SOME EFFECTS OF SULFURING ON TWO VARIETIES OF APPLES PRESERVED BY DEHYDRATION

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SULFURING AND DEHYDRATION OF APPLES

HAYDAR

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AN ABSTRACT OF THE THESIS OF

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Title: Some effects of sulfuring on two varieties of apples preserved by dehydration.

Apples are grown abundantly in Lebanon. The surplus apples could be dehydrated to reduce the burden of marketing them fresh. The main problem involved in the process is that of browning; both enzymatic and non-enzymatic. Previous studies showed that sulfur dioxide inhibits both types of browning and could be applied by dipping cut fruits in sulfurous acid salts, or more commonly by exposure to fumes of burning sulfur. Absorption and retention of SO_2 are affected by the length of time of sulfuring and concentration of the gas in the cabinet. However, little data are available on the process of sulfiting apples before dehydration.

In the present study, Starking and Golden Delicious apples were peeled, cored, sliced to ¼ inch thick slices and dipped in 1, 2, 3, 4, and 5 percent sodium metabisulfite (SMB) for 1 minute, or in 5 percent SMB for 1, 4, 7, and 10 minutes. SO_2 absorption was determined after dipping and SO_2 retention after drying. In addition, effects of sulfuring in 1 and 2 percent SMB with and without steam blanching for 1 minute on the rehydration ratio and degree of browning after dehydration and during storage were studied. The degree of browning was determined colorimetrically at 440 mu of alcoholic apple extracts, and by comparing the color of these extracts visually with reference color solutions. The catechol test was used for studying penetration of SO_2 through apple slices and effect of time of steam blanching on inactivation of polyphenolase enzymes in the slices.

The results of the present investigation showed that absorption and retention of SO_2 were increased almost linearly by increasing sulfite concentration. Increasing the time of dipping increased slightly SO_2 absorption but appreciably SO_2 retention. Blanching and or sulfuring at both 1 and 2 percent SMB increased the rehydration ratio of both apple varieties after drying and during storage, but blanching affected adversely the texture during rehydration. Starking apples showed slightly higher rehydration ratio than did Golden Delicious apples. Untreated and blanched apples turned brown to the same extent and became hardly acceptable after three months of storage. Sulfuring before dehydration decreased the rate of browning during storage particularly at the higher level. Blanching increased SO_2

content in dried apples and decreased its loss during storage. The visual method of measuring the degree of browning gave similar results to the colorimetric method but was less sensitive and less practical. Golden Delicious apples turned brown slightly less than Starking apples after dehydration and during storage. Prevention of enzymatic browning could be achieved by steam blanching for two minutes or by dipping in SMB solution for periods of time ranging between 7 minutes in 5 percent SMB and 25 minutes in 1 percent SMB.

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I. INTRODUCTION

Drying is one of man's oldest methods of food preservation. The sun drying of fruits was practiced during Biblical times by the Persians, Greeks, and Egyptians. It was not until the latter part of the nineteenth century, however, that attempts were first made to dry foods by using sources of heat other than the sun; such as the heat from fire. The great stimuli for the dehydration industry were the two World Wars during which rapid improvements in the methods and installations for food dehydration developed. Several new methods were then developed, such as drum drying, vacuum drying, and more recently freezdrying. Today the dehydration of foods has become a well established industry.

During preparation, processing, or storage many fruits tend to become darker in color and acquire a brownish appearance. This type of deterioration in color, which is referred to as the browning reaction, has long been recognized as one of the most important problems of fruit preservation. One type of browning reaction is known to be enzymatic in nature and occurs in freshly cut tissues that contain the active enzymes; the other type of reaction is non-enzymatic and can occur after inactivation of the enzymes. The darkening in the color of fruits that occurs during drying is due to the non enzymatic type of browning reactions. Different methods for preventing this darkening in color have been developed.

The most effective method of preventing browning is that of treating the fruits, prior to drying, with sulfur dioxide. This method is extensively used in fruit and vegetable dehydration because it inhibits both enzymatic and non enzymatic browning reactions, and also helps to protect carotene and ascorbic acid during dehydration and storage. Furthermore, sulfur dioxide treatment permits the use of higher drying temperatures, and at certain levels acts as a fumigant for insects control. Sulfur dioxide can be applied by burning sulfur, using solutions of sulfurous acid salts, or more recently by using liquid sulfur dioxide. The use of sulfite solution (sodium sulfite or metabisulfite) on cut vegetables before drying became a standard practice in the British Commonwealth countries and in the United States during World War II.

Fruit production ranks first in Lebanon's Agricultural production, and apples come next only to citrus in fruit production. More than 90 percent of the 104,000 tons of apples produced in 1966 was exported (Anonymous, 1967). Refrigeration and marketing of that amount present some problems, which may be overcome in part by the use of the method of dehydration. Like other food products, dehydration of apples reduces the cost of packaging, storage, and transportation. It is thought that during seasons of increased production and lower prices, such as the 1967 season, a large portion of the apples, particularly those of poor quality that would normally be sold fresh at very low prices, could be dried.

This study was carried out to investigate the best conditions for the process of sulfuring local varieties of apples using sulfite

solutions to prevent darkening in color during dehydration. Golden Delicious and Starking were the two varieties investigated because they constitute the major portion of apples grown in Lebanon. The effect of the time of dipping and concentration of sulfite solution on the absorption and retention of sulfur dioxide by the two varieties of apples to be preserved by dehydration was studied. Also the effect of different levels of SO_2, with and without steam blanching on non enzymatic browning of the two varieties during storage was investigated. The purpose of the present study then was first, to find the pattern of sulfur dioxide absorption and retention during the dehydration of apples, and second to find out which treatment or combination of treatments give a better quality of dehydrated apples. It was also intended to find out whether any differences could be observed between the two apple varieties due to these treatments.

II. REVIEW OF LITERATURE

Various developments in the technology of dehydration of apples resulted in a considerable amount of literature. This review will include primarily references concerned with the browning phenomenon in dehydrating apples and the sulfuring treatments associated with it.

General Aspects of Dehydration of Apples

Saxena et al. (1956) have stated that apples for dehydration are selected with respect to variety, size and maturity. Varieties that are firm in texture and yield a dried product of white color are preferable. Gravenstein, Yellow Newton Pippin, Winesap and Jonathan are among the varieties used for drying in the United States. Gravenstein has been reported by Cruess (1958, p. 602) to be one of the best of the early varieties for drying purposes. Other suitable varieties are Winterlemons and Jacops in Germany, and lal-Amri and Golden-Delicious in India (Saxena et al. 1956). A high sugar to water ratio is desirable because of the increased yields obtained. Regularity of shape and characteristic size of the fruit are also important in mechanical peeling (Smock and Neubert, 1950, p. 279). According to Von Loesecke (1955, p. 35) apples smaller than 2¼ inch in diameter are uneconomical to use because wastage will be greater and handling will increase per unit weight. Apples should be ripe, and

sometimes cured for proper maturity, for removing chlorophyll and for giving a uniformly dried product (Rechert, 1953).

Apples should be carefully sorted and thoroughly washed before peeling. If the peels and cores are to be utilized for vinegar production, stock feed or other purposes, the apples must be washed in warm dilute hydrochloric acid solution (1.5 to 3 percent) and rinsed to remove residual traces of insecticides (Cruess, 1958,p.602). The apples are then peeled and cored by a machine operated by hand or motor. Other methods like hot lye peeling in 2 percent sodium hydroxide or steam peeling have been used satisfactorily (Kassab, 1949). The whole peeled apples are trimmed, sliced into rings ¼ to ½ inch thick or diced in ¼ inch cubes or quartered, and sulfured to prevent subsequent browning during dehydration and storage (Von Loesecke, 1955, p. 37; Cruess, 1958, p. 603). The slices could be kept firm in texture if dipped in 0.1 to 1.0 percent solution of calcium chloride alone (Anonymous, 1946), or in combination with sodium acetate (Atkinson and Strachan, 1942; Woodruff and Cecil, 1945).

Apples are dried sometimes in an air-blast tunnel dehydrator, or more commonly in a kiln equipped with a fan to increase air flow and shorten drying time (Brekke and Nury, 1964, p. 484). Drum driers, spray driers and more recently vacuum driers are also used for producing apple powders or nuggets (Saxena et al. 1956). The trays are loaded at the rate of 2 pounds per square foot and the temperature in the drier ranges between 145°F at the hot end and 165°F at the cool end; or between 165°F and 180°F in a two stage dehydrator (Brekke and Nury, 1964, p. 485). Relative humidity of about 60 percent at the

exhaust end of the drier, air velocity of 600 to 800 linear ft. per minute, and a recirculation ratio of 50 to 75 percent are satisfactory in tunnel dehydratores (Saxena et al. 1956).

The yield in drying apples varies with variety and size of the apples, and is about 1/7 of the fresh weight of the fruit (Cruess, 1958, p. 604). The drying time is about eight hours, and the final moisture content should not exceed 24 percent during marketing, according to the federal regulations in the United States (Brekke and Nury, 1964, p. 485). Apples are generally dried to about 18 to 20 percent moisture in the drier, and later hydrated to the desired moisture level and resulfured to obtain 2500 to 3000 ppm SO_2 prior to final packaging (Cruess, 1958, pp. 604-605). The dried product is packed in paper cartons with lining of pliophilm, polyethylene bags, cellophane bags, and tin containers (Saxena et al. 1956).

Enzymatic and Non Enzymatic Browning

Browning of food products is normally an undesirable feature. With the exception of few cases such as the brown color of beer, bread crust, coffee, potato chips and few others, browning is considered as a distinct sign of deterioration in the flavor and the nutritional value of the food (Braverman, 1963, p. 302). Numerous investigations were undertaken to elucidate the chemical changes involved in browning and hence to develop methods of controlling it. Two types of browning reactions occur; some are enzyme-catalyzed and some occur non-enzymatically. Enzyme-catalyzed browning reactions have been

reviewed by Joslyn and Ponting, 1951; and non-enzymatic browning reactions were reviewed by Stadtman (1948) and Reynolds (1963, 1965).

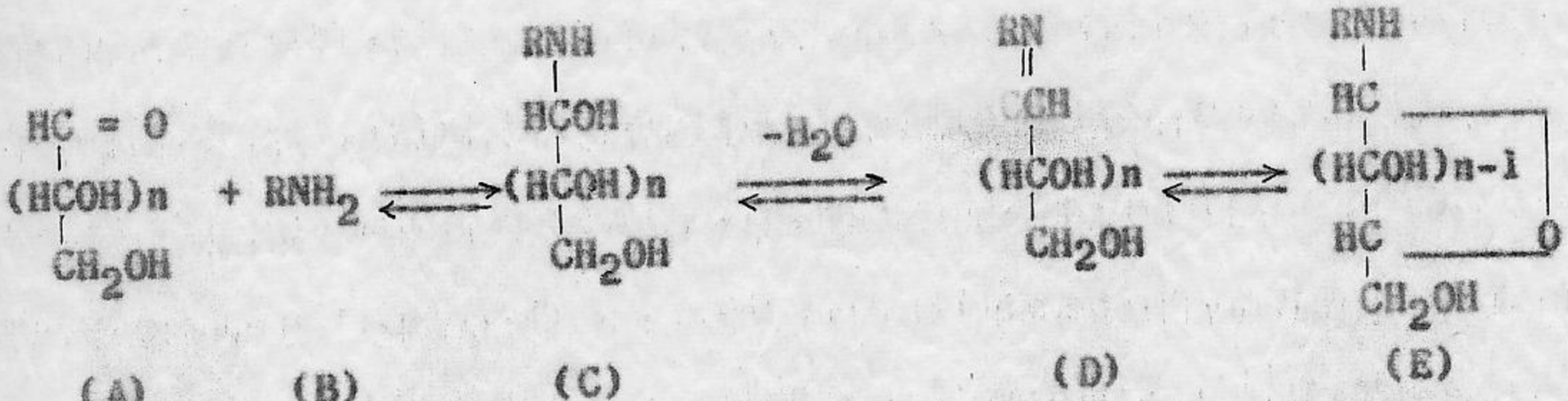
Enzyme-catalyzed oxidative browning has been known for a long time (Kastle, 1910), and its first recognition is probably ascribed to Lindent in 1895 (Braverman, 1963, p. 294). Onslow during the 1920's made a systematic investigation of non-enzymatic browning in many fruits and divided them into two groups: those that brown readily, such as apples, apricots, and bananas, containing catechol substances and the appropriate enzymes, oxygenases; and those that do not brown readily, such as citrus fruits, lacking oxygenases and catechol compounds (Onslow, 1920). Later studies have shown that the enzymes peroxidase and catalase are always present in both groups of fruits, while the oxygenases are absent in the latter group. Furthermore, it has been found that the group of polyphenolase enzymes are responsible for enzymatic browning, and that the group of peroxidases, catalases, and cytochrome oxidases do not take part in it (Braverman, 1963, pp. 294-296).

The course of reactions involved in enzymatic browning is not fully elucidated, but it is agreed upon that the mechanism involves initial enzymatic oxidation of the O-benzene derivatives and final polymerization into colored compounds (Joslyn and Ponting, 1951, p.22). The control of enzymatic browning is based on inhibition of the enzymes, removal of oxygen, and to a limited extent obtaining a fruit through breeding that will contain less of the substrate or enzyme (Ponting, 1960, pp. 105-106). Steam blanching to inactivate the enzymes followed by a relatively short sulfuring treatment gave

satisfactory results (Cruess, 1943). Many chemicals such as citric acid, thiourea, glutathione, and cysteine have been found effective in the control of enzymatic browning, but among all of them sulfur dioxide is the most widely used and the most effective (Saxena et al. 1956; Ponting, 1960, p. 110).

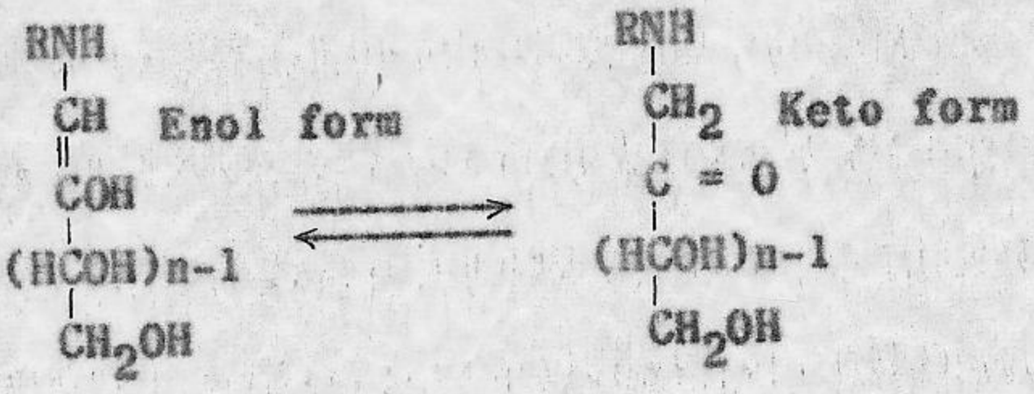
Although the chemistry of non enzymatic browning has been the subject of numerous investigations, the reactions involved are not well understood and many important aspects remain to be elucidated (Meyer, 1960, pp. 110-111; Reynolds, 1965, pp. 266-268). Three theories have been introduced to illustrate non enzymatic browning in food products, namely a) the Maillard reaction, b) the ascorbic acid theory, and c) the active aldehyde theory (Stadtman, 1948, p. 327; Braverman, 1963, pp. 302-308). It has been suggested that browning of citrus juices is caused by the ascorbic acid decomposition (Moore et al., 1942). In the caramelization of sugars the active aldehyde theory applies suitably (Braverman, 1963, p. 306). However, browning of dried fruits is mainly due to the reaction between amino acids and reducing sugars or the Maillard reaction (Reynolds, 1965, p. 256).

In the Maillard reaction carbohydrates having a free carbonyl group (A) combine with amino acid (B) to form an addition product (C), then Schiff's base (D), then an N-substituted glycosylamine (E) which undergoes Amadori rearrangement forming N-substituted 1-amino -1-deoxy-2-ketose (F) (Braverman, 1963, p. 303) as shown below:



(A) (B) (C) (D) (E)

Amadori Rearrangement

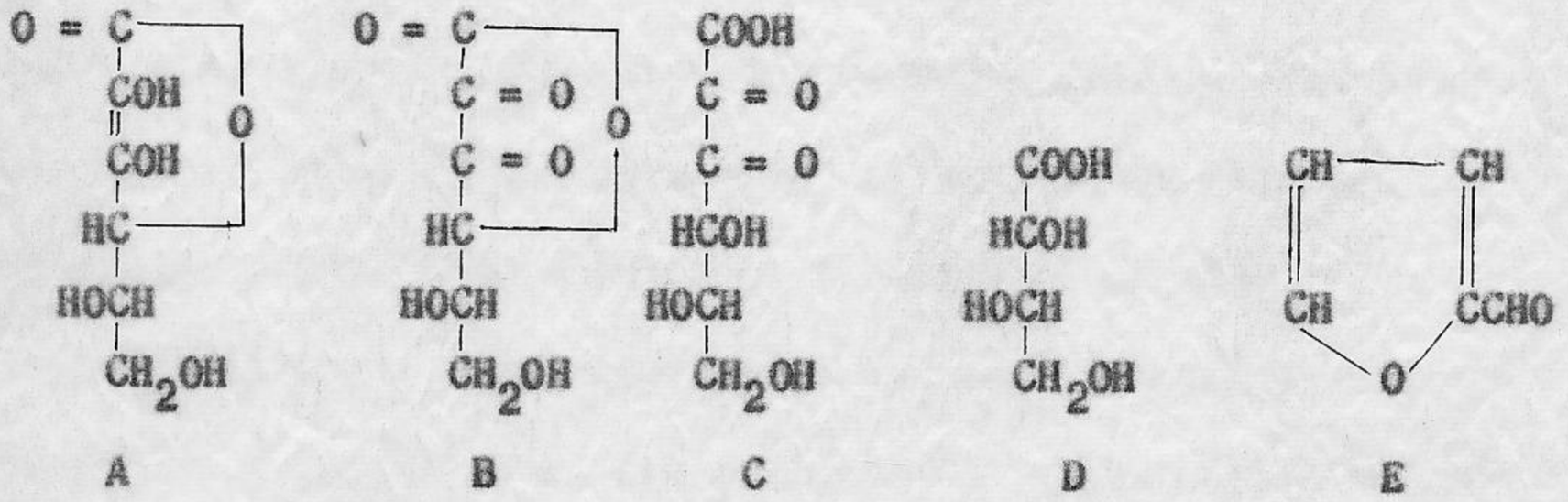


(F)

Different mechanisms have been introduced to explain the rearrangement (Reynolds, 1965, pp. 175-176). The product of the Amadori rearrangement can then undergo a number of fates depending on the conditions of the reaction. It can, in neutral or acid media, lose water and form a ring compound of the Schiff's base of hydroxy methyl furfural or furfural, and then eliminate the amine to form the free hydroxy methyl furfural, or furfural. In the dry state it can form reductones , or it can break down into smaller molecules such as acetol, pyruvaldehyde, diacetyl and other carbonyl compounds, all of which can react with amines to form aldimines or ketimines; or polymerize to aldose and similar large molecules which subsequently react with amines and form the final brown pigments called melanoidines, (Hodge, 1953; Meyer, 1960, pp. 110-111).

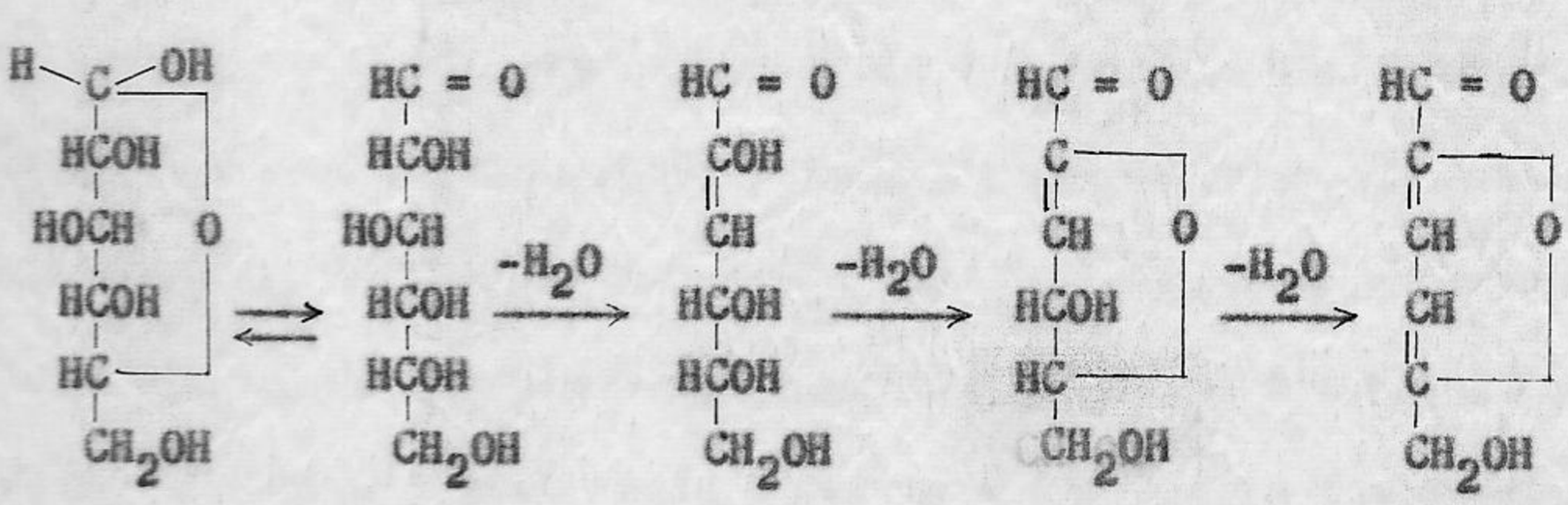
The decomposition of ascorbic acid, under aerobic or anaerobic conditions, leads to the formation of brown pigments. Among the

degradation products of L-ascorbic acid (A) shown below are dehydro-L-ascorbic acid (B), 2,3-diketo-L-gulonic acid (C), L-thereonic acid (D) and furfural (E), Reynolds, 1965, pp. 232-234).



A B C D E

The active aldehyde theory postulates that browning involves the decomposition of sugars and sugar acids to furfuraldhydes or similar compounds characterized by having an active carbonyl group, and that these products condense with nitrogen and/or polymerise to form brown, resinous materials (Stadtman, 1948, p. 327). Wolfrom et al. (1948) offered a scheme implying the dehydration of sugars and the formation of hydroxymethyl furfural (A) during the caramelization phenomena, as shown below:



(A)

The extent of browning in foods has been evaluated in the early studies by the visual inspection of the fruit, the color grades being

determined by comparing the experimental samples with a series of standard color samples which were arbitrarily assigned numerical rating (Nichols and Reed, 1931; Nichols et al. 1938). The color of dried apples, cranberries, and vegetables has been evaluated by use of Munsell color disks (Continental Can Company, 1944a). The results were reported in terms of the percentage of each color required to match the color of the sample tested. The optical density (absorbance) method has been widely used by many investigators for the measurement of browning in dried fruits and vegetables. The extraction of brown pigments with 50 percent alcohol has been satisfactory (Stadtman, 1948; Nury and Brekke, 1963). Other concentrations of alcohol such as 70 percent (Bhatia and Amin, 1962) and 55 percent (Hendel et al. 1950) have been used. Stadtman et al. (1946a) reported that using alcohol weaker than 40 percent gave turbid extracts of apricots, and that alcohol stronger than 60 percent gave variations in color intensity. The time of extraction ranged from one hour (Hendel et al. 1950) to 24 hours (Stadtman et al. 1946a). Nury and Brekke (1963) found that the equilibrium during the extraction of brown pigments occurred after about ten hours. The different wavelengths used in the measurement of the brown pigments were 390 mu (Hendel et al. 1950), 420 mu (Hendel et al. 1950; Bhatia and Amin, 1962), and 440 mu (Stadtman et al. 1946a; Nury and Brekke, 1963); the latter has been reported to be a suitable wavelength for measuring brown pigments in general (Mescher, 1954).

Stadtman et al. (1946a) stated that the optical density as an index to browning does not give consistent values with the visual

appearance of the fruit, unless all fruits tested have the same initial SO_2 content and the same history with respect to SO_2 treatment. Stadtman et al. (1946a) developed a method, involving visual comparison of 50 percent alcoholic extracts of dried fruit with standard reference solutions under standard conditions. Hendel et al. (1950) reported that only slight effects on the optical density of the brown pigments were due to the differences in SO_2 content of the dried vegetables.

Drying conditions, especially at high temperature and for long drying time, are known to increase the rate of browning (Van Arsdel, 1964, p. 9). Schrader et al. (1943) found that high temperature and or high humidity during drying of apples increased the degree of browning during both drying and storage. Lowering the final moisture content of dried apples was found by Thompson and Schrader (1949) to be the most important factor in prolonging shelf life and decreasing the rate of browning.

Storage conditions; namely, temperature, humidity, and availability of oxygen, affect the rate of browning during storage. It is generally accepted that increase in temperature during storage hastens the appearance of browning in foods and food products (Meyer, 1960, p. 259). Apple nuggets containing 0.8 percent moisture became appreciably darker after 2 months' storage at 130°F; significantly changed in color after 6 months' storage at 98°F; but only a small change was observed after 12 months at 75° to 80°F (Continental Can Company, 1944a; Heberline and Clifcorn, 1944). Dried apples stored well for 12 months at 50°F (Barger, 1941) while at 77°F they could not

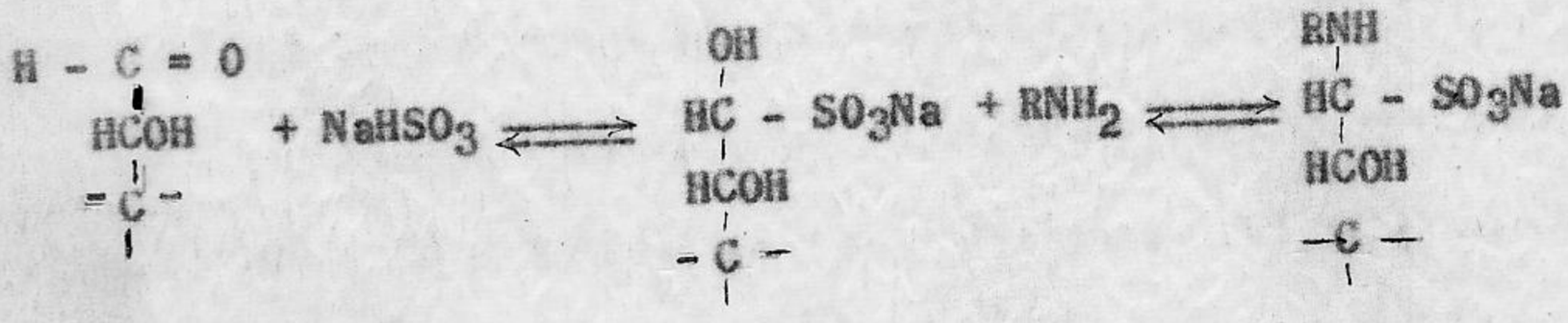
be stored for more than 4 months (Edit, 1938). High humidity during storage increased non enzymatic browning in some dehydrated tropical fruits (Bhatia and Amine, 1962). Dried apples stored at 25°C and 0 percent humidity remained in good condition for over three years at which time they contained 0.4 to 0.7 percent moisture (Culpepper and Caldwell, 1927). The presence of oxygen was found to increase the rate of non enzymatic browning in dried apples (Nichols and Reed, 1931; Continental Can Company, 1944a, 1944b; Thompson and Schrader, 1949), and a minimum of air in the package contributed to the shelf life of the product.

The procedures available to the food technologist for the inhibition of non enzymatic browning in foods include control of moisture content of the product, control of temperature of storage, removal of active constituents in the foodstuff, and sulfuring (Reynolds, 1965, p. 245). Sulfur dioxide is widely used commercially, and compared to the other inhibitors seems to be the most effective one (Stadtman, 1948, p. 360; Gehman and Osman, 1954, p. 87; Saxena et al. 1956). Early studies suggested that SO_2 content of fruits above a certain level stops the darkening of dried fruits (Morgan et al. 1931; Nichols and Reed, 1931; Hamburger and Joslyn, 1941). Later it was shown that sulfur dioxide does not stop browning but retards it (Stadtman, 1948; Legault et al. 1951).

The factors affecting browning and loss of sulfite in stored dehydrated fruits and vegetables have been investigated extensively. The browning curves for dried sulfited apricots (Stadtman et al. 1946a, 1946b) and vegetables (Leagault et al. 1947, 1951; Hendel et al. 1955)

showed an initial lag, or induction period followed by rapid, almost linear, rise; increasing the sulfite content prolonged the lag period, but had little effect on the subsequent rate of browning. The rates of browning and of sulfite disappearance were affected by the presence of oxygen, and almost to the same extent by the temperature of storage and the moisture content of the dried fruit and vegetable (Legault et al. 1949, 1951; Stadtman et al. 1946a, 1946b).

Sulfites inhibit browning by blocking the functional carbonyl group of sugars and preventing their combination with the amino compounds, (Stadtman, 1948, p. 363; Gehman and Osman , 1954, p. 55; Braverman, 1963, p. 303) thus forming a sulfite addition product as shown in the reactions below:



Consequently further formation of the Schiff's base is hindered.

The antioxidant action of SO_2 has also been considered to contribute to its inhibitory effect on the formation of melanoidins (Humberger and Joslyn, 1941; Stadtman, 1948, p. 363; Hodge, 1953). Ingles (1959a,b) proposed that under some conditions bisulfite oxidized reducing sugars with the liberation of elementary sulfur. Song and Chichester (1967a, b) examined the previous mechanisms and found them to be unsatisfactory from the kinetic point of view in illustrating the inhibition of the Maillard reaction by bisulfites. They proposed

a general mechanism of inhibition of the Maillard reaction by free radicals or equally reactive species derived from original inhibitor molecules. The mechanism involved attack by such free radicals on chromopheric intermediates and melanoidine precursors.

Sulfuring Prior to Dehydration

All cut fruits except persimons are sulfured before drying to retain their high quality, and especially a light color. The most widely employed procedure involves exposing the cut fruit on trays to fumes of burning sulfur in a closed and tightly sealed cabinet (Mrak and Phaff, 1947). The amount of sulfur used, the time of exposure, and the level of SO_2 desired vary depending upon the type of fruit, its moisture content, pretreatment such as lye dipping or water dipping, and limitations set on the final SO_2 content (Brekke and Nury, 1964, pp. 482-483). The treatment with sulfite solutions (sulfites or metabisulfites) prior to dehydration, often called sulfiting, has been practiced for over 20 years on many foods such as apples, snap beens, cabbage, carrots, potatoes and sweet potatoes. In the United Kingdom, where blanching by immersion in hot water is popular, it was found convenient to "sulfur" by adding sulfite salts to the blanching bath (Lazar and Rasmussen, 1964, p. 205). Mackinney *et al*. (1943) favored sulfiting of vegetables, after the regular steam blanching, as brief dips not to exceed 15 seconds in duration.

Apples are frequently sulfured in continuous sulfuring tunnels containing fumes of burning sulfur or by submersion in a bisulfite bath (Mrak and Phaff, 1947). In sulfuring which is more widely used,

the slices are exposed to the burning sulfur for about 30 to 40 minutes (Cruess, 1958, p. 603). About 7 pounds of sulfur per ton of fruit is sufficient (Von Loesceke, 1955, p. 38). The addition of 3 percent sodium nitrate (Orton, 1946) or very little amounts of oil (Bisson et al. 1942) greatly improves the burning quality of sulfur. Some investigators (Cruess, 1958, p. 603; Walker et al., 1955) recommend immersing the cut fruit in dilute 1 to 2 percent brine until they are ready for sulfuring.

For sulfite dipping of apples, whole, halved or sliced fruits are dipped in an aqueous solution of one to two percent bisulfite (Brekke and Nury, 1964, p. 484). The method has been considered impractical by Mrak and Phaff (1947) because of the poor penetration and leaching of sugars during dipping. The sulfiting process is used satisfactorily for apples to be preserved by freezing (Tressler and Evers, 1957, p. 520) and dehydrofreezing (Walker et al. 1955). Although sulfurous acid solutions penetrate the apple slices much more rapidly than do sulfites, the latter are preferred because of their less offensive odor in the frozen apples (Tressler and Evers, 1957, p. 520).

Absorption and Retention of Sulfur Dioxide

Both absorption and retention of SO_2 were found to increase, but not proportionally, by increasing time of sulfuring (Fisher et al. 1942, McBean et al. 1964, 1965). Increasing the gas concentration increased also absorption (Fisher et al. 1942; McBean et al. 1964), but contradictory results were reported concerning retention (Chace

et al., 1930; Fisher et al., 1942; McBean et al., 1965). The "gas environment value" introduced by Long et al. (1940) as the sulfuring time in minutes multiplied by the mean gas concentration during the process, has been found by McBean et al. (1965) to be of doubtful utility owing to the difficulty of measuring the mean gas concentration.

Fruit characteristics affect SO_2 absorption and retention. The latter is affected by the kind of fruit (Long et al., 1940; Bhatia et al., 1962). For example, apricots had the fastest absorption and the least retention while pears showed opposite results (McBean et al. 1964, 1965). Variety of the fruit was found to affect absorption and retention markedly (Bhatia et al. 1962) or slightly (Long et al. 1940; McBean et al. 1965). Immature fruits absorb SO_2 rapidly but retain it poorly (Mrak and Phaff, 1947). Irrigation was found to increase both absorption and retention, and the presence of skin had opposite effects (McBean et al. 1964, 1965).

High drying temperature or high relative humidity decreased SO_2 retention which suggested an association between SO_2 retention and water removal. The effect of air velocity was insignificant (McBean et al. 1965). Some investigators (Chace et al. 1930; McBean et al. 1964, 1965) reported slight effect of temperature during sulfuring on absorption and retention while others (Fisher et al. 1942; Mrak and Phaff, 1947) emphasized its effect.

Blanching before sulfuring was found by Nichols and Christie (1930) and by Chace et al. (1933) not to affect SO_2 absorption or retention, but McBean et al. (1965) commented on their results that although the final content of SO_2 was not affected, absorption decreased

and retention increased due to this treatment. Mrak and Phaff (1947) recommended cooling blanched fruits before sulfuring to avoid the poor absorption if sulfured hot. Blanching after sulfuring increased appreciably the retention of SO_2 in apricots (Chace et al. 1933) but only slightly in peaches and pears (McBean et al. 1965).

Little data, however, are available about the absorption and retention of SO_2 using the sulfiting procedure. Walker et al. (1955) found that a direct mathematical relationship existed between the time of dipping, the concentration of SO_2 in sulfiting solutions and the absorption of SO_2 by the apple slices. The relationship was given in two equations; one applies for constant time of dipping and different concentrations of SO_2; the other applies for constant SO_2 concentration and different times of dipping. The equations were:

$C_1 = C_o (N_s)^{3.32 \text{ Log } 10 (S_1/S_o)}$ For constant time,

$C_1 = C_o (N_t)^{3.32 \text{ Log } 10 (t_1/t_o)}$ For constant concentration,

Where

C_1 = Level of SO_2 in slices resulting from an increase in time of dipping or in SO_2 concentration (ppm).
C_o = Level of SO_2 in slices resulting from the original treatment (ppm).
S_o = Original concentration of SO_2 in the tank (ppm).
S_1 = Proposed higher concentration of SO_2 in the tank (ppm).
t_o = Original time of treatment (min.).
t_1 = Proposed longer time of treatment (min.).
N_s = Increment of concentration in slices due to increase in solution concentration $(C_1-C_o)/C_o$.
N_t = Increment of concentration in slices due to increase in time of treatment $(C_1-C_o)/C_o$.

Experimental values of N_s ranged from 2.0 to 2.2 and those of N_t from 1.4 to 1.5.

Several investigators (Von Loesecke, 1955, p. 53; Bhatia et al. 1962) using the sulfiting procedure, obtained unsatisfactory absorption

of SO_2 by bananas. Inefficient retention in case of papaya and fairly good retention associated with adverse effects on the texture of pineapple were reported by Bhatia et al. (1962). Walker et al. (1955) and Talburt et al. (1950) recommended acidification of the sulfite solution with citric acid or hydrochloric acid in order to increase the penetration of SO_2 through apple slices. The first authors found that the penetration was inversely proportional to the pH of the sulfite solution. Unlike pH, the temperature of the dipping bath was found uncritical within the temperature range used in normal operation 60 to 90°F (Talburt et al. 1950).

Mackinney et al. (1943) found great differences in SO_2 absorption between carrots and cabbages and interpreted them to be less due to variation in the vegetable than to the nature of the pieces and the draining of surplus solution. Talburt et al. (1950) observed great differences in the permeability of SO_2 between different varieties of apples. Immaturity of apples was found to lessen the rate of penetration while ripening hastened it.

Walker et al. (1955) found that for the elimination of browning in dehydrofrozen apples, a smaller increase, percentagewise in the sulfite concentration was more beneficial than in that of dipping time. They studied the effect of solids build up in the sulfite tank and found that penetration of SO_2 through apple slices became slower, but neither the absorption nor the retention were affected. In the extreme case where the concentration of solids in the dip approached that in the apple itself, a compensatory increase of about 30 percent in SO_2 concentration in the tank was required.

Talburt et al. (1950) recommended the use of SO_2 concentrations less than 0.6 percent in order to avoid excessive losses of SO_2 from the solution and noxious fumes around the bath.

High relative humidities and high wet bulb temperature during drying decreased the penetration but increased the retention of SO_2 in dehydrofrozen apples (Talburt et al. 1950). Walker et al. (1955) found rapid SO_2 loss (about 50 percent in 5 min.) at the beginning of drying and the loss was not affected by the relative humidity used. The greatest loss of SO_2 in sulfured banana occurred during the first three hours of dehydration, and was explained to be due to the fast removal of the loosely held SO_2 from the surface of the fruit, and to the increase of SO_2 fixation as drying proceeded (Bhatia et al. 1962). McWeeny et al. (1964) found that the decrease in measurable SO_2 during hot-air dehydration of sulfited potato strips was predominantly accounted for by the chemical reaction of the bisulfite rather than its physical removal as a volatile sulfur compound.

Laboratory studies on leaching losses during the processing of apples showed that losses may range from a minimum of about 5 percent of total sugars present for an immersion time as short as one minute, to a maximum of about 50 percent for a 24 hour soaking period (Myln and Seegmiller, 1950). One minute dipping of sliced apples in a 0.25 percent of SO_2 has been recommended by the Western Utilization Research Branch (Tressler and Evers, 1957, p. 520) to be used before freezing. Tressler and Evers (1957, p. 520) stated that weaker solutions such as 0.05 percent SO_2 may be used but the length of immersion should be increased to 10 minutes accordingly. Amin and Bhatia (1962) found

that sulfiting compared with sulfuring caused more destruction of ascorbic acid because of the leaching losses during sulfiting, however, the sulfiting time was very long (30 minutes).

III. MATERIALS AND METHODS

Preparation and dehydration of apples: The apples used in this study were obtained from the market in Beirut. Two local varieties were used; namely, Golden Delicious (G) and Starking (S). The apples were thoroughly washed in tap water, mechanically cored and sliced to ¼ inch thick slices, and dipped in one percent sodium chloride solution to prevent immediate enzymatic browning. Then different batches of each of the varieties received the proposed treatments which included steam blanching and dipping in different concentrations of sodium metabisulfite (SMB) for different periods of time. Treated slices were then loaded in single layers on aluminium foil paper, placed on trays and dried in a forced-draft oven[1] at 175 ± 5°F during the first four hours, then at 155 ± 5°F until the moisture level reached 10 to 20 percent. The dried slices were rehydrated to 21 to 22 percent moisture content by spraying with distilled water, and were left for two days until the distribution of their moisture became equilibrated.

Absorption and retention of sulfur dioxide: Sulfur dioxide absorption was determined in apple slices after the sulfite treatment, and SO_2 retention was determined after drying. Both absorption and retention were expressed in parts per million. The retention ratio was calculated as follows:

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[1] Hotpack., Phila., Pa., U.S.A.

$$\frac{SO_2 \text{ retained, ppm (dry basis)}}{SO_2 \text{ absorbed, ppm (dry basis)}} \times 100.$$

Absorption and retention were determined in apple slices dipped in 1, 2, 3, 4 and 5 percent SMB for one minute and in slices dipped in 5 percent SMB for 1, 4, 7 and 10 minutes.

Sulfur dioxide content was determined by the Munier Williams method (Horwitz, 1960, p. 400) in which SO_2 is liberated by distilling the sample for 1½ hours in a dilute hydrochloric acid solution. The sulfurous acid produced is carried into a 3 percent neutral hydrogen peroxide solution by a current of carbon dioxide. The sulfuric acid formed now is titrated with a standard solution of 0.1N NaOH, and the level of SO_2 is calculated accordingly.

Treatments of apples to be tested during storage: Six batches (5 kg each) of each of the two apple varieties used were given the following treatments:

Batch No.	Treatment
S_1 & G_1	Untreated (control).
S_2 & G_2	Dipped in one percent SMB for one minute.
S_3 & G_3	Dipped in two percent SMB for one minute.
S_4 & G_4	Blanched for one minute.
S_5 & G_5	Blanched for one minute then dipped in one percent SMB for one minute.
S_6 & G_6	Blanched for one minute then dipped in two percent SMB for one minute.

The dried apples of each batch were packed separately in cellophane bags, stored at room temperature and tested at one month intervals for sulfur dioxide level, degree of browning and rehydration

ratio.

Measurement of browning: The degree of browning was determined by two methods:

1. The method of Nury and Brekke (1963): In this method the brown pigments in 2 grams of ground dried sample were extracted with 70 ml of 50 percent alcohol by shaking gently for 16 hours, which was found in this investigation to be a satisfactory time as shown in Figure 1. The extract was diluted to 100 ml and filtered through No. 1 Whatman filter paper. The absorbance of the filtrate was measured at 440 mu using a spectrophotometer (Beckman Model DU) and was considered an indication of the extent of browning in the sample.

2. The method of Stadtman et al. (1946a) was used in order to obtain a browning index that is consistent with the visual appearance of the fruit. In this method a standard color solution was prepared which represented the color of an extract of dried apples at "the limit of edibility"; that is brown apples that are barely acceptable to the average person. The following salt solutions were used in the preparation of the standard color solution: Solution A: 50 g of cobaltus sulfate diluted to one litre with 4 percent sulfuric acid. Solution B: 2.5 g of potassium dichromate diluted to 250 ml with 4 percent sulfuric acid. Solution C: 25 g of cupric sulfate ($CuSO_4.5H_2O$) diluted to 250 ml with 4 percent sulfuric acid.

The standard color solution was prepared by mixing 8 ml of A, 2.5 ml of B, 0.4 ml of C and 425 ml of 4 percent H_2SO_4. The browning index of this solution was arbitrarily chosen to be unity.

A reference color solution was prepared as follows: 25 g of

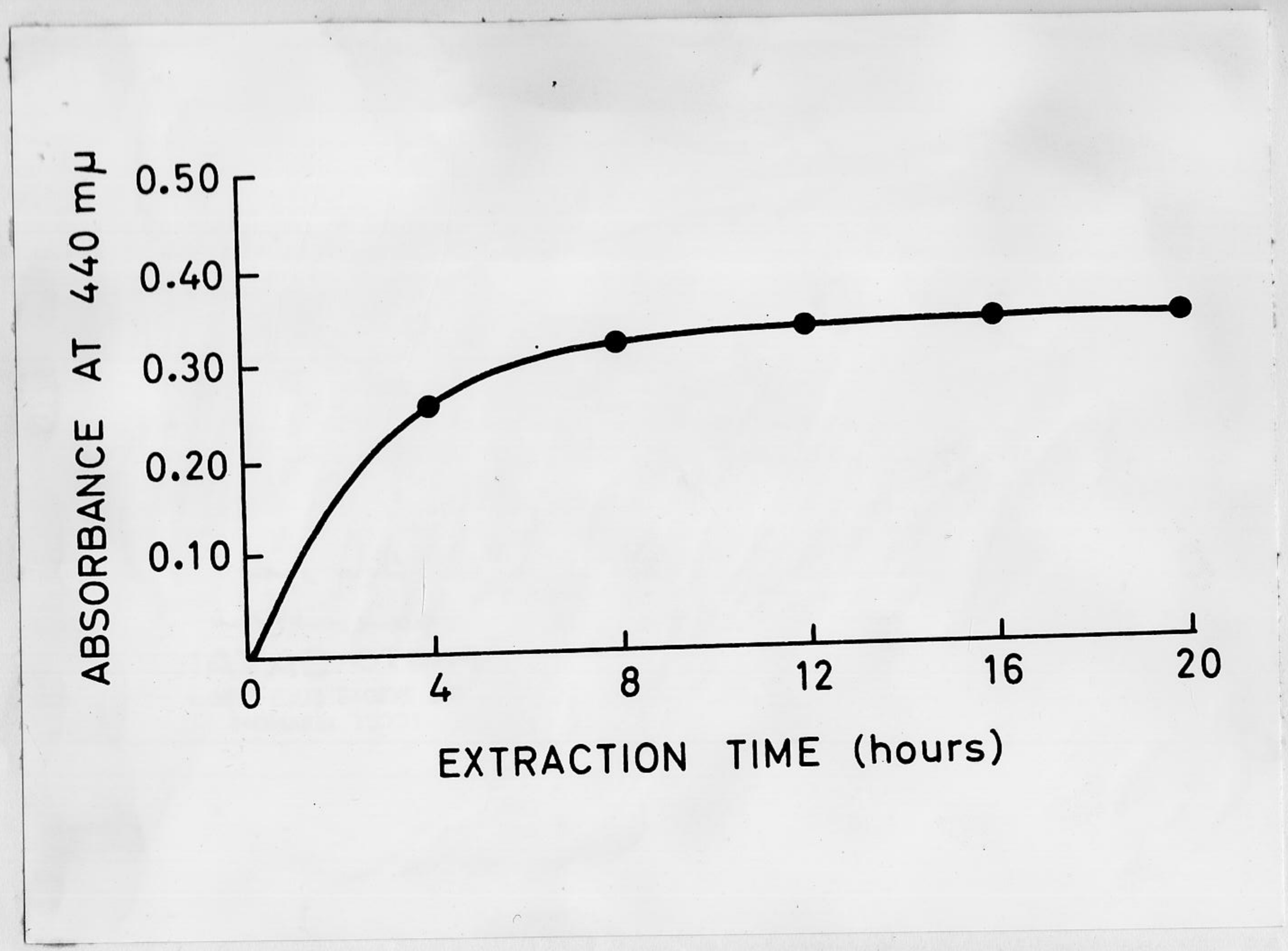

Figure 1. Effect of time of extraction on absorbance of alcohol extract of dried apples.

dark brown apples were extracted with 250 ml of 50 percent alcohol by shaking gently for 16 hours. Part of the filtrate was diluted with 50 percent alcohol until a color was obtained which matched the standard color solution when compared at standard conditions to be mentioned later. This reference color solution was assigned a numerical value of unity. Other reference solutions were prepared by suitable dilution of the alcoholic extract.

Determination of browning index: Approximately 15 ml of the clear extract as obtained in the method of Nury and Brekke (1963) were placed in a small glass vial (8 X 2 cm inside diameter). The depth of the solution was adjusted to exactly 4 cm, and the browning index was determined by visual comparison with the reference solutions. In making the comparisons, a white background was installed and the vials were viewed from the top, looking down through the solutions. The only light source was a 500 Watt bulb suspended about four feet above the table on which the comparisons were made.

Determination of rehydration ratio: The rehydration ratio was determined according to the method suggested by Utilization Research of the U.S. Department of Agriculture (Anonymous, 1944). Ten gram samples of the dry apple slices were placed in 600 ml beakers, and 100 ml of distilled water were added to each. The beaker was covered with a watch glass, placed on an electric hot plate, and the contents were brought to a boil within three minutes, and then boiled for five minutes. The boiled mixtures were filtered in Büchner funnels using Whatman No. 1 filter paper. Tap-water suction was applied for one minute during which the drip from the funnels almost stopped. The

dehydrated slices were then removed from the funnels, and weighed immediately. The test was repeated and the rehydration ratio was expressed as follows:

$$\frac{\text{Drained weight of the rehydrated sample}}{\text{Weight of dehydrated sample used}}$$

Determination of moisture: Moisture was determined according to the A.O.A.C. method (Horwitz, 1960, p. 264) with minor modifications. Samples were dried at 70 ± 1°C under high vacuum for 12 hours. A stream of air, dried by passing over concentrated sulfuric acid, was introduced into the vacuum oven at the rate of 2 bubbles per second.

Measurement of enzymatic browning by catechol test: The penetration of sulfur dioxide through apple slices of the two varieties was tested according to Ponting (1944) by spreading immediately one percent solution of catechol on the exposed surface of slices that have been cut in cross section. The black zones formed after few minutes showed the location where the SO_2 did not reach. Thus a minimum time of dipping apple slices in SMB solutions could be measured when the black zone did not appear any more in the cross section of the slice.

1	696	811
2	1463	1685
3	2228	2191
4	3105	3408
5	3596	3817

x Average of two determinations.

IV. RESULTS AND DISCUSSION

Absorption and Retention of Sulfur Dioxide

This experiment was conducted to study the effect of time of dipping and concentration of the sulfite solution on sulfur dioxide absorption and retention by the two apple varieties. The relationship between concentration of the sulfite solution and SO_2 absorption is shown in Table 1 and is reproduced in Figure 2.

Table 1. Effect of concentration of sulfite solution on SO_2 absorption by the two apple varieties; (time of dipping: 1 minute).

Concentration of $Na_2S_2O_5$ (percent)	SO_2 absorption (ppm)[x]	
	Starking	Golden Delicious
1	696	811
2	1463	1685
3	2228	2191
4	3105	3408
5	3598	3817

x Average of two determinations.

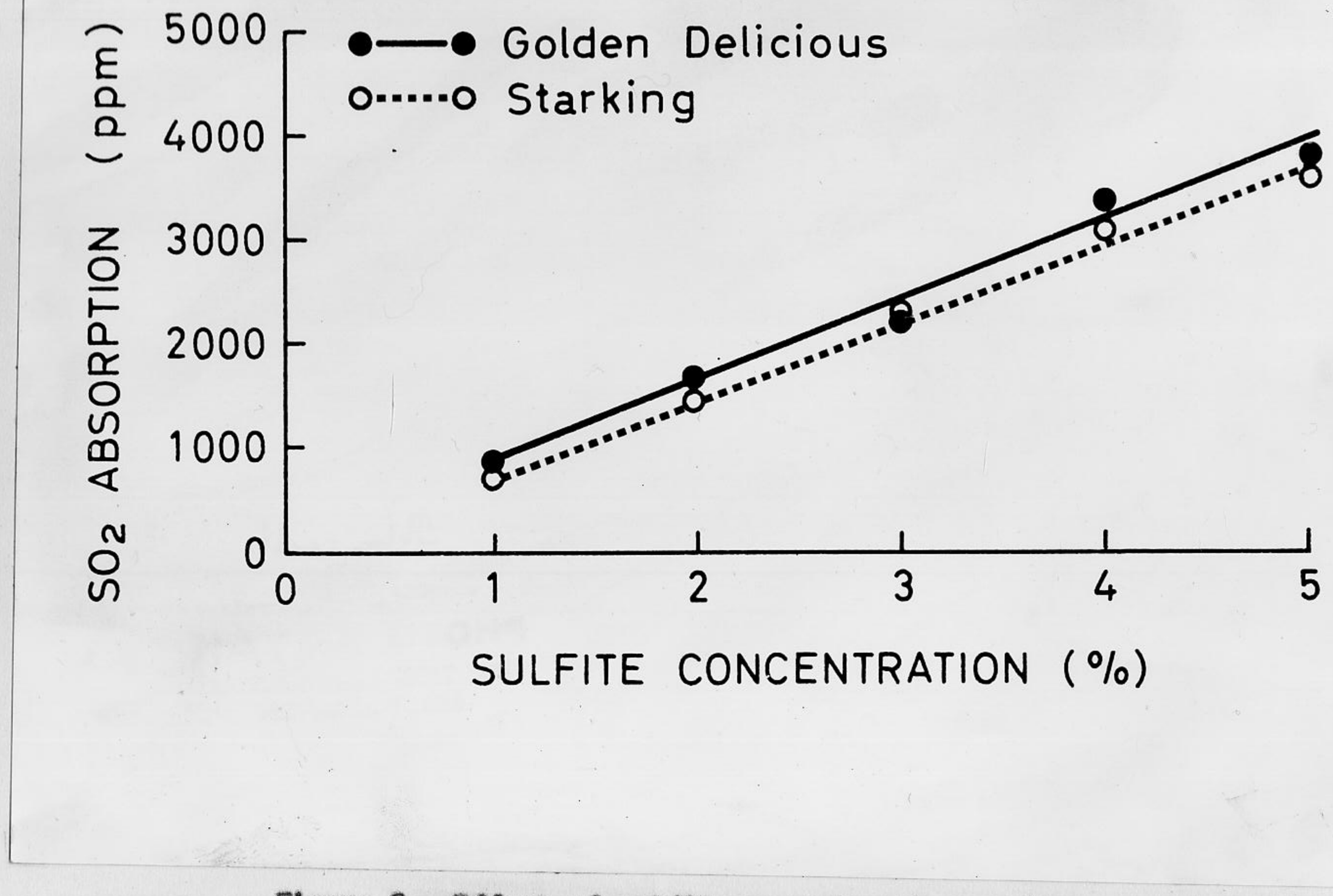

Figure 2. Effect of sulfite concentration on SO_2 absorption by the two apple varieties.

The results indicated that the absorption of SO_2 by the two apple varieties increased in a linear relationship with increase in sulfite concentration. These results are in agreement with the equation of Walker et al. (1955) for prediction of increased SO_2 absorption from initial SO_2 value. Thus the equation could be used satisfactorily for calculations of the SO_2 absorption by apple slices. The same pattern of SO_2 absorption was observed in the two varieties with slight variations; Golden Delicious apples absorbed SO_2 slightly more than did Starking.

The effect of time of dipping on SO_2 absorption as shown in Table 2 and Figure 3 is different than that of sulfite concentration.

Table 2. Effect of time of dipping on SO_2 absorption by the two apple varieties; (concentration of the sulfite solution: 5 percent).

Time of dipping (minutes)	SO_2 absorption (ppm)[x]	
	Starking	Golden Delicious
1	3598	3817
4	4661	4408
7	5026	4747
10	5215	5422

x Average of two determinations.

Sulfur dioxide absorption increased in curvilinear fashion by increasing time of dipping. Thus the rate of SO_2 absorption decreased

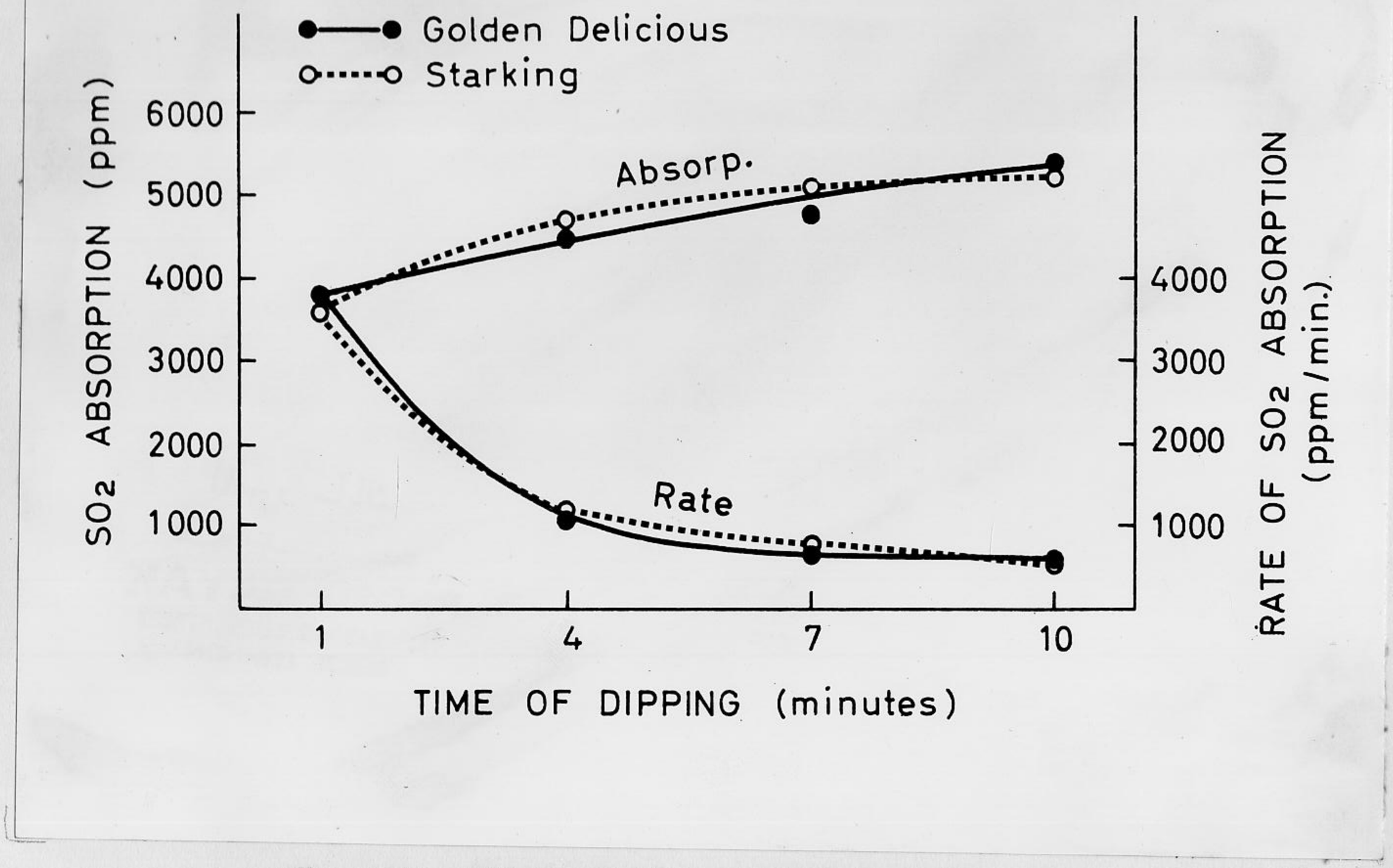

Figure 3. Effect of time of dipping on SO_2 absorption by the two apple varieties.

with time. This might be attributed to the concentration gradient, that is the continuous decrease with time in the difference between SO_2 concentration in the sulfite solution and its concentration in apple slices. On the other hand this decrease in the rate of absorption may be due to decrease with time in the rate of penetration of sulfite solution into apple slices. The results, however, do not agree with the equation of Walker *et al*. (1955); and this may be explained by the differences in times of dipping used in both cases. Dipping periods used in the present experiment were longer than those used by Walker *et al*. in the development of their equation.

The retention of sulfur dioxide was affected by the concentration of the sulfite solution as shown in Table 3 and Figure 4.

Table 3. Effect of concentration of sulfite solution on SO_2 retention in the two apple varieties; (time of dipping: 1 minute).

Concentration of $Na_2S_2O_5$ (percent)	SO_2 retention (ppm)[x]	
	Starking	Golden Delicious
1	961	787
2	2415	2316
3	3332	3456
4	4066	4798
5	4816	5225

[x] Average of two determinations.

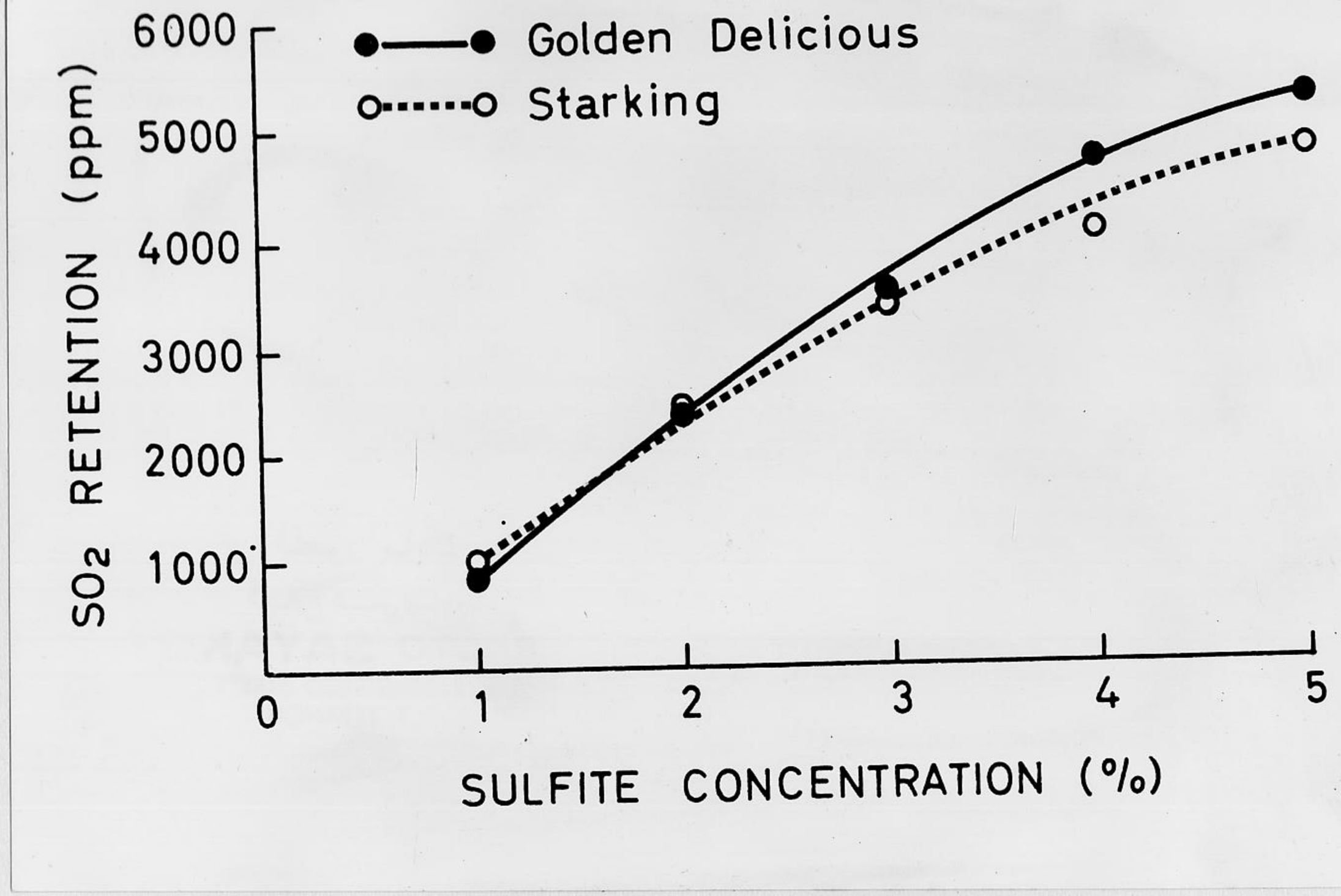

Figure 4. Effect of sulfite concentration on SO_2 retention in the two apple varieties.

The retention of SO_2 increased in both varieties by increasing sulfite concentration; but the increase was greater in Golden Delicious at the higher concentrations of the sulfite solution.

Table 4 and Figure 5 show the effect of time of dipping on SO_2 retention in the two apple varieties.

Table 4. Effect of time of dipping on SO_2 retention in the two apple varieties; (concentration of the sulfite solution: 5 percent).

Time of dipping (minutes)	SO_2 retention (ppm)[x]	
	Starking	Golden Delicious
1	4816	5225
4	5462	5774
7	6503	6959
10	8662	8424

[x] Average of two determinations.

The retention of SO_2 increased appreciably by increasing time of dipping. However, the increase in SO_2 retention was greater than that in SO_2 absorption. The explanation to this could be that in case of short periods of dipping, the absorbed sulfur dioxide held on the surface of the apple slices was subjected to greater loss during drying than the sulfur dioxide which penetrated to the inner parts due to longer periods of dipping.

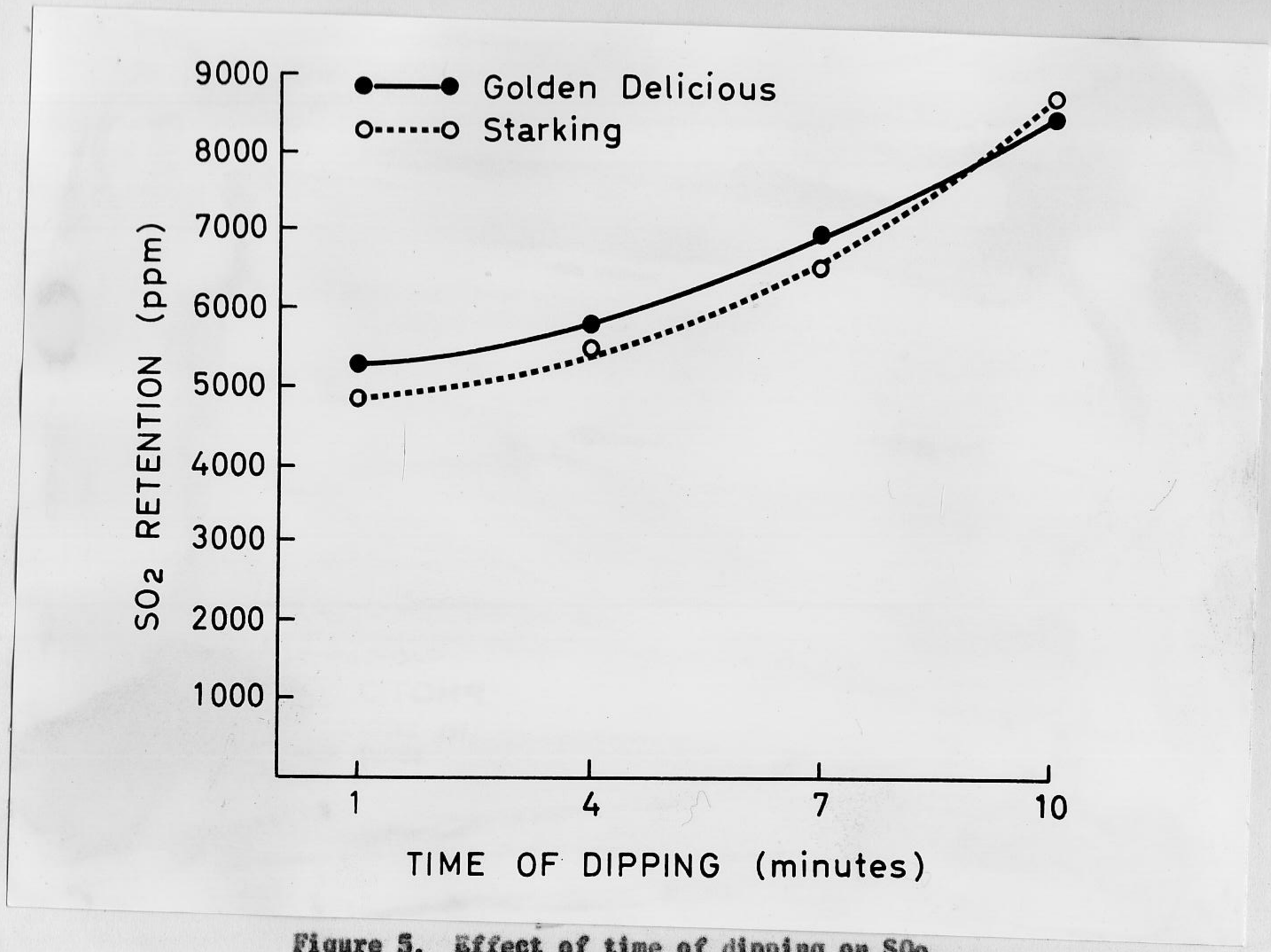

Figure 5. Effect of time of dipping on SO_2 retention in the two apple varieties.

The effect of sulfite concentration on the retention ratio of SO_2, determined on dry basis, is shown in Table 5.

Table 5. Effect of concentration of sulfite solution on the retention ratio of SO_2 in the two apple varieties; (time of dipping: 1 minute).

Concentration of $Na_2S_2O_5$ (percent)	Retention ratio of SO_2[x] (percent, db)[xx]	
	Starking	Golden Delicious
1	20.3	15.6
2	23.8	20.5
3	21.4	22.7
4	19.8	21.2
5	19.9	20.4

[x] Average of two determinations.

[xx] Dry Basis

The retention ratio of SO_2 was similar in both varieties of apples and did not change appreciably with sulfite concentration except at low concentrations at which Golden Delicious variety had lower retention ratio than did Starking. The reason for this deviation is not clear.

The retention ratio as affected by time of dipping is shown in Table 6.

Table 6. Effect of time of dipping on the retention ratio of SO_2 in the two apple varieties; (concentration of the sulfite solution: 5 percent).

Time of dipping (minutes)	Retention ratio of SO_2[x] (percent, db)[xx]	
	Starking	Golden Delicious
1	19.9	20.4
4	17.6	19.6
7	20.1	21.2
10	24.8	23.3

[x] Average of two determinations. [xx] Dry basis.

The retention ratio tended to increase at longer dipping periods since the retention values increased to a greater extent than the absorption values at these dipping periods.

Both absorption and retention of sulfur dioxide by fruit tissue are affected by drying conditions such as temperature and relative humidity. Under the experimental conditions used, drying temperature could not be precisely adjusted, and was subjected to great variations of ± 5°F. Relative humidity during drying was not controlled. The apples used throughout the study were not necessarily uniform with respect to origin and storage conditions. These factors combined would make the data obtained for sulfur dioxide absorption and retention more valid in terms of general patterns observed than in terms of absolute values.

Rehydration and Browning of Apples

This experiment was conducted to study the effects of sulfuring with and without blanching on rehydration ratio and degree of browning. In general, the high quality product of dried fruits has high rehydration ratio and low degree of browning. Thus any treatment that increases the rehydration ratio or decreases the degree of browning is assumed to improve the quality of dehydrated apples. The rehydration ratio of the treated samples after dehydration and during storage is shown in Table 7. All of the treated samples, except one, had higher rehydration ratios after dehydration and during storage than the control. S_6 was the only sample used from the 1967 production, and was less ripe than the other samples. This might explain its peculiar rehydration ratio.

Sulfuring at both levels, 1 and 2 percent, increased the rehydration ratio of dehydrated apples of both varieties. Blanching increased the rehydration ratio in both varieties, but to a lesser extent than sulfuring. The combination of blanching and sulfuring did not show a cumulative effect. Starking apples had slightly higher rehydration ratios than those of Golden Delicious, except in one sample, S_6. The rehydration ratio did not change appreciably during storage; a slight increase was observed in most of the samples.

No data have been reported in the literature about the effect of sulfuring on the rehydration ratio. The results obtained in this experiment on the effect of blanching on the rehydration ratio were in agreement with those reported by Bhatia et al. (1962) on pineapples.

Table 7. The rehydration ratio of the different treatments of the two apple varieties during storage[1,2].

Treatment	Batch No.	Storage (months) 0	1	2	3
Untreated	S_1	3.33	3.40	3.35	3.37
	G_1	2.95	3.10	3.15	3.10
Sulfured 1 percent	S_2	4.00	3.92	3.94	3.98
	G_2	3.90	3.90	3.89	3.92
Sulfured 2 percent	S_3	3.84	3.99	4.07	4.10
	G_3	3.67	3.83	3.90	3.90
Blanched	S_4	3.52	3.55	3.66	3.62
	G_4	3.25	3.30	3.36	3.38
Blanched and sulfured 1 percent	S_5	3.91	4.26	4.20	4.24
	G_5	3.52	3.78	3.67	3.76
Blanched and sulfured 2 percent	S_6	3.10	3.22	3.30	3.31
	G_6	3.51	3.55	3.43	3.46

[1] S = Starking, G = Golden Delicious.

[2] Values are average of duplicates.

However, the method used for the determination of the rehydration ratio appears to be unsatisfactory, because the samples after rehydration were not of similar consistency or texture; the blanched samples became soft in texture while the unblanched samples were more firm. This might have affected the results obtained as well as their interpretation, suggesting that other methods need to be devised for the proper evaluation of the rehydration ratio of dried fruits. The adverse effect of blanching on the texture of the rehydrated apples indicated that blanching is unlikely to be used in dehydration of apples.

Results showing the development of browning, measured by absorbance at 440 mu, during storage of the different samples from both varieties are shown in Table 8 and Figure 6. The results indicate that unsulfured samples (S_1, G_1, S_4 and G_4) had the highest degree of browning after dehydration and during storage. The degree of browning did not increase in a linear fashion during storage; a result which is not in agreement to that reported by Legault et al. (1951) for unsulfited vegetables. Blanched samples (S_4 and G_4) followed the same browning pattern of the control. Thus blanching showed no appreciable effect in preventing non-enzymatic browning. Sabry (1961) reported similar results on browning of dried apricot pulp; Qamareddin. Both the control and blanched apple samples were hardly acceptable after three months of storage. However, the data do not justify the use of the absorbance value as an indication of acceptability of dried apples.

The sulfured samples showed less browning during storage than

Table 8. Light absorbance at 440 mu during storage of the different treatments of the two apple varieties.[x]

Batch No.	Storage (months)			
	0	1	2	3
S_1	.053	.061	.076	.098
G_1	.043	.052	.068	.090
S_2	.037	.039	.047	.054
G_2	.034	.037	.043	.051
S_3	.023	.024	.027	.030
G_3	.019	.022	.024	.028
S_4	.056	.063	.077	.101
G_4	.051	.058	.071	.092
S_5	.033	.034	.037	.044
G_5	.032	.034	.038	.043
S_6	.027	.028	.029	.031
G_6	.031	.032	.034	.036

[x] Average of duplicates.

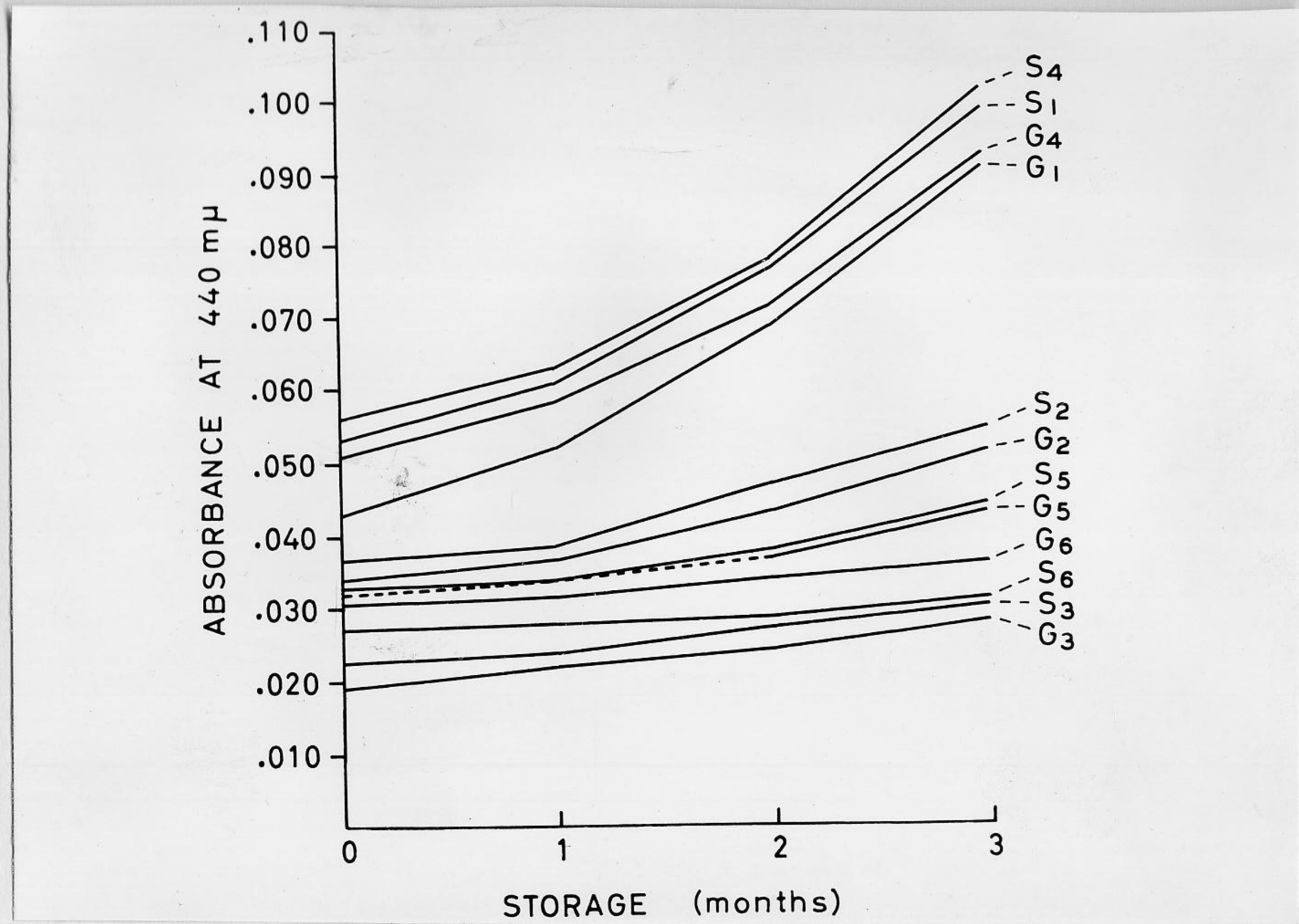

Figure 6. Light absorbance at 440 mu during storage of the different treatments of the two apple varieties.

the unsulfured, and sulfuring at 2 percent level was more effective than at 1 percent level. This is in agreement with the results reported by Stadtman et al. (1946a) on dried apricots and by Sabry (1961) on dried apricot pulp. In the present experiment there was a period at the beginning of storage during which little browning occurred, and this period was longer the higher the SO_2 content was in the sample. This is in agreement with the results reported by Stadtman et al. (1946a) for dried apricots, and by Legault et al. (1951) and Hendel et al. (1955) for dried vegetables. The combination of blanching and sulfuring was slightly more effective than sulfuring alone in the retardation of browning. This is probably due to the increased SO_2 content brought about by blanching. In all of the treatments, except one, Golden Delicious apples turned slightly less brown than Starking during both dehydration and storage, suggesting that the Golden Delicious variety may be more suitable for drying, from the browning point of view.

The development of browning during storage, as measured by the visual method of Stadtman et al. (1946a) is shown in Table 9 and Figure 7. The data are in agreement with those obtained by using the absorbance method. Blanching offered no protection against browning while sulfuring was effective in preventing browning particularly at higher concentrations. However the absorbance method was more sensitive in detecting smaller changes occurring in the degree of browning. This demonstrates that the absorbance method, at the wavelength used, was applicable when comparing different samples with different SO_2 content, which is contrary to the findings of

Table 9. Development of browning during storage of the different treatments of the two apple varieties (Unit of 1 is arbitrarily chosen for a reference colored solution).

Batch No.	Storage (months)			
	0	1	2	3
S_1	0.4	0.5	0.6	0.75
G_1	0.35	0.4	0.5	0.7
S_2	0.3	0.3	0.35	0.4
G_2	0.3	0.3	0.35	0.4
S_3	0.2	0.2	0.2	0.25
G_3	0.2	0.2	0.2	0.25
S_4	0.45	0.5	0.6	0.8
G_4	0.4	0.45	0.55	0.7
S_5	0.3	0.3	0.35	0.4
G_5	0.25	0.25	0.3	0.35
S_6	0.2	0.2	0.2	0.25
G_6	0.25	0.25	0.25	0.3

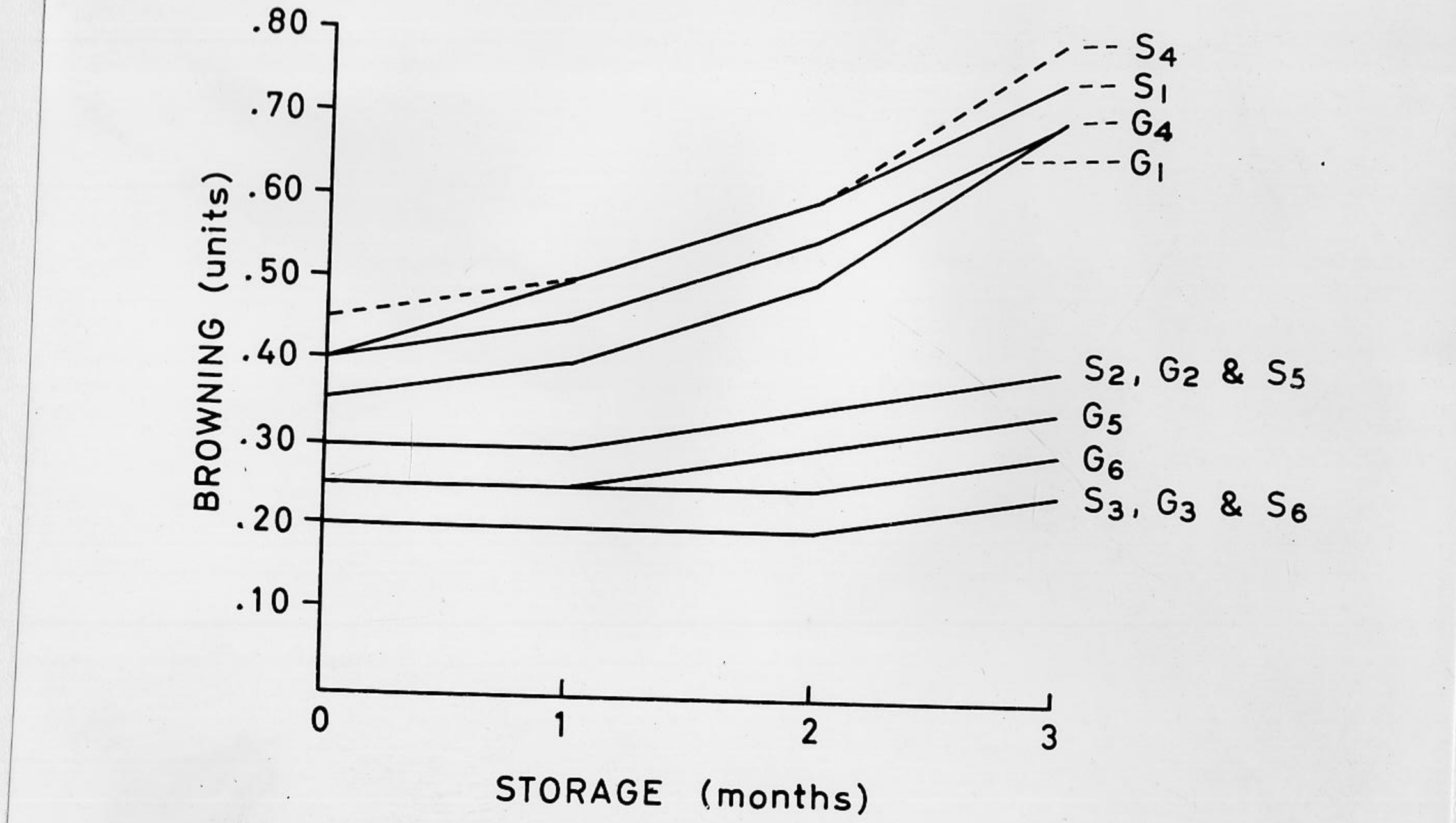

Figure 7. Development of browning during storage of the different treatments of the two apple varieties (unit of 1 is arbitrarily chosen for a reference colored solution).

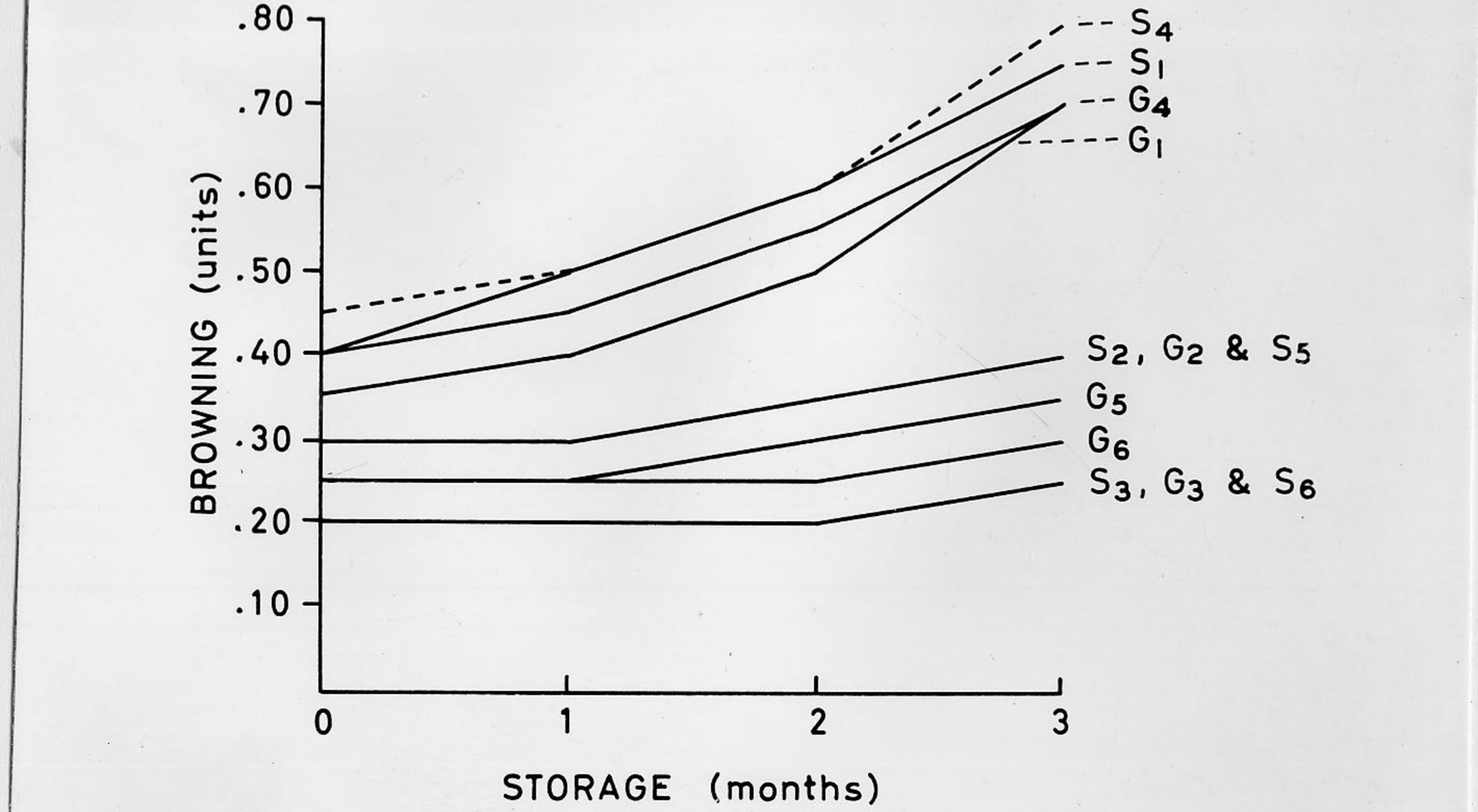

Figure 7. Development of browning during storage of the different treatments of the two apple varieties (unit of 1 is arbitrarily chosen for a reference colored solution).

Stadtman et al. (1946a) for dried apricots. However, these authors used samples with greater differences in SO_2 content than those used in the present experiment.

Sulfur dioxide content of the different apple samples during storage is given in Table 10 and Figure 8. The data indicate that samples from both varieties blanched before sulfuring had higher SO_2 content after drying and during storage than unblanched samples. Similar results were reported by Sabry (1961) for dried apricot pulp, and were explained to be due to the removal of gases, including oxygen, from the tissues during blanching; thus the oxidation of SO_2 to sulfate is partially eliminated.

The sulfiting procedure gave the desired levels of SO_2 in dried apples (about 3000 ppm) by using 2 percent SMB solution with and without blanching. The differences observed in the degree of browning of the different samples after dehydration which is probably enzymatic, lead to the study of SO_2 penetration through apple slices and enzyme inactivation by steam blanching. The minimum time of dipping in different concentrations of the sulfite solution required for SO_2 to penetrate through apple slices and to prevent the enzymatic browning was determined by using the catechol test. The results are shown in Table 11, and only for those dipped in 1 and 5 percent SMB are also shown in Figure 9.

Table 10. Sulfur dioxide content (ppm) of the treated apple varieties during storage[x].

Batch No.	Storage (months)			
	0	1	2	3
S_2	815	528	337	202
G_2	885	493	320	168
S_3	2585	2006	1618	1280
G_3	2672	2024	1550	1197
S_5	1240	1021	741	640
G_5	1275	1056	708	607
S_6	3450	2886	2460	2359
G_6	3309	2956	2662	2527

x The values are averages of duplicates.

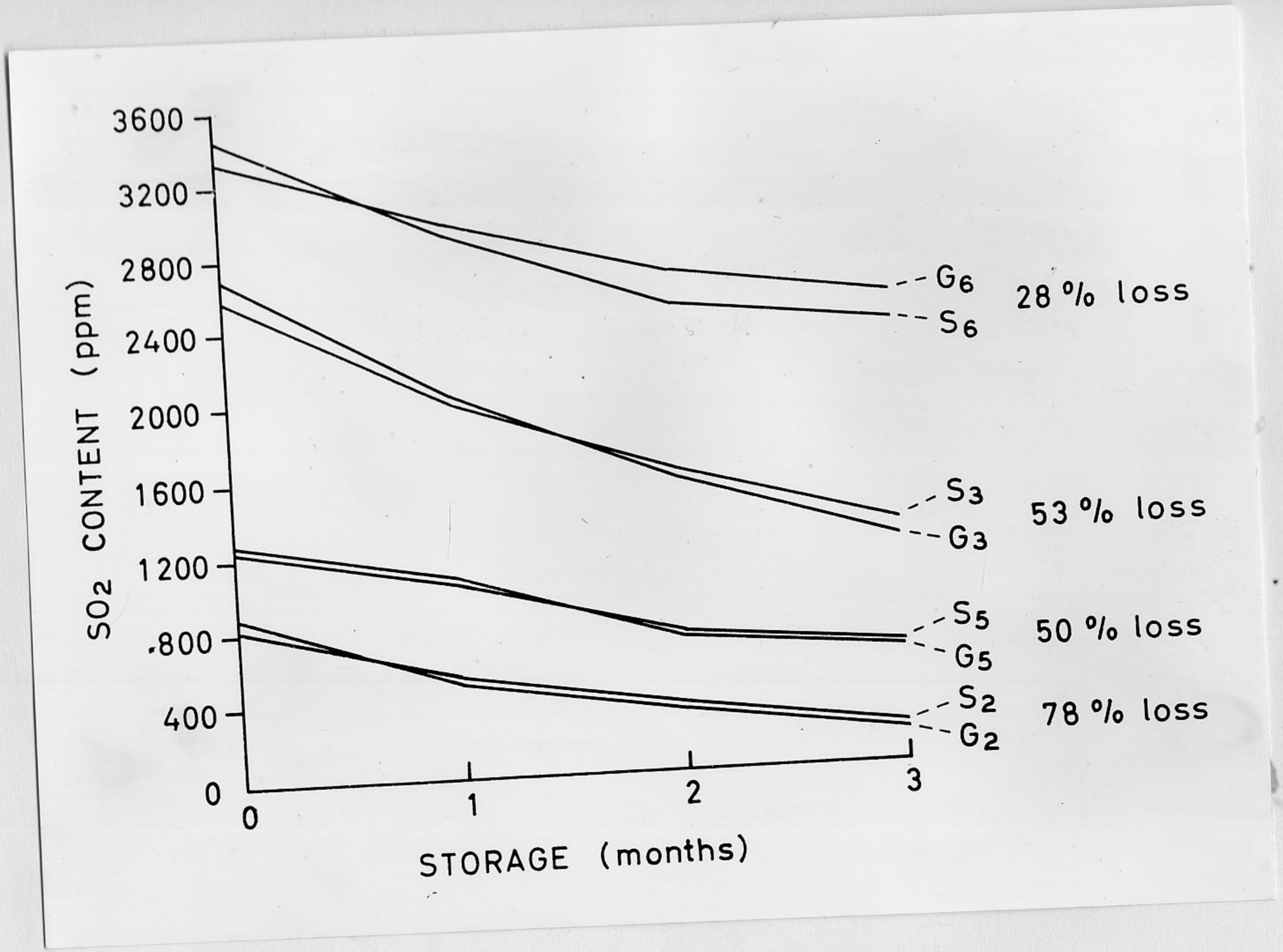

Figure 8. Sulfur dioxide content (ppm) of the treated apple varieties during storage.

Table 11. Minimum time of dipping required for complete penetration of SO_2 through apple slices[x].

Concentration of $Na_2S_2O_5$ (percent)	1	2	3	4	5
Time of dipping (minutes)	22-25	13-16	10-12	8-9	6-7

[x] Thickness of the slices is 6 ± 0.4 mm.

The results indicate that, from the penetration point of view, dipping apple slices for 1 minute was not satisfactory in any of the sulfite concentrations used, and that much longer time is needed. Although the penetration of sulfur dioxide increased by increasing both time of dipping and concentration of the sulfite solution, the value of time multiplied by concentration was not of value as an index of SO_2 penetration.

The penetration of SO_2 through Starking apple slices seemed to be slower than that through Golden Delicious; but neither the method used nor the data obtained could suggest a definite conclusion. Furthermore, penetration of SO_2 through apple slices may have continued during drying. But, since the method used is based on enzyme activity, it was not possible to detect the amount of penetration during drying. Thus other methods should be devised for the study of penetration of SO_2 through apple slices. The use of radioactive sulfur may prove a helpful tool.

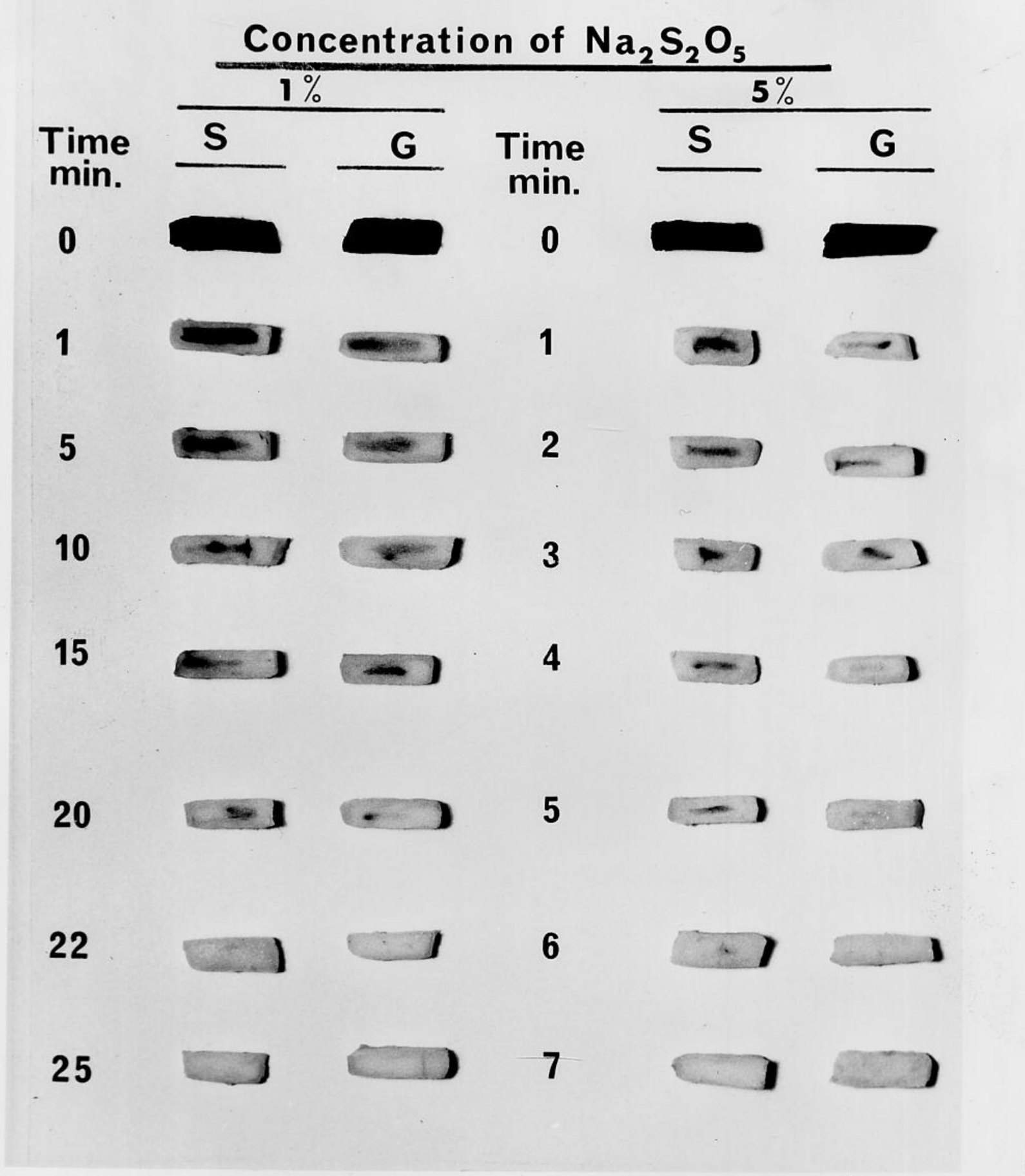

Figure 9. Effect of time of dipping and sulfite concentration on SO_2 penetration in the two apple varieties.

To find the time of steam blanching required for inactivating polyphenolase enzymes, the catechol test was also used and the results are given in Table 12.

Table 12. Effect of time of steam blanching on inactivation of polyphenolase enzymes in apple slices[x].

Time of steam-blanching (minutes)	Variety	Catechol test
1	S	+
	G	+
1½	S	++
	G	++
2	S	+++
	G	+++

[x] S = Starking; G = Golden Delicious
\+ , Slightly effective;
++ , Moderately effective;
+++, Very effective.

The results show that the two varieties behaved similarly, one minute of steam blanching was not enough, while two minutes were needed for complete inactivation of the polyphenolase enzymes.

V. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Sulfur dioxide absorption and retention in apple slices of Golden Delicious and Starking varieties were found to increase almost linearly by increasing concentration of the sulfite solution between 1 and 5 percent while the retention ratio was not appreciably affected. Increasing the time of dipping over one minute increased SO_2 absorption only slightly, and this was attributed either to the continuous decrease between SO_2 concentration in the solution and that in the apple slices, or to decreased rate of sulfite penetration through apple slices with time. The retention of SO_2 increased appreciably by increasing time of dipping probably because of decreased loss of SO_2 during drying due to more penetration with longer times of dipping. Thus the retention ratio tended to increase with longer times of dipping.

Minor differences were observed between the two varieties of apples, but may not be necessarily a function of variety. Further studies about effects of maturity and storage of apples, and temperature and relative humidity during drying on the absorption and retention of SO_2 using the sulfiting procedure are needed. Variability in fruit characteristics and drying conditions is recommended to be kept as low as possible in order not to affect reproducibility of results.

Sulfuring and or blanching of apple slices before dehydration

increased the rehydration ratio after drying. But blanching was not recommended because of its adverse effect observed on the texture during rehydration. The method used for determination of rehydration ratio did not seem reliable, and other methods such as determination of reconstitution values versus boiling time should be devised and evaluated.

Blanching of apples before drying offered no protection against non-enzymatic browning, while sulfuring brought a definite effect particularly at higher levels. Blanching increased appreciably SO_2 content after drying and decreased its loss during storage. Thus the combination of blanching and sulfuring was more effective than sulfuring alone in retarding browning of dried apples. Untreated apple slices and those blanched before drying became hardly acceptable after three months of storage during which their rate of browning was increasing. Storage times longer than the three months used in this experiment are recommended for further studies.

Optical density at 440 mu for apple extracts gave good indication of degree of browning in both sulfured and unsulfured dried apples during storage. Visual comparison of these extracts with reference color solutions gave similar patterns to those obtained from optical density, but the method was less sensitive to small changes in color, and not as practical.

Enzymatic browning in apple slices could be avoided by steam blanching for two minutes or by dipping in sulfite solutions for periods of time enough for complete penetration of SO_2 inside the slice. This penetration was found to increase with both sulfite

concentration and time of dipping; time of dipping ranged between seven minutes in 5 percent SMB and 25 minutes in 1 percent SMB for the penetration to be complete. The catechol test used in this study did not seem suitable for accurate and quantitative studies on penetration of SO_2, and use of radioactive sulfur should be adapted for this purpose.

Apple slices of Starking variety, despite their higher rehydration ratio, seemed to be less suitable than Golden Delicious for drying as far as browning during drying and storage is concerned. Further studies about suitability of other varieties for drying are needed.

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