sodium bisulfite, or no treatment), speed of drying, heat, light, and the type of food and its condition at the time of drying. The results of this study show that these factors are important and that the interaction between them is important in determining the optimum method for drying fruits and vegetables.

Each of the fruits and vegetables was treated by steaming or blanching and by dipping in sodium bisulfite. An untreated sample acted as a control. The treatments had some striking effects on appearance and vitamin retention.

Steaming

The treatment by steaming or blanching generally did not improve the color but rather gave the dried food a cooked and dull or translucent appearance. This was especially evident in beans where the color of steamed samples ranged from a darker forest green to an olive green. Potatoes and apples were translucent and somewhat yellow as a result of the steaming process. In potatoes, the steaming caused gelatinization of the starch liberated in the cutting process and the resulting stickiness made the potato strips difficult to handle on the dryers. The unsteamed potato samples were light and almost crumbly when dried whereas the steamed samples were hard and brittle. It appears that this hardening was caused partly by the gelatinization and subsequent drying of the starch in combination with the loss of intercellular air spaces caused by steaming. The loss of the air spaces causes the translucent appearance in foods which have abundant air spaces such as apples and potatoes. Steaming also caused dried apple samples to become somewhat tougher and more rubbery than unsteamed samples.

Steaming was beneficial in the drying of foods having tough, water repellent skin such as grapes. The skin prevents water from escaping and thus makes drying more difficult. The steaming process causes the waxy cutin layer of the skin to break down and permits a faster rate of moisture transfer at the surface of the fruit. Minute breaks in the skin occur and moisture transfer is facilitated. This was demonstrated by the fact that the skin of the steamed grapes lost the sheen of fresh grape skin and became dull and buffed looking. Also, the steamed grapes required only thirty-six hours to dry while other grape samples required up to 192 hours for drying to an equivalent moisture level. The quicker drying allowed by steaming helped to retain the color in dried grapes, and the brown-black color occurring in grapes on extended drying was reduced. Longer drying also reduced the ascorbic acid content of grapes. The blanched samples showed ascorbic acid values comparable to or higher than the untreated or dipped samples. In foods where it was possible to dry all samples for the same period of time, the blanched samples were significantly lower in ascorbic acid retention compared to the other samples.

The appearance of some foods was not improved by steaming. Tomatoes were good examples. Steaming caused the tomato slices to become an amorphous mass, and handling was difficult. Removal from the drying trays was almost impossible in the dried state. Thicker slices of tomato would be helpful. The effect of steaming would be slightly reduced, but more importantly, the untreated or dipped slices would be easier to handle, especially in removing them from the dryers. The .5 cm slices dried paper thin and broke into small pieces on removal from the dryers. Bananas showed similar properties as the steaming caused the tissues of the banana fruit to soften and lose integrity.

A review of the results demonstrates that the retention of vitamin C or ascorbic acid is not enhanced by steaming or blanching. Vitamin C if very labile in heat, especially in the presence of oxygen (Hendel, 1960). Ascorbic acid is also water soluble and some leaching of the vitamin occurs during processing. For this reason steaming is preferred to water blanching. All of the foods tested with the exception of corn, grapes, and apples showed that steaming significantly reduces the amount of ascorbic acid in the fresh and the dried samples. The possible reason that grapes did not show the reduction of ascorbic acid in the blanched sample has been mentioned previously.

Steaming preserved the color in yellow vegetables high in beta-carotene. The squash samples which were steamed did not bleach as did the unsteamed samples. Tomatoes, also high in beta-carotene also showed the effect of steaming in stabilizing the color in that steamed samples showed higher beta-carotene levels than the untreated samples. Part of this protective effect by steaming might be the inactivation of peroxidases which lead to the breakdown of the beta-carotene molecules (Moyer, 1943). Beta-carotene is also sensitive to oxidation. The process of steaming or blanching eliminates the intercellular air spaces and would thus reduce the amount of oxygen available for oxidation of beta-carotene.

Thiamin is heat labile to some degree depending on the pH of the food and is more stable in an acid environment (Beadle, et al., 1943). Thiamin becomes more labile as the pH increases and the protonated form of thiamin becomes less dominant. Overall, the foods showed the steaming process to cause some loss of thiamin. Some of this loss may be attributed to leaching since thiamin is water soluble. Corn and sweet potatoes showed that steaming significantly destroyed the thiamin. The tomato samples, however, showed steaming to have a protective effect on the thiamin. Part of this may have been the increased acidity of tomato over corn or sweet potatoes or it could also have been the result of thiaminase activity in the fresh samples which destroyed thiamin during the preparation of the sample for analysis (de Ritter, 1976).

Sodium Bisulfite Dipping

The use of sulfur such as a 2% sodium bisulfite solution in the drying of foods is a common practice. The results show that this usage may be either beneficial or detrimental to various aspects of food quality. The appearance of foods which are subject to browning such as bananas, potatoes, and apples was greatly improved by the sodium bisulfite treatment. Samples of these foods subjected to this treatment showed no signs of browning and retained a fresh-cut appearance in both undried and dried samples. The sodium bisulfite treatment is also known to protect dried foods against heat damage caused by excessive temperature (Cruess, et al., 1944), an important consideration in the case of the modified direct dryer where temperatures above 82° C were found on clear sunny days.

The treatment with sodium bisulfite was detrimental to the pigments in the case of the green beans. The treated samples seemed to have the color bleached out when exposed to the light. Some samples so treated showed spotty green areas, possibly due to incomplete penetration of the sodium bisulfite. Sulfur treatment was also shown to bleach cherries to a white color in other investigations by the author. Sodium bisulfite seemed to have no effect on the yellow vegetables corn and squash.

In the case of tomatoes, the treatment with sodium bisulfite showed no improvement in color or quality, however, the soaking caused softening of the tomato tissue and made the tomato slices much more difficult to handle.

Treating the foods before drying by dipping in 2% sodium bisulfite solution improved the retention of ascorbic acid in both the undried and the dried samples. All foods except grapes and apples showed significant increases in ascorbic acid retention in both undried and the dried samples. The constant degradation of ascorbic acid after harvest and during preparation caused the protective influence of the sodium bisulfite to be magnified with the ascorbic acid values in undried samples of beans, tomatoes, and potatoes significantly higher in the dipped samples than in the untreated samples.

The treatment with sodium bisulfite did not seem to affect the retention or degradation of beta-carotene; however, the effect on thiamin was marked. The results coincide with studies by Leichter and Joslyn (1969) which indicate that thiamin is destroyed in the presence of sulfite. The thiamin level was significantly lower in the bisulfite treated samples than either the steamed or the untreated samples in tomatoes, bananas, potatoes, squash, and sweet potatoes. Corn showed the dipping treatment to be better than the blanching but worse than no treatment in thiamin retention. This may have been caused by the treatment with bisulfite being done with the corn still on the cob. The outer tissue layer on the corn kernels may have prevented penetration of the bisulfite solution, and thus the destructive effect on the thiamin would not have been evident.

The type of tissue is important as the penetration of the bisulfite is affected. Foods with porous tissues such as potatoes, squash, apples, bananas, and sweet potatoes showed thiamin to be nearly completely destroyed in dipped samples. Foods which have a skin or which are more firm such as corn and beans showed a smaller loss in thiamin possibly because of increased difficulty of bisulfite penetration as all foods were dipped for the same time period without regard to the food type.

No Treatment

Drying of foods in the natural state without steaming or sodium bisulfite treatment allows the natural processes of browning and enzyme action to proceed unchecked. This is not always detrimental to quality, however, as some foods are not subject to rapid degradation by browning, and the results indicate the retention of the vitamins is better in untreated samples in many cases. This does not take into consideration reactions which might occur during storage; however, the low moisture content of dried materials would tend to reduce enzyme activity and vitamin degradation. Ascorbic acid for example, increases in stability as water activity decreases (Vojnivich and Pfeifer,1970).

The appearance of untreated tomato slices was good and the absence of problems associated with treatments made the untreated samples the most acceptable and easy to work with. Squash samples which were untreated were bleached by the light; however, the appearance was very good when dried in the indirect dryer and the electric dehydrator were protected from the sunlight. No color change was noted under these conditions.

The use of any treatment usually involves some type of trade-off. For example, the use of steaming preserves the color and inactivates enzymes responsible for vitamin and flavor degradation, but the treatment also destroys and leaches out ascorbic acid. It also caused handling problems in soft foods such as tomatoes and bananas. The use of sodium bisulfite protected the ascorbic acid and reduced browning but it also destroyed thiamin.

The drying of untreated fruits and vegetables subject to browning showed some interesting features. While these foods generally begin to brown immediately after preparation, it was found that the exposure to air and the rapidity of the initial drying made a great difference. In bananas, apples, and potatoes, all subject to rapid browning on exposure to air, the electric dehydrator allowed drying with minimal browning. The dehydrator had a fan which forced air over the food, causing the constant rate drying period to be comparatively short as the outer layer was quickly dried and further drying depended on diffusion of moisture from the inner tissues (falling rate period). As the outer layers of cells were dried, a barrier formed which reduced the contact of oxygen with the substrates necessary for browning. Bananas, apples, and potatoes dried in this manner immediately after preparation were dried with some browning occurring but not sufficient to be objectionable. This would be satisfactory for short term use, but the browning was found to continue (the rate depending on water content of the food and storage conditions) slowly during storage. The rapid drying of the outer layer is also beneficial in the retention of ascorbic acid in untreated samples. Beans, potatoes, and squash all show the dehydrator to improve ascorbic acid retention over other dryers in regard to untreated samples.

In studying the retention of beta-carotene the only significant difference indicated was in tomatoes where the treated samples were both significantly higher in beta-carotene than the untreated sample.

Treatment by steaming or dipping in sodium bisulfite solution was significantly detrimental to thiamin. Significant decreases were indicated in corn, potatoes, squash, apples, and sweet potatoes, all of which showed that both treatments significantly reduced thiamin levels compared to the untreated samples. The destruction of the thiamin by sulfite is caused by the sulfite causing cleavage of the thiamin into the thiazole and pyrimidine groups.

Appearance

Overall the main factors in the quality of appearance seemed to be the speed of drying, the heat involved, the exposure to light, and the pretreatment.

The speed of drying and especially the speed of the initial part of the drying process is very important in maintaining the color as well as the nutrients of a food. Foods such as the grapes which required a long period to dry showed a definite darkening as drying time was extended. Blanched grapes, for example, dried in two days and were light brown or light green while the untreated and dipped samples required eight days to dry and were a dark brown raisen color. The amount of browning on apples, bananas, and potatoes also became more intense as a function of drying time.

Bananas, potatoes, and apples, which are very susceptible to browning, showed a marked improvement in appearance when the initial drying was rapid. For most of the samples this occurred in the electric dehydrator where the outer layer of tissue was quickly dried by the moving air. This thin dry layer apparently reduced the availability of oxygen to a moist substrate and thus inhibited browning of the tissues.

Heat influenced the drying speed and also makes a difference in appearance. Lower temperatures found in the electric dehydrator and the direct drying method gave a more natural appearing product. High temperatures such as those found in the modified direct dryer on a good clear day seemed to decrease the color quality and in some cases where the food was near the black sides of the dryer the food became scorched and burned looking. These samples also became very brittle and hard. This was especially evident with the tomatoes and the apples.

The exposure to light generally appeared to be detrimental to the color although this did not apply in all cases. The beans and squash were especially sensitive to light. The carotene and chlorophyll pigments, being light sensitive, were undoubtedly affected. The squash was especially interesting in that the areas exposed to the light were bleached white while areas protected on the undersides of the slices were not affected and remained yellow-orange.

The blanching treatment reduced browning reactions and stabilized the color in yellow samples such as squash and helped to some degree in others. In the case of white foods such as the potatoes, bananas, and sweet potatoes, the blanching process caused some yellowing and darkening. Dipping in sodium bisulfite was a great help in vegetables and fruits subject to browning reactions. When dipped, these foods retained their natural light color. Dipping darker vegetables such as squash and beans seemed to cause some bleaching of the pigments.

Dryers

The dryer types had a significant influence on the quality of the foods dried. The direct dryer maintained the lowest temperature with circulation of the air around the food being a function of the ambient air movement. The modified direct dryer produced the highest temperatures with air movement generally slow and governed by the convection currents caused by heating. Ventilation holes in the top and bottom of the dryer were provided. High temperatures found in the modified direct dryer caused some problems. The syrup exuded by grapes was found to be most severe in the modified direct dryer, possibly because of the higher temperatures found there. Localized high temperature areas seemed to affect the drying of some foods. The areas close to the back and sides appeared to have very high temperatures. Apples and tomatoes drying in these areas became very hard and scorched to black in appearance. The indirect dryer had temperatures generally around 14^{o} C lower than the modified direct dryer with air movement slow and governed by convection with the dryer acting as a small solar chimney. The air was thus pulled over the drying tray. Both the modified direct dryer and the indirect dryer showed widely fluctuating temperatures. These wide fluctuations were caused by variations in the sunlight; wind conditions also contributed by increasing or decreasing ventilation and air movement inside the dryers, especially the indirect dryer.

The electric dehydrator was the most constant in temperature as it was controlled by a thermostat rather than by the sun. The temperature was lower than either the modified direct dryer or the indirect dryer but was generally higher than the direct dryer. Air movement was rapid and governed by a fan in the dehydrator.

It might be expected that ascorbic acid which is labile in the presence of heat and oxygen might be reduced the most in the dryers which became hottest and had the most air movement. The overall average of all foods showed that the ascorbic acid levels of undried food were either superior to the dried foods or the difference was insignificant (as in the corn). The drying then did have a significant effect on the ascorbic acid. The retention of ascorbic acid in the electric dehydrator was significantly better than that in the modified direct dryer in beans, tomatoes, potatoes, squash, apples, and sweet potatoes. This would indicate that light, heat, or possibly the aforementioned rapid initial drying of the food in the electric dehydrator, would be the cause. In potatoes the electric dehydrator was better than the indirect or the direct methods, but in sweet potatoes the differences among the three methods were insignificant. It thus appears that the rapid drying might be the basic cause for the increased ascorbic acid levels of the electric dehydrator over the solar dryers. In beans the indication would be that the greatest contributing factor in ascorbic acid destruction would be oxygen. The indirect and direct dryers would be the dryers most subject to atmospheric air movement. The electric dehydrator also would have a high air turnover rate; however, in the dehydrator the heated air caused the outer layer to dry very quickly, thus reducing the amount of oxygen which could reach the moist part of the food. As already mentioned, the stability of ascorbic acid is inversely proportional to moisture content, and the slower drying during the constant rate period in the indirect and direct dryers would allow the moisture and oxygen combination to have a greater effect on the ascorbic acid of the samples. The reduced air flow in the modified direct dryer along with the increased speed of drying caused by higher temperatures would account for the increased efficiency over the other two solar dryers in ascorbic acid retention.

When all foods were considered compositely, the high temperature in the modified direct dryer significantly lowered the ability for foods dried therein to retain ascorbic acid. The direct drying method was next lowest. The indirect dryer and the electric dehydrator showed no significant difference between them but both were significantly better than the methods where light was concerned. This coincides with the study reported by Ahmed, et al. (1976) where it was observed that light causes the destruction of vitamin C. Of the solar methods tested the indirect method appears to be the best for retaining the ascorbic acid with the modified direct dryer being the poorest and the direct method falling in between. All of these differences were statistically significant.

The retention of beta-carotene varied widely among the fruits and vegetables when compared to the drying methods. Grapes, tomatoes, and squash indicated that all drying methods caused significant losses of beta-carotene; however, bananas showed that drying was better in beta-carotene retention. It should be noted that bananas have much less beta-carotene than the tomatoes or squash, and the losses in the latter would be much more noticeable. Vitamin A is reported to be sensitive to oxidation, especially in the presence of light with particular reference to ultraviolet light although this is reported as being variable (Hellendoorn, et al., 1971).

It is interesting that the dryers exposed to light, the direct and modified direct dryers, showed the least amount of beta-carotene retention in dried samples. It is also important to note that there was no significant difference between the modified direct dryer and the direct dryer as would have been expected. The glass top of the modified direct dryer should have screened out the ultraviolet light rays and thus reduced the amount of beta-carotene destroyed; however, this was not found to be true. The absence of light in the indirect dryer did seem to help, however, in that the indirect dryer was found overall to improve significantly the retention of beta-carotene.

The movement of air did not seem to play a large role in the destruction of beta-carotene as the electric dehydrator proved significantly better for beta-carotene retention than any of the solar dryers for high beta-carotene foods. This may have been due to the more rapid drying which occurred in the dehydrator. Samples of squash required only 34 hours to dry in the electric dehydrator, whereas the solar dryers required 56 hours. Samples of sweet potatoes dried in 30.5 hours in the electric dehydrator while the solar dryers required 55 hours because of cool temperatures and fall showers. In the warmer times of the fall, the drying times would have been comparable, but as the cooler weather became dominant, the electric dehydrator became the more rapid method of drying. It should be noted that in beans where the samples on all dryers were dried for equal times, the electric dehydrator was significantly better in preserving beta-carotene than the direct and modified direct dryers but was not significantly better than the indirect dryer.

Thiamin proved to be very stable with only small differences occurring between the drying methods. All dryers were found to produce significant losses from the undried state when all foods were considered overall; however, sweet potatoes and corn showed some dried samples having significantly more thiamin than the undried samples. The main destructive force of thiamin would be heat (Beadle, et al., 1943), especially in more basic foods (Farrer, 1955). In both corn and beans the modified direct dryer was found to be the most destructive to thiamin. In some of the more acid foods such as tomatoes and apples the modified direct dryer was somewhat more effective; however, most of the differences between dryers in the foods were not significant, and the extreme variability in the order of dryer effectiveness in thiamin retention makes it difficult to generalize about the best drying method where thiamin is concerned.

Dryer Temperature Variation

The nutritional value of the foods proved to be related in some degree to the temperature applied during the drying process. The best product was produced when dried at lower temperatures in the 40-60° C range while higher temperatures such as those found in the modified direct dryer on bright sunny days (85-90° C) were destructive to some vitamins. By comparing the dryer temperatures to the ambient temperature it is possible to note a definite correlation between dryer type and the temperature which can be expected at a given ambient temperature. This correlation would allow dryer choice in a given area according to the expected ambient temperature. That is, on a hot sunny day the modified direct dryer might attain temperatures too hot for satisfactory drying while the indirect dryer might fall in the correct temperature range. On a colder day the direct or indirect methods might not be hot enough whereas the modified direct dryer might be just right.

The temperature data from all dryers were graphed against the ambient temperatures for corresponding days. In all cases the maximum dryer temperature for the day was graphed with the maximum ambient temperature for the day. Variations in the duration of sunshine to attain the given temperatures for the day along with wind conditions which tend to reduce the temperature especially in the direct and indirect dryers caused the values to give a scattered array on the graph. A best fit method was used to determine the approximate lines as shown. (see figure 5)

It was then possible to determine general mathematical equations which allow approximate expected temperatures to be determined for any of the solar dryers at a given temperature. In practice the temperatures would probably be slightly higher or lower depending on the sun and wind conditions.

The formulae given were found to be applicable between ambient air temperatures of 20^{0} C and 36^{0} C and give the temperatures expected in the given dryer. "A" is the ambient air temperature.

Temperature of Direct Dryer $^{o}C = (A + 3.33) + 2(A - 24)$

or DD $^{o}C = 3(A) - 44.67$

Temperature of Indirect Dryer $^{o}C = 2.8(A - 21) + (A + 1.67)$

or ID $^{o}C = 3.8(A) - 57.13$

Temperature in Modified Direct Dryer

$^{o}C = 2.8(A - 21) + (A + 16.67)$

or MDD $^{o}C = 3.8(A) - 42.13$

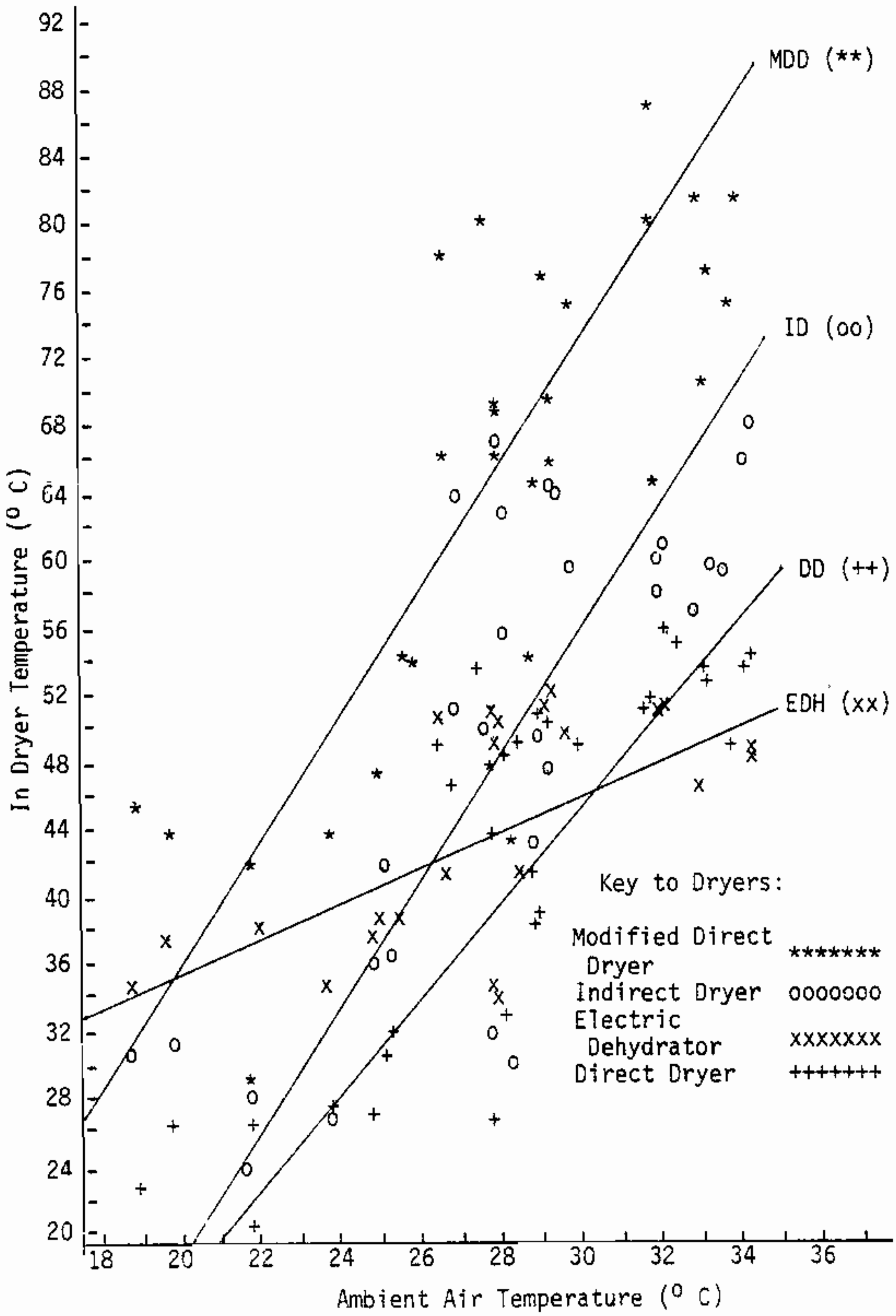


Figure 5. Dryer Temperature Comparison

It might be noted that the modified direct dryer is a constant 15° C hotter than the indirect dryer at any given temperature.

The electric dehydrator was influenced to some degree by the ambient air temperature but was generally much more constant in temperature. At room temperature the electric dehydrator operated at 44° C. Higher ambient temperatures seemed to give the heating element a head start and temperatures as high as 52° C were observed when the ambient temperatures were over 32° C. In general, however, the electric dehydrator maintained temperatures between 43° C and 51° C when operated outside in suitable drying weather. Lower temperatures also caused a reduction in temperature by increasing the work load of the heating element as the electric dehydrator showed a temperature of only 35° C when the ambient temperature was 19° C.

Use of the given formulae might allow selection of a dryer suitable for a given climate and solar condition by allowing for temperature adjustment. The formulae are, however, applicable to the dryers as constructed, and modifications to ventiliation systems, design, or color may significantly change the performance and make the formulae useless in predicting temperatures.

Sources of Variation

One of the biggest problems in the study was the involvement of biological material. Anytime that plants or animals are used in a study a great deal of variation enters because of the variability and differences among the separate individuals and even within the same individual. Where possible the samples were ground with a mortar and pestle and mixed to obtain a more homogenous mixture of tissue. Where the moisture level of the dried food material was sufficiently high to prevent using the grinding method, the samples were cut into small pieces. Even this was not sufficient and the variability in the results was considerable. Experimental and procedural errors would also be involved in the variability. The tomatoes were especially noted in that in one slice of a tomato, the color would range from white in the center to deep red on the skin. In all cases the attempt was made to use as homogenous a mixture of tissues as possible.

The characteristics of the individual fruits and vegetables were also variable. Some of the foods such as tomatoes, grapes, and corn had a tough outer skin. The skin was not removed in these cases and caused increased drying times. The grapes were dried whole, and the skin was very effective in reducing moisture losses causing some samples to require 192 hours of drying time. The skin on the tomatoes is also very effective in preventing water loss; however, the tomatoes were sliced and the exposed flesh was sufficient to eliminate the moisture retaining effect of the skin.

Some of the foods had the skins removed before treating and drying. These included potatoes, apples, sweet potatoes, squash, and bananas. In all except apples it is the practice to remove the skin before eating and thus the preparation for drying was as it would be in order to use the foods.

Another difference between the foods was the type of tissue involved. The potato, banana, tomato, squash, and apple samples all had a soft parenchymous tissue with many air spaces. The steaming process caused these foods, especially tomatoes and bananas, to become soft and difficult to handle. Sweet potatoes, beans, and corn had a firmer tissue and the steaming treatment did not cause the same loss of integrity found in the previously mentioned foods. Grapes were used with the skins intact and thus were not a problem to work with; however, it is probable that because of the tissue type and high water content, steaming of peeled grapes might reduce them to a mush as with the tomatoes.

It may be noted in the results that the treated samples may be higher in a vitamin than the untreated samples. This is understandable with the dried samples in view of the protective interactions possible with treatments, light, and so on. It might seem questionable in the undried samples, however. The problem again reverts to the fact that biological materials are being considered. Fruits and vegetables do not die at harvest time but continue to live, with little or no immediate effect on the metabolism although the life functions slow as the time from harvest increases. The enzymes are active and in fresh fruit numerous reactions are taking place until they are stopped in some manner. Salunkhe, et al. (1973) report that unless the enzymes are inactivated, up to 80% of the carotene may be lost. Blanching, however, is reported to reduce the losses to less than 5%. Most of these reactions are concerning catabolism and respiration since the source of energy in the plant has been removed. Some of the reactions continue to produce vitamins (Eheart and Odland, 1972). Microorganisms present may also contribute either to the increase or decrease in vitamin levels as time passes.

The vitamins studied are affected by peroxidases, causing the destruction of beta-carotene, and oxidases which catalyze the destruction of ascorbic acid (Moyer, 1943). Thiaminases aid in thiamin breakdown (de Ritter, 1976). All of these enzymes are constantly working from the time the food is harvested. Steaming is effective in stopping the enzyme action while sodium bisulfite slows oxidation of ascorbic acid. Thus the reactions and vitamin losses in treated samples are slowed or stopped but continue unhindered in the untreated samples. All samples were kept frozen in an effort to keep these problems at a minimum.

The preparation of the samples for analysis might also have contributed to some vitamin losses especially in the untreated samples. The pulverizing, cutting, and mixing prior to analysis would have increased the surface area, oxygen contact, and enzyme-substrate contact, causing increased reactions for the short period of preparation time.

With an understanding of the sources of variation which are possible, the major emphasis was placed on treating all samples exactly the same. The study done was not to get exact "book" values but rather to compare the effects of the treatments and drying methods; therefore the equal treatment of all samples during the analyses was of the utmost importance.

It also became evident that there are many interactions occurring within any given food which are peculiar to that food. The steam treatment for example made significant differences in the retention of ascorbic acid in most of the foods, but in apples, corn, and grapes there was no significant loss in steamed samples. Sodium bisulfite protected the ascorbic acid in many foods, giving the dipped samples higher ascorbic acid values than the untreated samples.

However, apples showed a slight but not significant decrease in the ascorbic acid of the dipped samples. Under identical conditions of drying, steamed samples of tomatoes were improved in thiamin retention over the untreated samples while most other foods showed the steam treated samples significantly lower in thiamin compared to the untreated samples.

The order in which the drying methods compared was also different depending on the food. (see figures 2,3, and 4) Ascorbic acid was the most constant in showing generally that the modified direct dryer and the direct dryer were the poorest for retaining ascorbic acid in the dired samples. Dried beans, however, indicated that the modified direct dryer was significantly better than the indirect dryer. A reversal of the usual trend. Beta-carotene retention figures showed more variability with about half of the foods showing the dryers to give significantly less beta-carotene, but bananas showed all dryers to give significantly increased beta-carotene levels over the undried samples. Thiamin also was variable; however, fewer differences were significant among dryers where thiamin was considered.

CONCLUSION

In reviewing the results of the study it becomes obvious that the drying problem is very complex and many factors must be taken into account. It also is evident that one single method is not the best for all foods and that interactions occur in each individual food. These interactions depend on the composition of the food, water content, enzymes, and textures. These and other factors seem to protect the vitamins in one food, have no effect in another, and may actually destroy vitamins in another food. These factors make it necessary to accept some exchanges in the drying of foods in order to get the desired product. For example, by dipping in a sodium bisulfite solution, the appearance was enhanced and the ascorbic acid was somewhat protected but the thiamin was almost totally destroyed. In areas where there is a shortage of fresh leafy vegetables and citrus fruits, the bisulfite protection of ascorbic acid might be desirable. In preparing foods for very fussy consumers the improved appearance might be more desirable than the thiamin retention. Steaming improves the color in some cases and may help to preserve the beta-carotene content, but the ascorbic acid content is reduced considerably and the texture and general appearance in some foods becomes less than desirable.

For those who advocate the "natural way" and desire to dry food without using any treatment, the nutritional quality of the food may be considerably reduced by the action of enzymes along with heat and light. The same factors can reduce the aesthetic appeal as well. For example, untreated potatoes dried in the direct dryer were somewhat darkened when removed from the dryer but became very black with time in storage. It may be psychologically beneficial for some people to trade vitamin content and appearance for a "natural" food which has not been treated and has no preservatives.

In any drying operation the food to be dried must be fresh and of the best quality. Drying should not be used as a last resort method of preserving food. Drying will satisfactorily preserve food, but it cannot improve on the original quality. It is also important to prepare each food according to the individual characteristics and to prepare it such that in the dried state it will be suitable for the intended use. For instance, if tomatoes are to be dried for soups, it would not be necessary to dry them as carefully cut slices.

The use of sodium bisulfite in pretreating fruits and vegetables subject to browning is very beneficial in preserving the light or white color. Bananas, apples, and potatoes definitely had a better color after drying if treated with bisulfite prior to drying. It is possible under some circumstances to dry fruits and vegetables without treatment and retain a good color; however, the color deteriorates during storage and shelf life is reduced. Steaming as a pretreatment generally decreased the quality of the color by changing it to a darker, translucent color characteristic of a cooked food. Steaming the light colored fruits and vegetables turned them a somewhat yellow color which was less appealing than the natural white preserved by the sodium bisulfite treatment. The texture of the softer foods was definitely changed by the steaming process and the texture created by steam treatment of bananas and tomatoes was definitely objectionable. Steaming stabilizes the color in foods with a high beta-carotene content and in this way was found to be beneficial.

One of the main factors in the appearance of the dried food was found to be the time and speed of drying. The most critical part is the amount of time the food spends in the constant rate period of drying. If this period is shortened by using a warm temperature and rapidly moving air, the color and appearance are improved as the availability of oxygen to inner tissue areas is reduced. Total drying time contributes to deterioration as the food begins to deteriorate at harvest, and although still alive and respiring, the quality declines because the life activities become catabolic rather than anabolic. The drying process slows and stops the deterioration and thus the quicker the food is dried the better the appearance and nutritional value will be.

The ascorbic acid content of the fruits and vegetables was reduced significantly by steaming in most cases. The use of sodium bisulfite before drying was found to protect the ascorbic acid significantly in all but corn, grapes, and apples. The ascorbic acid content was greater than in the untreated samples as a result of this protective influence. The utility of the bisulfite treatment as a method of preserving the ascorbic acid in dried foods is doubtful, however, if fresh foods are available in sufficient quantity to supply the ascorbic acid necessary in the diet. This is true because the consequent destruction of thiamin may not be desirable, and where fresh foods are available for supplying ascorbic acid, the thiamin may be the more desirable nutrient in the food dried for storage.

Heat was found to be detrimental to the ascorbic acid as foods are dried. The modified direct dryer was found to be the poorest in preservation of ascorbic acid. The difference was significant between the modified direct dryer and the direct dryer. The modified direct dryer reached the highest temperatures of all drying methods. Both methods involving direct light retained less ascorbic acid than either the indirect solar dryer or the electric dehydrator. All drying methods showed significant losses of ascorbic acid when compared to undried samples. The electric dehydrator and the indirect solar dryer showed no significant differences except in beans and potatoes where the electric dehydrator was significantly better in preserving ascorbic acid.

The treatment before drying made no significant difference in beta-carotene retention of dried foods. The untreated samples in the case of tomato did, however, show lower values than the treated samples. Heat and light seemed to be the critical factors in the destruction of beta-carotene in drying fruits and vegetables. The direct dryer which exposed the food to direct sunlight was the poorest or next poorest for beta-carotene preservation in six of the foods dried. The modified direct dryer where the food was shielded by a sheet of glass but also had higher temperatures was found to be the second poorest for beta-carotene preservation in six of the nine foods and the poorest for potatoes and the foods overall.

The indirect method of solar drying was significantly better in preserving beta-carotene than either of the methods involving the exposure of the food to sunlight. All solar methods were inferior to the electric dehydrator in beta-carotene retention. Drying in all cases significantly reduced the beta-carotene content of the foods compared to the undried samples.

Thiamin was the most stable of the vitamins studied during the drying process. The treatment of the foods using sodium bisulfite showed the thiamin to be destroyed. All foods showed that drying significantly reduced the thiamin content. It was shown that heat, along with the natural pH of the food, made the largest difference. This coincides with the findings of Mulley, et al. (1975), as they reported that thiamin stability decreases with increasing pH, especially with pH values greater than 6.0. Acid foods such as tomatoes and apples showed better tolerance to heat, and the hottest dryer (modified direct dryer) proved to be somewhat better than the other dryers. The low acid foods such as beans, corn, and squash showed the modified direct dryer to be inefficient in preserving thiamin. Overall, heat was the biggest factor in contributing to thiamin losses other than sodium bisulfite treatment. Light was also a factor. The direct dryer was significantly better than the modified direct dryer, but the electric dehydrator and the indirect dryer were not significantly different from either the direct dryer or the modified direct dryer.

In the drying of fruits and vegetables, contamination is a definite problem since the food cannot be dried without exposure to moving air. The direct method of solar drying where the food is placed in the open on trays is the most susceptible to contamination by wind, dirt, insects, and birds. Covering the food with netting or cheesecloth is a viable solution but not entirely satisfactory in a windstorm. The enclosure of the drying trays in the modified direct dryer, indirect dryer, and electric dehydrator produced a much cleaner product. It would be possible to use the direct method by enclosing the trays in a screen box although the dust problem would still exist.

One other big consideration in drying is the weather conditions. Those dryers protected from rain (modified direct and indirect dryers) were found to be able to dry the food satisfactorily even with intermittent rain showers if the humidity did not remain high for extended periods. The direct drying method was totally unsatisfactory because the food rehydrated with each rain and the process of drying began again almost as if the food was fresh as far as water content was concerned. The use of a direct drying method would necessitate protecting the food from inclement weather. Many areas where drying would be done would have little problem with weather, however, since the harvest season is generally quite sunny and relatively dry.

Overall it is generally indicated that the best product is produced in a dryer which operates at a temperature in the range of 40-60^{o} C and which provides a rapid flow of heated air over and around the food. The indirect dryer showed these qualities although improvements could be made. The electric dehydrator was generally the best for food preservation, and a combination of a solar collector acting to heat the air and then channel the air through a properly insulated solar chimney to the drying chamber would allow the sun to be used to dry the food in place of electricity and still maintain a rapid air flow at the proper temperatures and humidities. The modified direct dryer dried the most rapidly when the sun was shining brightly; however, the high temperatures (85-90^{0} C) possible in that particular dryer are not desirable in preserving the nutritional value of food. This dryer would be helpful in areas where solar radiation is less intense and temperatures attained could be maintained in the ideal region. The modified direct dryer would probably not be useful in tropical areas unless modifications were made to regulate the temperature and avoid the extreme high temperatures possible in the dryer.

Of the solar dryers tested, the best overall dryer would be the indirect dryer. Properly modified, this dryer could provide high quality dried produce to individuals without high initial cost or high maintenance costs. The dryer could be simply and inexpensively constructed. The second best dryer would be the modified direct dryer. This dryer could be modified in order to provide more rapid ventilation and thus lower temperatures. The number of ventilation ports could be increased and regulated on low radiation days to maintain the necessary temperatures for drying.. Small sliding covers might be used to cover or open the ports. The modified direct dryer with proper modification might be the best for solar drying in low income areas because of ease of construction and simplicity of use.

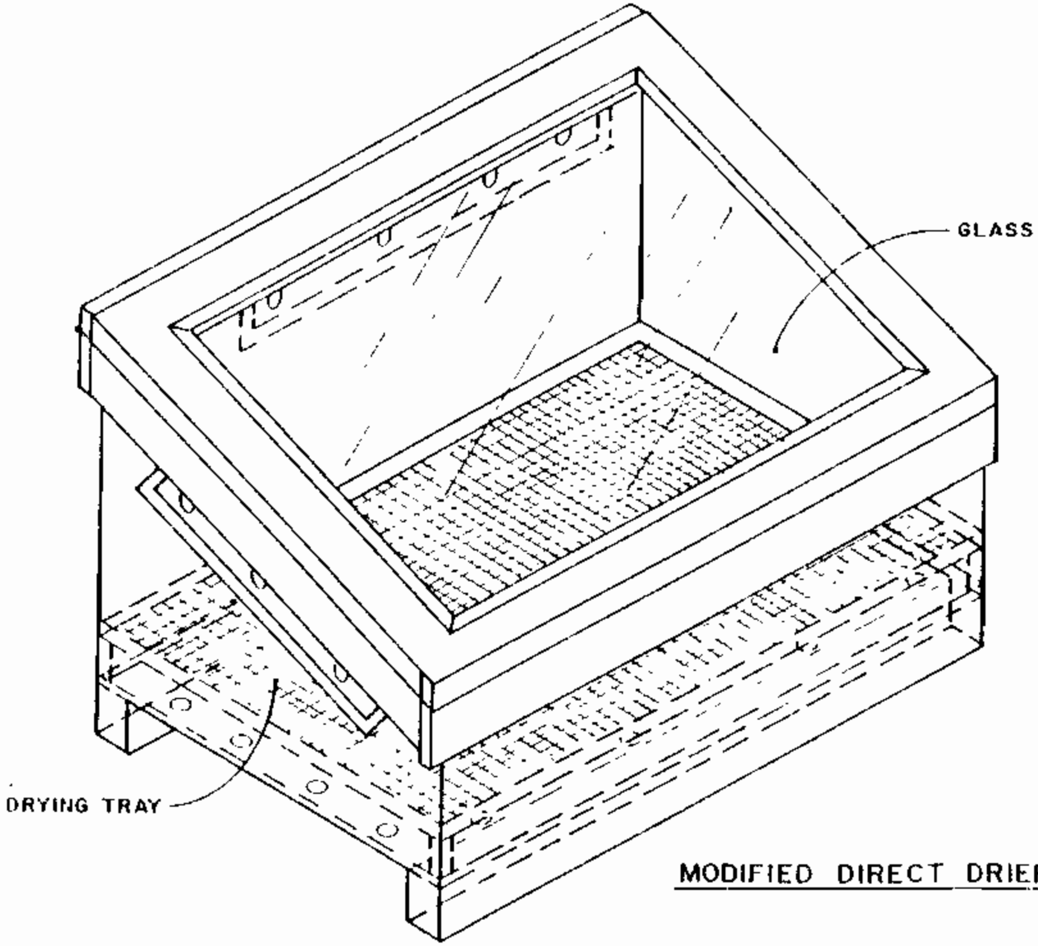
The direct method of drying would be the least desirable because of high vitamin losses, susceptibility to inclement weather, and contamination problems. In emergency situations or for drying produce which would otherwise go to waste it would, however, be a suitable method.

Solar drying as a method of food preservation can be used in almost all world areas and should be used to preserve food where possible. Proper combination of treatment and drying methods would result in adequate nutrient retention and suitable appearance. Solar drying also is economical and preserves the fossil fuels necessary for other more expensive types of food preservation such as freezing and canning. While fresh foods should be eaten in season, drying of the excess will provide year round nutrition.

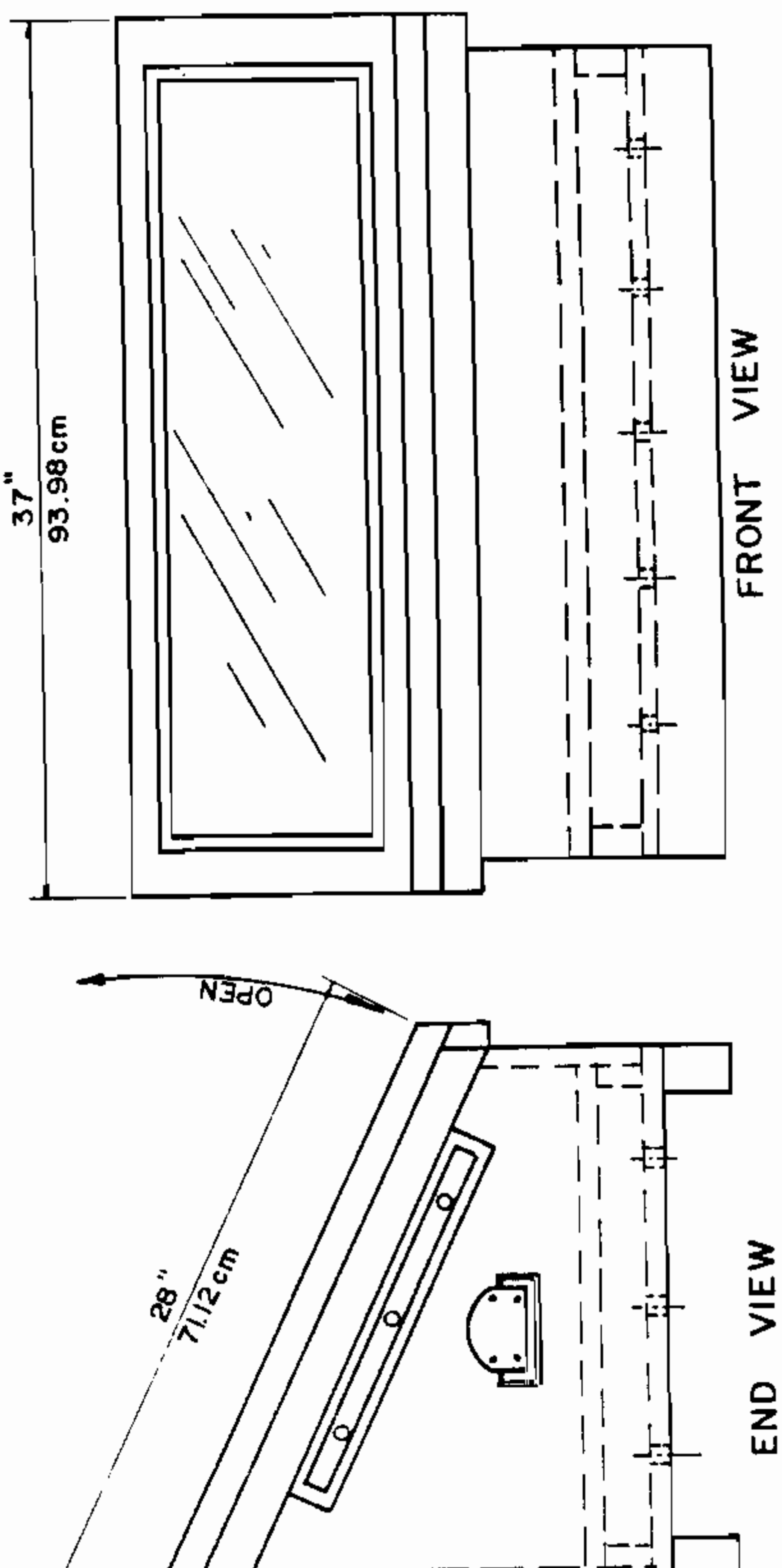
APPENDIX

APPENDIX A

Modified Direct Dryer



MODIFIED DIRECT DRIER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OPEN
28"
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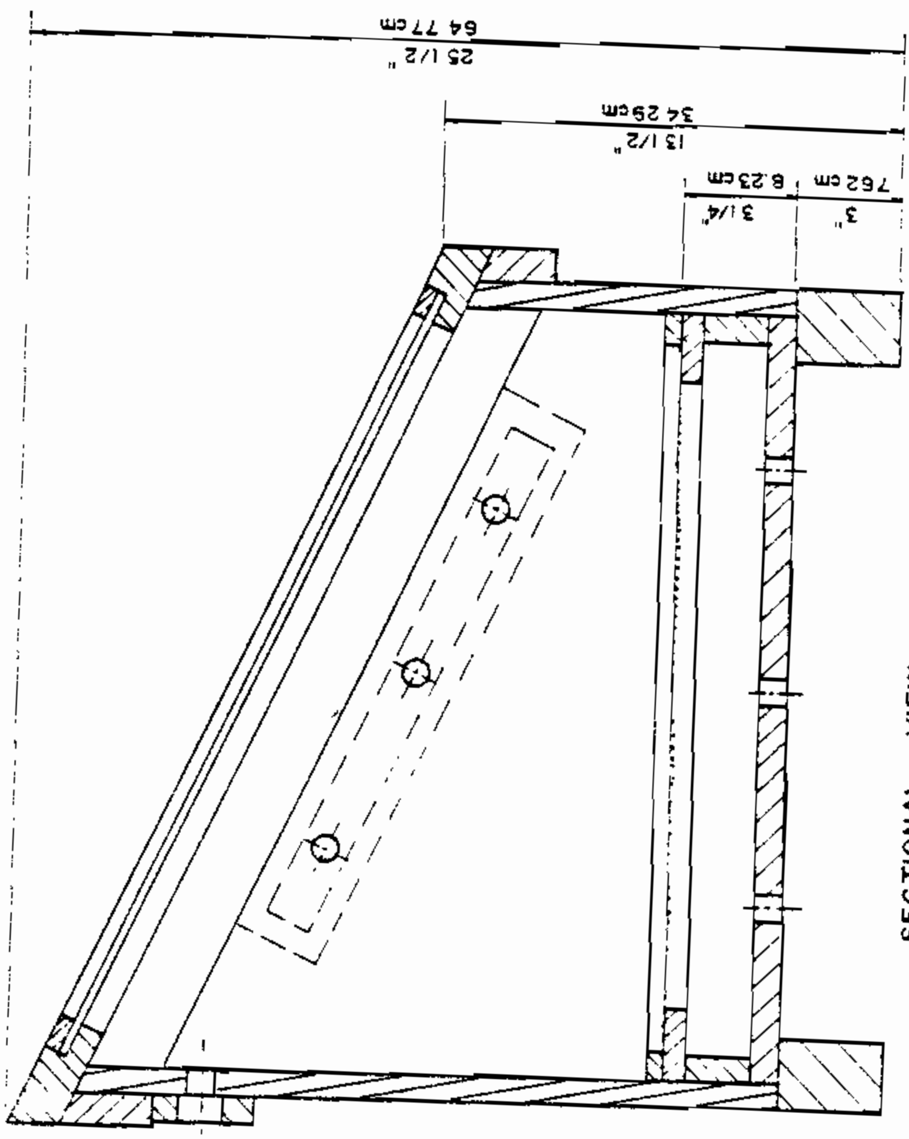
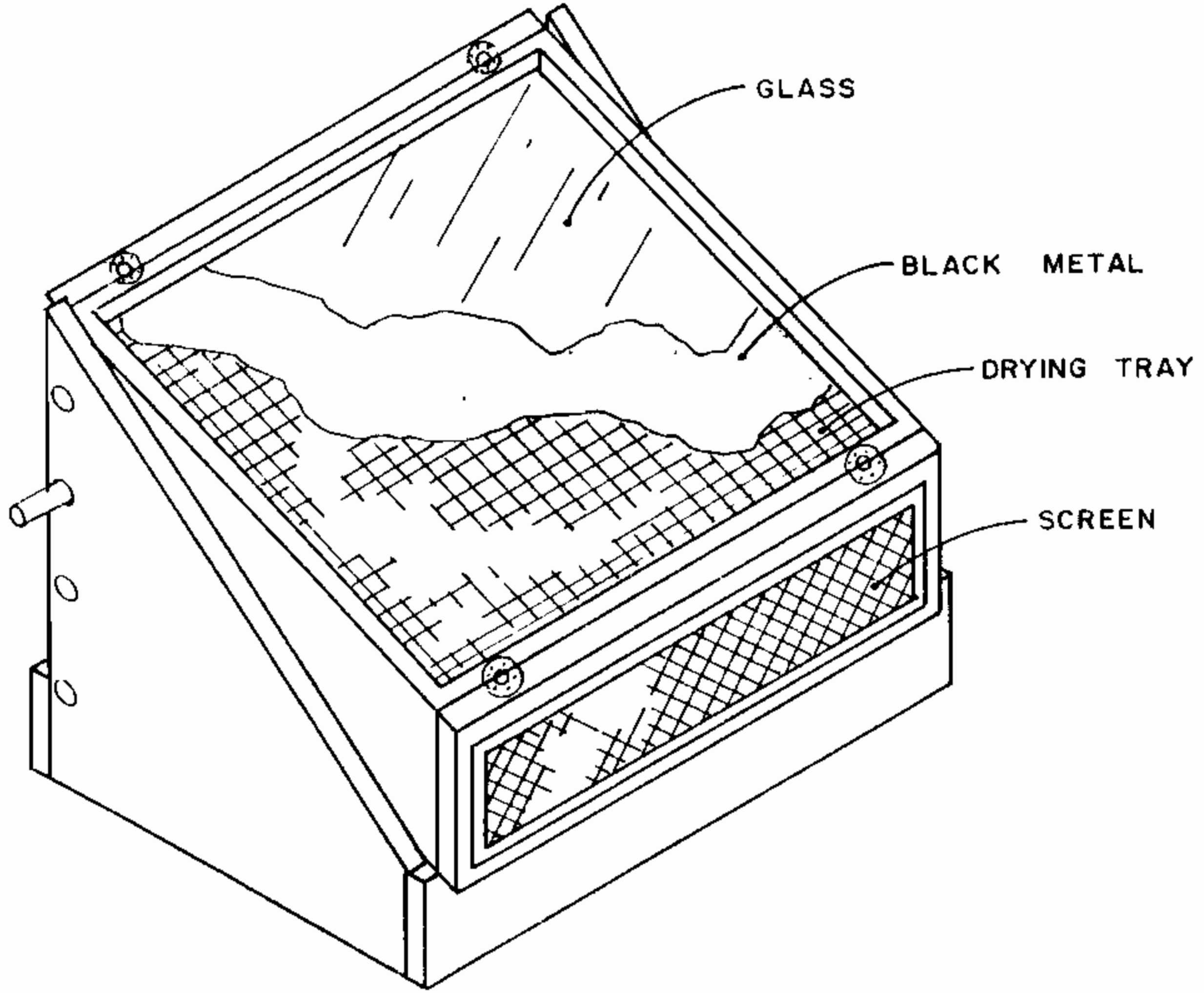
END VIEW



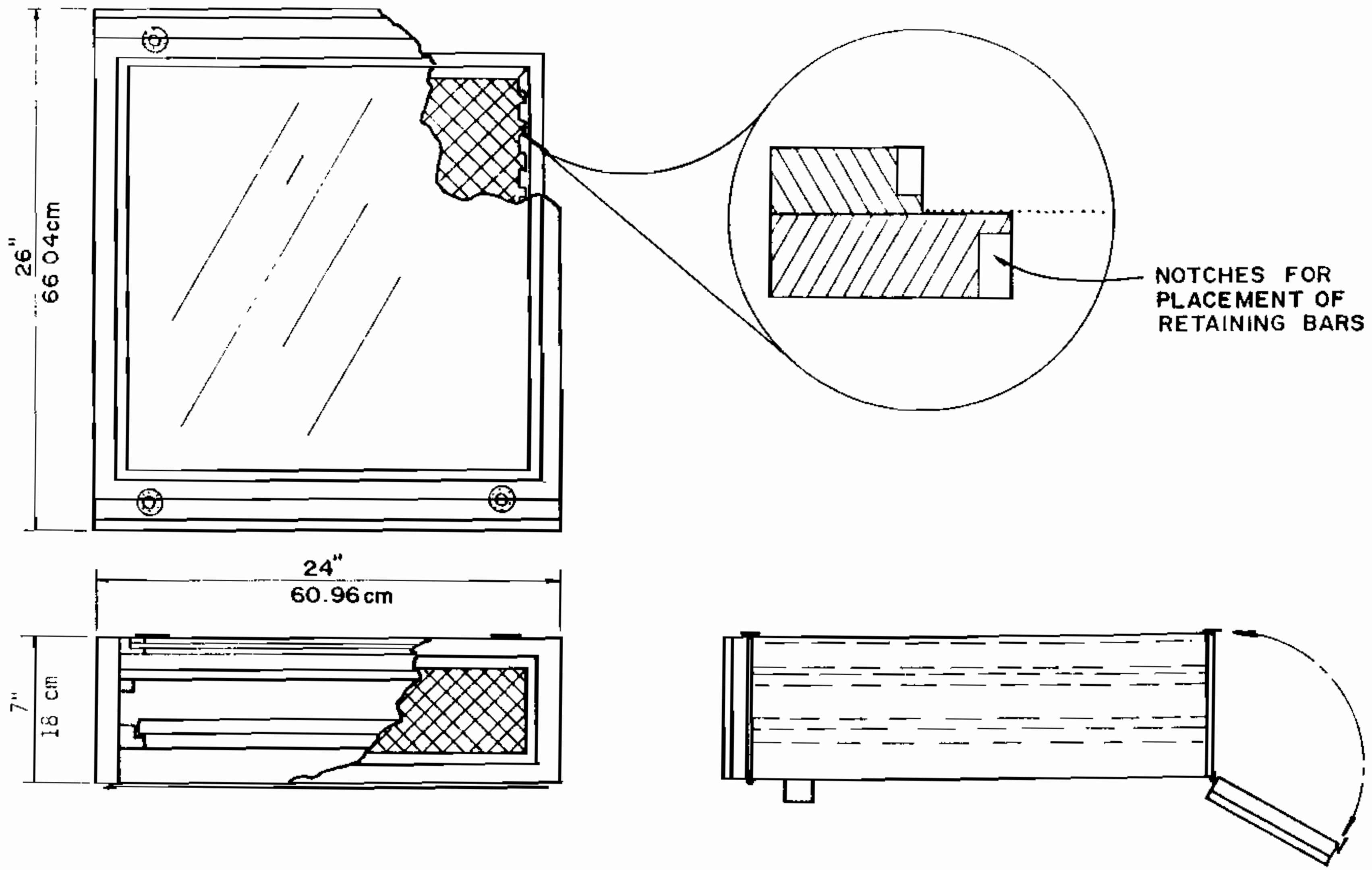
SECTIONAL VIEW

APPENDIX B

Indirect Dryer



INDIRECT DRIER



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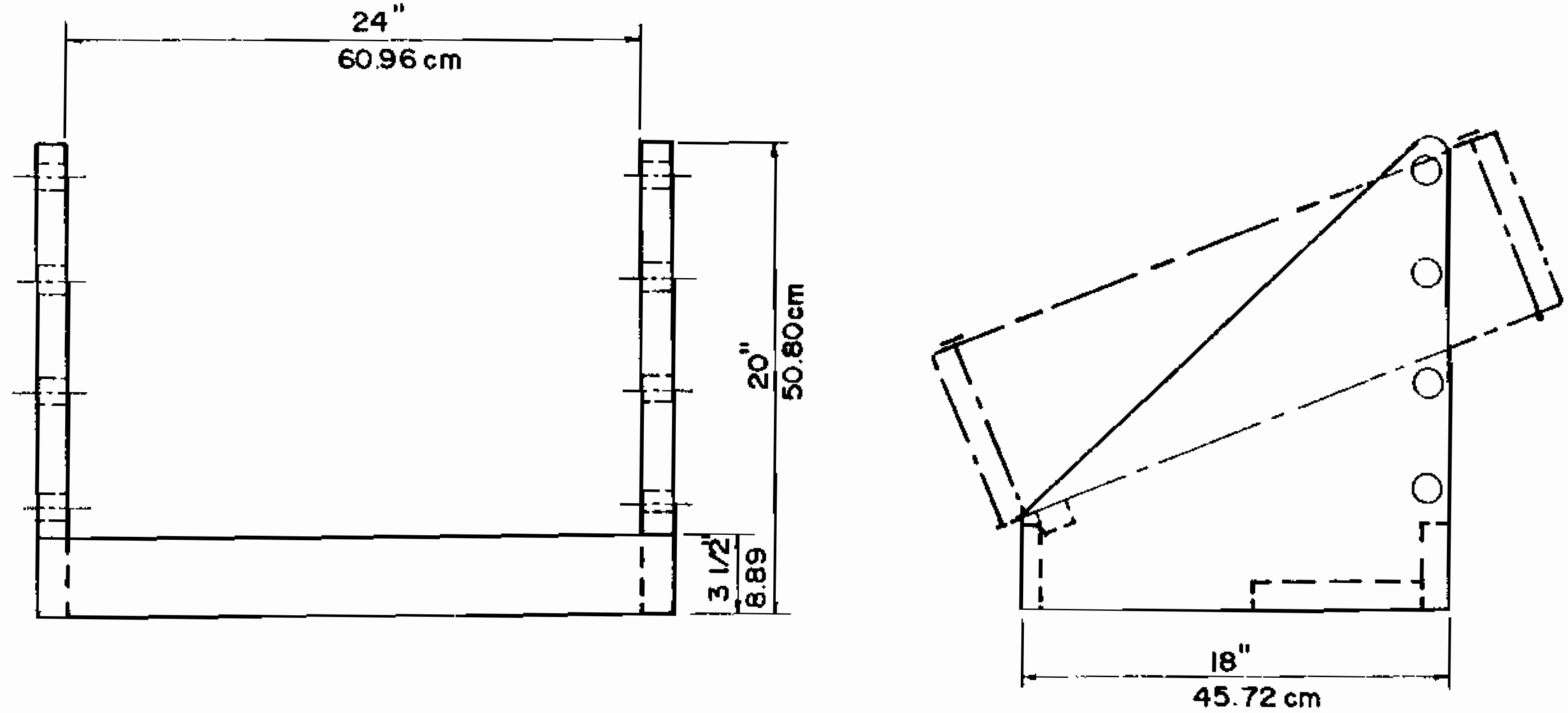

INDIRECT DRIER - STAND

APPENDIX C

Significant Difference Charts

1. Significant differences among dryers and treatments
2. Significant differences among dryers—Ascorbic Acid
3. Significant differences among dryers—Beta-Carotene
4. Significant differences among dryers—Thiamin
5. Significant differences among treatments

SIGNIFICANT DIFFERENCES AMONG DRYERS AND TREATMENTS

	Ascorbic Acid			Beta-Carotene			Thiamin		
	D	T	DT	D	T	DT	D	T	DT
Beans	X	X	X	X		X		X	
Corn							X	X	X
Grapes	X			X			X		
Tomatoes	X	X	X	X		X	X	X	
Bananas	X	X	X	X		X		X	
Potatoes	X	X	X	X			X	X	
Banana Squash	X	X		X		X	X	X	
Apples	X			X				X	
Sweet Potatoes	X	X	X	X			X	X	

Significant differences at the .05 level shown by "X". (Using the f-test)

D = between dryers
T = between treatments
DT = between both dryers and treatments combined

Significant differences between dryers, between treatments, and between both dryers and treatments combined

ASCORBIC ACID

Significant Differences Between Dryers
Using the Duncan Multiple Range Test

	1&2	1&3	1&4	1&5	2&3	2&4	2&5	3&4	3&5	4&5
Beans	X	X	X	X	X	X	X	X		X
Corn										
Grapes	X	X	X	X			X			
Tomatoes	X	X	X	X	X	X	X			
Bananas	X	X	X	X			X		X	X
Potatoes	X	X	X	X		X	X	X	X	X
Banana Squash	X			X	X	X			X	X
Apples	X				X	X	X			
Sweet Potatoes	X	X	X	X		X				
All Foods Combined	X	X	X	X	X	X	X		X	X

Significant differences shown by "X"

Key to dryers:
1. Undried Control
2. Modified Direct Dryer
3. Indirect Dryer
4. Electric Dehydrator
5. Direct Dryer

BETA-CAROTENE

Significant Differences Between Dryers
Using the Duncan Multiple Range Test

	1&2	1&3	1&4	1&5	2&3	2&4	2&5	3&4	3&5	4&5
Beans	X	X		X	X	X			X	X
Corn					X	X				
Grapes	X	X	X	X	X			X	X	
Tomatoes	X	X	X	X				X	X	
Bananas	X	X	X	X		X		X		X
Potatoes	X					X				
Banana Squash	X	X	X	X	X	X		X	X	X
Apples	X		X	X	X			X	X	
Sweet Potatoes	X			X	X		X		X	X
All Foods Combined	X	X	X	X	X	X		X	X	X

Significant differences shown by "X"

Key to dryers:
1. Undried Control
2. Modified Direct Dryer
3. Indirect Dryer
4. Electric Dehydrator
5. Direct Dryer

THIAMIN

Significant Differences Between Dryers
Using the Duncan Multiple Range Test

	1&2	1&3	1&4	1&5	2&3	2&4	2&5	3&4	3&5	4&5
Beans	X									
Corn	X	X	X	X	X	X	X	X	X	X
Grapes	X			X					X	X
Tomatoes	X	X	X	X						
Bananas			X			X				
Potatoes			X			X		X		X
Banana Squash	X	X	X	X				X		X
Apples				X						
Sweet Potatoes			X	X						
All Foods Combined	X	X	X	X			X			

Significant differences shown by "X"

Key to dryers:
1. Undried Control
2. Modified Direct Dryer
3. Indirect Dryer
4. Electric Dehydrator
5. Direct Dryer

SIGNIFICANT DIFFERENCES AMONG TREATMENTS

	Ascorbic Acid 1	Ascorbic Acid 2	Beta-Carotene 1	Beta-Carotene 2	Thiamin 1	Thiamin 2
Beans	X	X				
Corn					X	X
Grapes						
Tomatoes		X	X			X
Bananas	X	X				X
Potatoes	X	X			X	X
Banana Squash	X	X			X	X
Apples					X	
Sweet Potatoes	X	X			X	X
All Foods		X	X		X	X

Significant differences shown using the planned comparison test. $F_{(1,15)} = 4.54$

Test #1 shows significant differences between the untreated samples and the treated (steamed and bisulfite dipped) samples

Test #2 shows significant differences between the steamed and the bisulfite dipped samples.

APPENDIX D

Raw Data Summary

1. Ascorbic Acid—Vegetables
2. Ascorbic Acid—Fruits
3. Beta-Carotene—Vegetables
4. Beta-Carotene—Fruits
5. Thiamin—Vegetables
6. Thiamin—Fruits

Key to Dryers:

UD - Undried Control
MDD - Modified Direct Dryer
ID - Indirect Dryer
EDH - Electric Dehydrator
DD - Direct Dryer

SUMMARY OF RAW DATA--ASCORBIC ACID--VEGETABLES
Values given are in mg/100 g dry wt.

	Beans		Corn		Potatoes		Banana Squash		Sweet Potatoes	
	1	2	1	2	1	2	1	2	1	2
UD Untreated	10.627	10.508	4.956	5.400	30.682	36.364	18.182	23.636	26.804	23.651
UD Steamed	8.659	7.123	5.932	5.583	29.866	38.852	16.418	15.299	19.726	17.922
UD Dipped	15.426	15.245	4.358	4.301	42.736	42.877	19.487	24.103	17.182	14.296
MDD Untreated	6.557	5.717	3.886	4.208	25.907	26.142	9.057	13.097	6.031	7.073
MDD Steamed	5.506	5.008	2.672	4.062	3.807	2.987	2.810	1.028	3.923	5.389
MDD Dipped	2.705	2.874	3.709	8.291	32.090	33.907	8.087	14.806	16.775	23.593
ID Untreated	4.235	2.596	4.281	3.713	16.752	13.522	18.754	20.838	7.816	8.933
ID Steamed	1.665	2.079	4.185	3.634	13.089	15.707	14.255	12.932	11.648	9.809
ID Dipped	4.016	3.755	6.035	4.523	35.203	38.841	22.102	16.459	23.553	21.871
EDH Untreated	10.814	9.949	5.025	4.479	24.971	27.840	25.776	18.248	7.208	8.162
EDH Steamed	2.245	2.412	4.964	5.698	24.168	18.045	15.770	18.553	10.926	11.827
EDH Dipped	6.205	6.699	4.774	5.769	41.458	37.206	23.405	23.405	27.554	22.785
DD Untreated	5.104	4.766	3.224	4.404	10.320	11.467	12.336	9.346	9.212	9.852
DD Steamed	1.933	1.902	3.764	4.007	5.611	5.322	.956	2.391	8.572	6.788
DD Dipped	2.457	2.999	4.587	5.241	27.555	31.573	13.424	12.996	23.444	10.029

SUMMARY OF RAW DATA--ASCORBIC ACID--FRUITS
Values given are in mg/100 g dry wt.

	Grapes		Tomatoes		Bananas		Apples	
	1	2	1	2	1	2	1	2
UD Untreated	7.113	7.990	145.540	117.371	7.059	6.373	5.924	5.151
UD Steamed	5.949	6.859	200.000	172.940	6.161	5.071	9.635	6.894
UD Dipped	6.680	6.583	237.031	266.667	6.993	6.807	3.935	4.568
MDD Untreated	2.265	3.494	53.035	30.016	1.233	1.555	2.206	3.483
MDD Steamed	2.265	2.525	6.799	16.460	1.560	2.170	1.982	2.522
MDD Dipped	2.299	1.939	27.819	21.113	2.777	2.151	4.293	2.336
ID Untreated	2.325	3.224	88.266	65.471	1.374	1.613	5.915	5.191
ID Steamed	4.316	3.480	108.170	49.631	0.000	0.000	5.670	3.635
ID Dipped	2.344	2.344	106.034	199.445	4.623	3.802	4.598	5.769
EDH Untreated	2.371	2.470	71.552	104.861	0.697	0.956	5.025	6.544
EDH Steamed	2.324	2.988	92.154	73.332	0.000	0.000	5.599	5.776
EDH Dipped	3.261	2.478	135.850	103.871	4.316	3.893	4.509	6.558
DD Untreated	1.609	3.358	116.741	71.298	0.000	0.757	7.308	5.884
DD Steamed	4.288	3.320	25.990	23.515	0.000	0.000	6.048	5.122
DD Dipped	3.598	3.259	102.539	91.553	2.871	2.566	4.762	4.762

SUMMARY OF RAW DATA--BETA-CAROTENE--VEGETABLES
Values given are in IU/100 g dry wt.

	Beans		Corn		Potatoes		Banana Squash		Sweet Potatoes	
	1	2	1	2	1	2	1	2	1	2
UD Untreated	664.0	666.8	847.3	386.6	68.7	45.6	47736.8	46979.1	631.8	672.3
UD Steamed	3469.7	1727.1	581.6	315.8	29.9	13.9	59535.7	66866.6	648.3	414.9
UD Dipped	907.6	577.9	859.3	740.8	47.0	0.0	61337.1	68389.7	773.4	509.8
MDD Untreated	489.2	600.2	1028.9	715.8	50.1	0.0	13968.8	21970.7	416.7	493.8
MDD Steamed	285.7	285.7	579.1	650.3	0.0	0.0	4997.6	4997.6	161.6	384.7
MDD Dipped	191.8	191.8	454.7	663.7	0.0	0.0	13907.5	8448.9	378.9	617.9
ID Untreated	903.7	707.0	364.1	--	0.0	29.9	21083.6	37776.7	860.9	552.8
ID Steamed	622.2	579.6	419.5	484.6	39.7	13.9	44095.3	35619.2	569.2	546.7
ID Dipped	1184.8	789.9	620.6	415.0	0.0	0.0	35097.8	38889.5	520.7	640.4
EDH Untreated	1216.9	1505.3	507.2	582.7	35.4	35.4	36361.1	47530.8	459.4	675.9
EDH Steamed	465.7	576.3	476.7	422.8	45.7	50.6	50740.7	43637.0	502.3	624.3
EDH Dipped	1343.3	1050.9	459.9	507.2	16.8	26.6	41598.5	42554.6	353.3	179.3
DD Untreated	361.6	420.7	285.6	496.2	23.9	0.0	21275.7	18403.2	88.5	154.6
DD Steamed	226.0	185.1	447.5	447.5	33.8	8.7	1445.0	5980.9	219.0	312.7
DD Dipped	160.6	210.8	535.5	770.4	13.4	0.0	11139.1	5198.2	203.0	314.8

SUMMARY OF RAW DATA--BETA-CAROTENE--FRUITS
Values given are in IU/100 g dry wt.

	Grapes		Tomatoes		Bananas		Apples	
	1	2	1	2	1	2	1	2
UD Untreated	868.7	689.4	35218.3	22500.6	735.4	735.4	654.8	912.4
UD Steamed	1086.5	651.9	37999.8	31869.1	632.0	616.2	927.6	692.3
UD Dipped	1016.7	1121.6	54949.3	44762.0	876.8	854.9	380.7	468.6
MDD Untreated	55.6	49.1	5078.9	7994.5	1104.3	1488.4	461.6	159.7
MDD Steamed	134.9	89.6	19236.9	24008.9	604.9	723.6	14.0	8.1
MDD Dipped	0.0	29.3	36747.7	18891.4	985.0	866.8	471.5	250.1
ID Untreated	234.1	201.8	12716.4	13098.5	876.5	866.6	150.9	991.1
ID Steamed	309.8	284.3	17342.5	18827.5	1500.9	980.6	548.3	562.5
ID Dipped	177.1	152.7	19210.4	8680.1	1277.7	1124.4	776.5	445.9
EDH Untreated	147.1	65.9	18251.4	28534.0	1312.3	1499.8	175.3	204.6
EDH Steamed	85.8	177.1	34126.4	22767.9	1706.0	1516.5	319.3	234.8
EDH Dipped	56.0	38.0	23798.5	21293.4	1526.9	1431.5	122.0	149.3
DD Untreated	16.3	22.2	24324.8	30475.3	702.0	1220.9	80.0	97.1
DD Steamed	59.4	59.4	26665.8	29296.3	857.7	1009.1	85.4	85.4
DD Dipped	100.2	51.5	10835.9	19484.3	993.0	1120.3	149.5	91.8

SUMMARY OF RAW DATA--THIAMIN--VEGETABLES
Values given are in mcg/100 g dry wt.

	Beans		Corn		Potatoes		Banana Squash		Sweet Potatoes	
	1	2	1	2	1	2	1	2	1	2
UD Untreated	104.4	82.4	94.4	85.8	213.6	162.5	181.8	126.5	54.6	48.5
UD Steamed	89.9	65.3	26.5	46.8	174.5	180.5	206.0	149.3	15.6	17.1
UD Dipped	64.2	63.9	62.6	100.0	24.5	21.2	127.2	71.8	4.8	4.8
MDD Untreated	56.3	59.1	60.8	63.3	190.8	224.9	107.9	107.9	51.7	65.3
MDD Steamed	76.7	74.7	7.5	18.6	174.1	146.0	57.1	81.3	35.1	28.8
MDD Dipped	42.7	42.7	27.3	24.7	24.2	18.2	39.6	39.6	5.0	5.0
ID Untreated	72.2	91.8	24.7	41.7	202.9	190.3	100.5	100.5	48.5	60.3
ID Steamed	91.9	76.5	62.3	67.8	173.3	227.3	114.3	95.9	27.7	30.7
ID Dipped	48.6	51.4	45.1	51.1	23.5	8.2	0.0	46.7	11.2	5.2
EDH Untreated	80.7	86.5	183.1	185.7	132.4	183.2	99.0	75.3	81.8	65.1
EDH Steamed	82.5	65.3	86.3	80.5	60.8	91.3	58.0	64.0	28.2	28.2
EDH Dipped	41.7	32.9	113.2	124.8	18.5	10.6	0.0	0.0	7.4	15.9
DD Untreated	87.2	90.1	146.0	146.0	209.8	164.0	113.6	101.4	52.5	65.3
DD Steamed	78.6	78.6	82.6	78.6	181.2	138.1	103.8	85.1	28.1	42.7
DD Dipped	55.4	12.1	120.2	88.1	28.7	23.0	84.6	90.3	16.2	22.7

SUMMARY OF RAW DATA--THIAMIN--FRUITS
Values given are in mcg/100 g dry wt.

	Grapes		Tomatoes		Bananas		Apples	
	1	2	1	2	1	2	1	2
UD Untreated	126.7	115.0	122.1	159.6	34.9	34.9	29.1	32.2
UD Steamed	149.1	121.8	357.6	235.3	26.5	41.1	45.5	24.9
UD Dipped	139.4	104.5	59.3	222.0	24.6	24.6	9.8	9.8
MDD Untreated	93.2	59.5	34.6	34.6	35.0	29.0	38.3	14.4
MDD Steamed	62.9	93.2	72.5	53.9	65.7	30.7	12.0	18.0
MDD Dipped	107.2	137.6	56.1	17.4	11.8	17.7	14.7	20.6
ID Untreated	138.1	121.8	45.6	113.7	27.0	27.0	30.2	27.3
ID Steamed	115.0	115.0	57.5	57.5	27.1	27.1	12.1	8.5
ID Dipped	113.1	90.3	25.2	11.6	15.2	8.6	14.8	11.9
EDH Untreated	109.2	98.2	24.7	24.7	16.7	19.6	17.5	26.4
EDH Steamed	106.5	172.9	30.3	92.9	17.1	22.7	26.6	17.7
EDH Dipped	107.7	66.5	24.0	29.8	17.2	8.0	11.7	11.7
DD Untreated	78.9	71.3	59.0	26.1	46.9	21.2	15.4	21.5
DD Steamed	92.7	110.9	30.7	43.1	24.2	18.2	18.5	8.6
DD Dipped	83.6	61.9	11.2	36.6	15.2	8.6	12.4	12.4

APPENDIX E

Moisture Content

Key to Dryers:

UD - Undried Control
MDD - Modified Direct Dryer
ID - Indirect Dryer
EDH - Electric Dehydrator
DD - Direct Dryer

MOISTURE CONTENT

	Beans	Corn	Grapes	Tomatoes	Bananas	Potatoes	Banana Squash	Apples	Sweet Potatoes
UD Untreated	88.20%	68.52%	87.91%	95.74%	79.60%	82.40%	94.50%	84.47%	67.02%
UD Steamed	89.19%	71.34%	88.57%	96.60%	78.90%	83.27%	94.64%	87.96%	67.86%
UD Dipped	88.98%	71.87%	89.67%	97.30%	83.84%	85.82%	96.10%	85.77%	70.90%
MDD Untreated	7.63%	6.84%	22.73%	13.38%	13.20%	17.06%	9.90%	13.87%	5.98%
MDD Steamed	9.55%	6.44%	22.76%	16.16%	13.08%	14.63%	12.44%	16.74%	13.34%
MDD Dipped	10.92%	8.33%	30.39%	19.48%	15.74%	17.42%	12.20%	15.67%	7.60%
ID Untreated	21.60%	8.43%	27.73%	23.64%	16.32%	16.43%	13.62%	17.16%	10.44%
ID Steamed	12.93%	9.19%	28.17%	21.42%	16.70%	15.96%	14.94%	17.46%	18.44%
ID Dipped	15.58%	10.02%	31.75%	20.78%	18.46%	14.78%	14.27%	16.27%	10.84%
EDH Untreated	7.53%	8.46%	29.15%	18.94%	11.08%	5.89%	12.32%	14.43%	5.66%
EDH Steamed	9.61%	7.34%	24.69%	18.18%	12.06%	6.90%	13.76%	15.17%	11.22%
EDH Dipped	8.79%	8.47%	23.33%	16.82%	12.66%	5.93%	12.84%	14.61%	5.64%
DD Untreated	11.25%	10.98%	28.52%	23.42%	18.08%	12.79%	14.40%	19.27%	21.84%
DD Steamed	12.21%	9.66%	27.70%	19.20%	17.40%	13.57%	16.36%	18.98%	28.84%
DD Dipped	16.98%	11.28%	26.35%	18.08%	18.16%	12.90%	15.82%	19.16%	23.22%

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SOLAR DRYING OF FOODS: EFFECTS OF DRYING AND TREATMENT METHOD ON VITAMIN RETENTION

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ABSTRACT

In light of the present emphasis on energy conservation and the world food problem, the use of solar energy in the drying of fruits and vegetables was studied. Five vegetables and four fruits were dried. Each food was dried using three solar methods and an electric dehydrator. All foods were treated before drying by steaming and by dipping in sodium bisulfite solution. After drying each sample was analyzed for ascorbic acid (vitamin C), beta-carotene (vitamin A), and thiamin (vitamin B_1).

It was found that the bisulfite treatment was useful in preserving the color of lighter colored foods subject to browning but it also destroyed the thiamin. Solar dryers which exposed the drying food to sunlight and high temperatures were less effective in preserving the nutrient value than dryers which protected the food from the light and maintained lower temperatures. Solar drying methods could be utilized in the developed and developing countries as economical and effective methods of preserving food.

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