AN ABSTRACT OF THE THESIS OF

Sitir M. Hassanein for the degree of Master of Science

in Food Science and Technology presented on May 3, 1982

Title: Color of Strawberry juice and Concentrate as Influenced by Heating and Storage Temperatures

Abstract approved: _____

Dr. Ronald E. Wrolstad
Substituting for Dr. Morris W. Montgomery

This investigation was conducted to study the effects of blanching and storage temperatures on the color of strawberry juice and concentrate. Strawberry juice and concentrate (42°Brix) were prepared from blanched crushed Tioga strawberries. Crushed strawberries were blanched, in a steam-jacketed kettle, at 70°, 80°, and 90°C for 1 min. Ascorbic Acid (AA), at a level of 0.01%, was added to one batch and hoped to counteract polyphenol oxidase (PPO) activity in the early stages of processing. Samples were then stored at 1°, 21° and 38°C and the chemical composition as well as the color parameters were monitored throughout the study.

Blanching at 70°C was found to heat-inactivate PPO in straw-

berries. Generally, blanching protected the compositional constituents, such as, anthocyanins (ACN), AA, leucoanthocyanins, flavanols and total phenolics. Initially, blanched samples contained higher concentrations of these chemicals than the unblanched (control) samples. Samples blanched at 80°C contained highest concentrations followed by those blanched at 90° and 70°C. This protective effect was markedly reduced in samples blanched with added AA. AA decomposition products seem to initiate other degradation reactions.

There was a considerable decrease in the juice chemical constituents upon concentration. A particular striking decrease was observed with AA where samples lost more than 75% of their initial content.

All samples experienced gradual losses of their chemical constituents accompanied by loss of the bright red color associated with freshly prepared juice and concentrate. The losses increased with increased storage temperatures. Storage at 38°C, as a result, was found to be a major factor in the loss of the chemical constituents and the rapid deterioration of the color. Concentrate samples developed burnt flavor by the third week and lost all ACN and AA contents by the end of the storage period. The loss was much less on storage at 21°C and least at 1°C.

At any storage temperature, samples blanched at 80° and 90°C retained more of their constituents as well as better color quality parameters when compared to the control or those blanched at 70°C. Samples blanched with added AA experienced greater losses of their color values and chemical constituents, particularly ACN and AA, when compared to samples blanched without AA.

ACN and AA degradation in samples stored at 1°C followed first order reaction kinetics, while browning formation in these samples and in juice samples stored at 21°C followed zero order reaction kinetics. Rate constants suggest a major role for AA in the deterioration of color. Moreover, they also suggest a protective effect on blanching on the overall quality of the juice and concentrate.

Blanching at 80°C for 1 min was the optimum processing temperature investigated, while low storage temperatures are, naturally valuable in retaining better color quality strawberry juice and concentrate.

Color of Strawberry Juice and Concentrate as Influenced by Heating and Storage Temperatures

by

Sitir M. Hassanein

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

June 1982

APPROVED:

Professor of Food Science and Technology in charge of major

Head of Department of Food Science and Technology

Dean of Graduate School

Date thesis is presented May 3, 1982

Typed by Ellen E. Schulz for Sitir M. Hassanein

Dedicated

to

Julie

ACKNOWLEDGEMENT

I would like to express my sincere appreciation to Dr. M. W. Montgomery for his consistent advice, encouragement and patience throughout the course of this study.

Special appreciation to Dr. R. E. Wrolstad for his valuable assistance and advice in preparing the manuscript. Dr. D. A. Heatherbell is thanked for his encouraging interest in this work.

Dr. A. F. Anglemier and Dr. D. P. Selivonchick are thanked for their advice throughout my graduate study.

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INTRODUCTION

Color is probably the most important parameter in assessing the quality of foods. A consumer would examine other quality parameters such as flavor and texture only after accepting that the color meets his or her expectation and experience of a quality product. This has always been the case with ACN containing fruits and vegetables, and specifically with strawberry and its products. Any deviation from the naturally rich red color of freshly prepared strawberry products would be perceived as inferior quality.

Strawberries owe their bright red color to ACN which are, being electron deficient, highly reactive and not stable in food systems. Degradation of ACN, and hence deterioration of the over-all color, may occur during harvesting, handling, processing and storage. Many factors have continually been studied in order to understand and assess the nature and role of these factors in the color stability. Factors such as processing and storage temperatures, enzymes, pH, sugar type and concentration and trace minerals are well documented to exert major influences on ACN and on color stability. Decomposition products of sugars

and AA are also known to contribute to the formation of the dark brown color associated with products stored for long periods of time under relatively high temperatures. Sugars and amino acids in Maillard reactions, may also lead to browning.

Browning may contribute to the loss of the overall color and acceptability of strawberry products more than the loss of ACN per se (Abers and Wrolstad, 1979). Chemicals such as sulfur dioxide, which inhibits PPO and some degradative reactions, have been used in fruit processing to control browning and ACN degradation. With the consumers' attitude towards chemical additives and their perceived health hazards food technologists are facing a new challenge; that is applying physical means to achieve what they could and could not achieve chemically.

Temperature would be the method of choice since it would inactivate and control the deleterious effects of the enzymes, present in natural systems, on color stability. Knowing the right temperature-time conditions, required to inactivate the adverse enzymes, and storage at lower temperatures would help in retaining the natural red color of strawberry products.

The main goals of this endeavor were to study the effects of processing and storage temperatures as well as the effects of added AA on the color stability of strawberry juice and concentrate. Processing temperatures were at or above that required to inactivate PPO in its natural system, as determined in this study, and storage temperatures were those commonly encountered

in storage places. AA was added at the lowest practical concentration in order to control browning during the early stages of processing. Major chemicals and color parameters were also studied throughout the storage period.

LITERATURE REVIEW

The retention of natural color in food products has long been a challenge to food technologists. With increasing emphasis being placed on the consumer acceptance of foods, the relatively rapid deterioration of the color of freshly prepared strawberry products has become a matter of great importance. The bright red color is an important quality index in juices and concentrates made from strawberries and, any deviation from the naturally attractive red color would be perceived as inferior quality by the consumer.

Anthocyanins and Strawberries

Strawberries, as many other fruits and vegetables, owe their red color to ACN pigments. The ACN system in strawberries is relatively simple compared to that reported for other fruits and berries. Sondheimer and Kertesz (1948) reported one major ACN in strawberries; four major ACN were reported in cranberries (Sakamura and Francis, 1961); Daravingas and Cain (1966) identified four major ACN in blackberries; and grapes are reported to possess no fewer than five major ACN (Harborne, 1967).

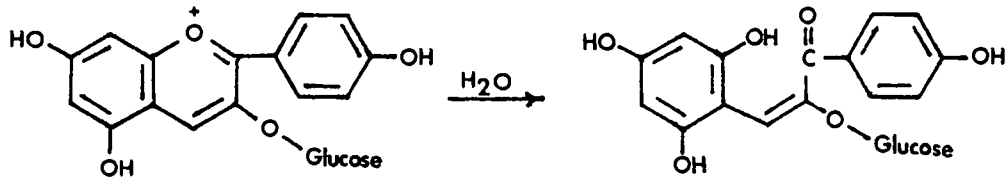
The principle ACN in strawberries were reported to be pelargonidin-3-glucoside (Pel-3-G) (Sondheimer and Kertesz, 1948), present in high concentration, and cyanidin-3-glucoside in much

lower concentration (Lukton et al., 1955). The rapid deterioration of the color of strawberry products was reported to be mainly due to the high instability of its ACN system (Cash and Sistrunk, 1971; and Markakis, et al., 1957). Other factors contributing to the formation of brown color have also been investigated. Abers and Wrolstad (1979) maintained that it was this brown color that was the major factor in the overall color deterioration.

Anthocyanins Degradation

Factors affecting ACN degradation and change or loss of the color in ACN containing products have been studied for some time. Strawberry has been the center of most studies in this respect due to its economic value, delicate nature and its relatively simple ACN system. The degradation of ACN and the formation of a dull brown color may take place during harvesting, handling, processing and storage of ACN containing fruits.

While many factors are known to affect the degradation rate of ACN, only two mechanisms have been postulated to explain how ACN degrade. Markakis et al. (1957) proposed that the major pathway involves initial opening of the pyrilium ring at position 1-2 with the formation of a ketone, i.e., a substitute chalcone.



This would be followed by further degradation of this ketone and would eventually lead to the brown color which has constantly been observed as an end product of the pigment. Adams (1973a), on the other hand, maintained that hydrolysis of the glycosidic bond, and not the opening of pyrilium ring, was the main pathway of ACN breakdown and that this hydrolysis was the rate degradation determining step. The liberated anthocyanidin would then undergo series of degradation steps leading to the formation of brown color. The proposed schemes are discussed in depth by Adams (1973b) and Markakis (1974) in their recent reviews concerning ACN stability.

Whatever the case might be, the electron deficient flavilium nucleus of the pigment makes it highly reactive, and the reactions normally involve decolorization of the pigment and are usually undesirable in the fruit industry (Clydesdale et al., 1976). While the products of the degradation of ACN at the pH of many fruit products are not well characterized, an insoluble red-brown precipitate would form as an end product (Lukton et al., 1956; Markakis et al., 1957; and Erlandson and Wrolstad, 1972). Still,

ACN are not primarily significant in the browning reactions, although they have been shown, in few cases, to be involved in secondary reactions (Mathew and Parpia, 1971).

Effect of Enzymes

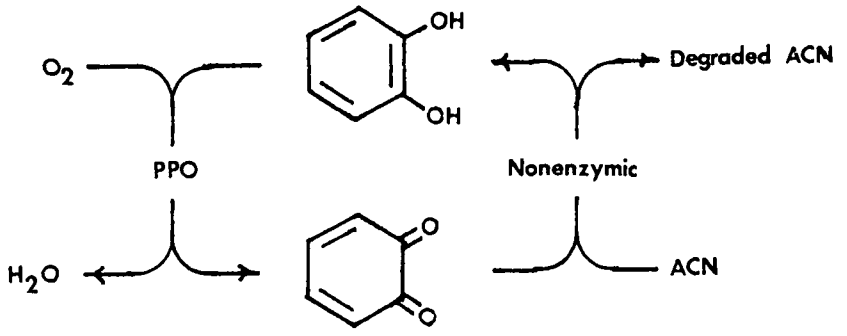
When fruit and vegetable tissues are injured during harvesting, handling, packaging or processing discoloration takes place. This color deterioration is usually referred to as enzymic browning. Naturally occuring enzymes capable of decolorizing ACN have been reported. ACN might be hydrolyzed by fungal glycosidase (Huang, 1955) with the liberation of the aglycone which in turn would undergo spontaneous transformation into colorless product capable of further degradation as described by Lukton et al. (1956). Peroxidase was also reported to accelerate the destruction of ACN pigment (Grommeck and Markakis, 1964). AA oxidase has long been known to be involved in the oxidative destruction of AA (Ponting and Joslyn, 1948) which may also lead to browning.

PPO is probably the most investigated enzyme in connection with browning and discoloration of fruits, vegetables and their products. PPO is widely distributed in the plant kingdon (Mayer and Harel, 1979) and has been associated with ACN degradation and color deterioration in several products. PPO, isolated from eggplant, was reported to specifically degrade ACN typical of

that fruit (Sakamura et al., 1966), and strawberry PPO was demonstrated to speed up the rate of discoloration of strawberry juice and puree (Cash and Sistrunk, 1971).

PPO extracted from different sources have shown multiple forms and varying degrees of utilizing substrates. While mushroom PPO has been shown to be active on both mono and dihydroxyphenols (Long et al., 1971), PPO extracted from other sources utilized only dihydroxyphenols (Cash et al., 1976; Halim and Montgomery, 1978; and Smith, 1980). Wesche-Ebeling (1981), in an extensive study of strawberry PPO, reported that the enzyme was most active towards (+)-D-catechin which is naturally present in strawberries.

Many theories were postulated on the role of PPO in the browning and discoloration of the color of ACN containing products. Although a PPO system, extracted from eggplant was reported to be specific for that fruit ACN (Sakamura et al., 1966), other workers suggested that ACN would be poor PPO substrates (Peng and Markakis, 1963; and Cash and Sistrunk, 1971). A widely accepted theory was proposed by Peng and Markakis (1963). According to this theory the o-phenolic sibstrates are enzymically oxidized to o-quinones which would react non-enzymically degrading ACN:



In any case, it appears reasonable to maintain that PPO plays a major role in the browning and discoloration of ACN containing products.

Effect of Temperature

The effect of temperature on ACN degradation and browning formation has long been noted. Many investigators have taken advantage of elevated temperatures to hasten and magnify results and most of the work was on ACN model systems. Meschter (1953) noted that the most important factor in changing the kinetics of the degradation of the color in strawberry products was temperature, and that the rate of color deterioration increased proportionally to the log of temperature. Most importantly, he reported that browning increased four times faster than the pigment loss. In strawberry jelly pigment loss obeyed first order kinetics at various processing temperatures (Decareau et al., 1956). Simialr results and observations were also report-

ed in strawberry juice (Mosorinski, 1975). Ponting et al. (1960) reported that the loss of color was followed by general browning as processing temperature increased.

The effects of high storage temperatures and duration of storage were significant in reducing the ACN pigment of canned red raspberries (Daravingas and Cain, 1965). Several investigators have established that the red pigment of strawberry products is unstable on heating and storage (Kertesz and Sondheimer, 1948; and Mackinney and Chichester, 1952). Moreover, Beattie et al. (1943) observed that color deterioration during storage was most marked in strawberry juice than the other fruit juices tested. Time and temperature of storage of strawberry products have been reported to exert a significant effect on loss of color and development of browning (Wrolstad et al., 1970; and Little, 1977).

However, blanching might prove beneficial in controlling adverse enzyme systems. Wrolstad et al. (1980) reported that blanching strawberries provided a protective effect not only on the ACN and color of strawberry concentrate, but also protected other chemical constituents as well. Blanching would inactivate PPO and most studies in this respect were performed on extracts of PPO from different sources and few attempts were made to heat-inactivate this enzyme in its natural system. Inactivation temperatures would markedly vary with the source of PPO, extraction and assay conditions as well as the maturity degree of the

fruit under test (Mihalyi et al., 1978). The half-life of avacado PPO was reported by Kahn (1977) to be 8 min at 70°C and 11.7 min for d'Anjou pears at the same temperature (Halim and Montgomery, 1978). The time required to reach 50% inactivation of strawberry PPO at 70°, 80° and 90°C were reported to be 2.78, 0.92 and 0.75 min respectively, using catechol as a substrate (Wesche-Ebeling, 1981). Dimick et al. (1951) studied the effects of heating on the activity of PPO in fruit purees and noted that the inactivation rate differed with each type of fruit investigated.

Effect of Ascorbic Acid

Besides heat and oxygen the main antagonist in the degradation of ACN would be AA. The reaction of ACN and AA is of interest since strawberries are relatively high in AA and because of the vitamin's nutritional value. The effect of AA on the color of stored juices was first suggested by Beattie et al. (1943) who observed that the pigment decreased at rates paralleling that of AA. Since then, the reaction of ACN with AA has been studied by several workers. The detrimental effect of AA on ACN and color of fruit juices has been well documented (Meschter, 1953; Sondheimer and Kertesz, 1953; Starr and Francis, 1968; and Calvi and Francis, 1978).

Dekker and Dickenson (1940) and Silverplatt et al.(1943)

reported on the oxidation of AA in the presence of cupric ions. Both groups demonstrated that H_2O_2 accompanied the cupric ion-catalyzed aerobic oxidation of AA to dehydro-ascorbic acid. Assuming that the H_2O_2 might be the oxidizing agent, Sondheimer and Kertesz (1952) extensively studied the degradation of Pel-3-G, the principle ACN in strawberries, in both model and natural systems. The reaction went well in the model system , but much less successful in the natural system. They concluded that H_2O_2, even at low concentrations, could oxidize Pel-3-G into less colored compounds. Reports by Starr and Francis (1968) and Shrikhande and Francis (1974) confirmed the detrimental effect of AA on ACN and that the degradation rate was primarily due to its oxidation product, H_2O_2, as previously postulated by Sondheimer and Kertesz (1953). Further investigations demonstrated that, at least in model systems, H_2O_2 was capable of oxidizing ACN and related flavilium salts (Jurd, 1968).

Poei-Langston and Wrolstad (1981), in their meticulous study on a model system of Pel-3-G, further confirmed the detrimental effect of AA on the pigment and maintained that AA played several key roles in color deterioration and polymer pigment formation. Moreover, they confirmed a direct condensation type of reaction between AA and ACN, as proposed by Jurd (1972), whereby unstable compounds were formed which, in turn, degraded to colorless products. AA may, furthermore, contribute to color deterioration

through reacting with amino acids (Kurata et al., 1973).

However, AA was reported to inhibit PPO induced browning. Sistrunk and Cash (1970) reported that AA delayed browning in strawberry puree until most of the AA was degraded. Similar observations were also reported by Skalski and Sistrunk (1973) and Pifferi and Cultrera (1974) and it was concluded that AA acted more as an antioxidant than a true PPO inhibitor.

Effect of Oxygen

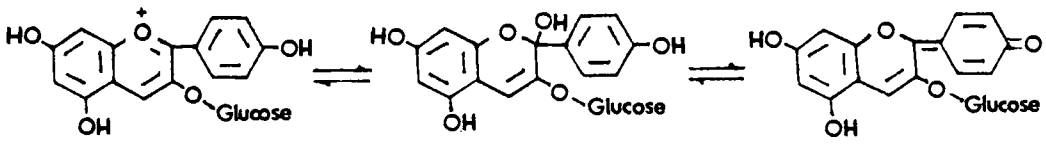
Tressler and Pederson (1936), working on bottled grape juice, were the first to demonstrate the adverse effect of headspace oxygen on the color deterioration. The degradation rate of Pel-3-G in both model system and strawberry juice was reported to increase in the presence of oxygen (Lukton et al., 1956). In a model system of Pel-3-G, Markakis et al. (1957) observed similar effects and reported first order degradation rate under nitrogen, while the degradation under air was much faster. Several workers independently confirmed greater losses in the presence of oxygen (Daravingas and Cain, 1965 and 1968; and Tinsley and Bockian, 1960). A synergistic effect of oxygen and AA on the degradation of ACN with subsequent loss of both ACN and AA was observed to be accompanied by increased formation of brown color (Sondheimer and Kertesz, 1953; and Markakis et al., 1957). Starr and Francis (1968) enlarged on this and monitored the effect of headspace

oxygen and AA concentrations in cranberry juice cocktail. This was the first time the rate of oxygen consumption was directly measured in ACN degradation studies; and as would be expected the degradation was fastest at the highest concentrations of AA and headspace oxygen. Similar observations were also reported by Wrolstad et al. (1980) and Poei-Langston and Wrolstad (1981).

Oxygen is, furthermore, utilized by certain enzymes and directly incorporated in the degradation of color and the formation of brown polymeric pigment. Both PPO and AA oxidase are known to require oxygen in their oxidizing activities. It seems apparent that oxygen is an integral part of more than one degradative pathway.

Effect of pH

Stability of ACN, as influenced by pH of the media, has been studied by a number of workers under a variety of systems and conditions. The majority of these studies were performed on the strawberry ACN system or its principle ACN, Pel-3-G. Wrolstad et al. (1970) reported that pH was the only objective measurement having a high correlation with color quality in frozen strawberries. ACN undergo structural transformation with changes in pH. Pel-3-G structural changes with pH are illustrated in Figure 1 (Wrolstad, 1976).



pH 1
Flavilium Cation

pH 4-5
Carbinol Base

pH 7-8
Anhydro Base

Figure 1. Structural transformation of Pel-3-G with changes in pH.

ACN stability was demonstrated to increase with the decrease of pH, in both model and strawberry juice systems, as pH was lowered towards 2.0 (Meschter, 1953; Lukton et al., 1956; and Tinsley and Bockian, 1960). Daravingas and Cain (1968) on their study on black raspberry ACN obtained similar results. Like Lukton et al. they found little effect of pH under nitrogen atmosphere, but observed a marked effect of pH under oxygen atmosphere. This was later corroborated by Adams (1973a) in an extensive study on cyanidin-3-glucoside system. When pH was lowered below 2.0, it seemed that hydrolysis of the glycosidic bond took place and the stability of ACN decreased (Meschter, 1953; and Daravingas and Cain, 1968).

Sistrunk and Cash (1970) reported a stabilizing effect of lower pH values on ACN and the overall color of strawberry puree. Skalski and Sistrunk (1973) and Sistrunk et al. (1980) reported

similar observations with grape juice and strawberry puree prepared from different cultivars. Strawberry PPO activity was reported to decrease as the pH decreased. Sistrunk and Cash (1968) demonstrated that, in frozen strawberries, decreasing the pH to 3.0 or lower inhibited PPO. Similar observation was also reported by Wesche-Ebeling (1981) on purified form of strawberry PPO.

Effect of Sugars

Systems that naturally contain ACN usually contain sugars, and their products frequently contain added sugars as well. The sugars of primary importance have been sucrose, glucose and fructose. The effect of sugars and their degradation products, primarily 5-hydroxymethyl-2-furfuraldehyde (HMF) and furfural, on ACN breakdown and color stability have been investigated. Tinsley and Bockian (1960), in their study on a Pel-3-G model system, demonstrated that sugars accelerated the destruction rates of ACN at 90°C. Furthermore, they observed that fructose promoted the largest change followed by sucrose with glucose causing the least effect. Increasing the concentration of sugars and the presence of oxygen aggravated the destruction rate. Daravingas and Cain (1965) reported significant increase in the destruction rate as the concentration increased from

0° to 25° Brix. However, the increase was not significant at 50° Brix. Whether this is the first protective effect at higher concentrations is not known nor has it been investigated.

Under acidic conditions HMF would be expected to be the major compound due to hexose decomposition, and furfural due to pentose decomposition. Furfural would also be formed from AA decomposition under the same conditions (Lamden and Harris, 1950). Sugars degradation products, as represented by HMF, were postulated by Livingston et al. (1955) to exert destructive effects on the color of various formulations of model sugar-acid-pectin gels. While Meschter (1953) reported that under aerobic conditions and on an equal weight basis furfural had greater effect on Pel-3-G degradation than HMF, Tinsley and Bockian (1960) observed that, under either oxygen or nitrogen atmospheres, the degradation rate of Pel-3-G was three to four times greater in the presence of HMF than in the presence of furfural on an equal molar basis. However, Daravingas and Cain (1968) reported that furfural exerted more detrimental effect on cyanidin-3-diglucoside than did HMF. Whatever the case might be, it would be reasonable to assert the destructive effect of sugars, or more precisely their decomposition products, on the stability of the color of ACN containing products.

Effect of Metals

Meschter (1953) observed a catalytic effect of copper and iron whereby copper would catalyze AA to dehydroascorbic acid, and the presence of iron would aggravate this effect with subsequent color deterioration. ACN, however, in the presence of heavy metals such as Fe, Mg, Mn and Al form complexes and undergo a bathochromic shift or decoloration (Markakis, 1974). Sistrunk and Cash (1970) studied the effects of $SnCl_4$, $SnCl_2$ and $AlCl_3$ salts on the color stability of strawberry puree. They noted that $SnCl_4$ was more effective in stabilizing both the color and AA of the puree than was $SnCl_2$. Although they observed a protective effect of $AlCl_3$ on the color, the salt did not affect the stability of AA. Wrolstad and Erlandson (1973) enlarged on this and studied the effects of these metals on the color and ACN degradation in strawberry puree and juice. While they observed similar protective effect on the color, there was no effect on ACN stability.

Protective Factors

Most of the research has been concerned with the influence of degradative factors on the stability of products containing ACN. A number of agents have been investigated for their possible protective effects, if any, and many conflicting observations have been reported. A protective effect of citrate in

simple systems has been reported (Meschter, 1953; and Sondheimer and Kertesz, 1952). However, Meschter observed a degradative effect in a more complex system. Nitrates were reported to provide a protective effect in the presence of ferric ions (Keith and Powers, 1965), yet ferric ions have been shown to catalyze degradative reactions. Thiourea has been shown to provide a protective effect on ACN with added AA in both model and strawberry juice (Sondheimer and Kertesz, 1953). Markakis et al. (1957) studied the effect of several chemicals and reported that only thiourea provided significant protective effect in strawberry juice and a model system of Pel-3-G.

Addition of sulfur dioxide to fruits in bulk storage prior to processing results in rapid bleaching of ACN, but its removal by boiling regenerates the color (Clydesdale and Francis, 1976). Sulfur dioxide is a powerful PPO inhibitor (Haisman, 1974; and Wesche-Ebeling, 1981). While it has been effectively employed to control enzymic browning, the exact mechanism of such action is not fully understood (Mathew and Parpia, 1971). Although cysteine is a weak PPO inhibitor (Wesche-Ebeling, 1981), it was reported to effectively inhibit browning reactions (Montgomery, 1976; and Skalski and Sistrunk, 1973).

ACN natural systems always contain phenolics as well. Many phenolics, such as catechin and chlorogenic acid, contain o-hydroxy groups and may, therefore, serve as PPO substrates and

contribute to browning. In fact, D-catechin, which is naturally present in strawberries, was found to be the best substrate for strawberry PPO among the possible phenolics tested by Wesche-Ebeling (1981). Markakis (1974) reported a possible copolymerization between ACN and other phenolics.

Some phenolics, however, have been shown to provide a protective effect on ACN and AA and hence, the overall color. Riboflavin, in the absence of AA, contributed to the instability of ACN pigment in strawberry juice (Pratt et al., 1954). Markakis et al. (1957) noted significant effect of riboflavin on the color of strawberry juice, while it definitely promoted the degradation in a model system of Pel-3-G. Flavonols, specifically quercitin, which is naturally found in strawberries (Williams and Wender, 1952) have been demonstrated to exert protective effects on ACN systems (Decareau et al., 1956; Markakis et al., 1957; and Shrikande and Francis, 1974) and on AA as well (Clegg and Morton, 1968).

The observed in model systems often does not accurately reflect the results obtained in natural systems. Moreover, the results obtained from studying one natural system may not, necessarily, reflect those obtained in a different natural system. Strawberry juice is one example as it has been demonstrated that Pel-3-G in its natural system is more labile than in model systems. Sastry and Tischer (1952) noted that the ACN pigments from Concord

grapes deteriorated faster in model systems than in natural systems. Ponting et al. (1960) investigated the color deterioration in grapes and other berry juices and concluded that grape juice appeared to retain color during storage somewhat better than the other juices studied.

Many factors affecting the stability of color in ACN containing products have been studied and it appears that processing and storage temperatures, oxygen, enzymes, AA and pH are the major factors influencing the degradative rate. Sugars breakdown products, amino acids, trace metals and H_2O_2 may also affect the degradation. Of the many compounds tested, the ones that are most likely to add to the stability of the color are the flavonols which are naturally found associated with ACN systems.

MATERIALS AND METHODS

Materials

Source of Strawberries

Strawberries, Tioga variety, were obatained from Fuji Farms, Troutdale, Oregon, on June 1979. They were harvested the same morning and were fully ripe. Upon arrival at OSU, Food Science Department, they were sorted out, spray washed thoroughly, drained, packed in No. 30 tins or plastic buckets of ca. 10 kg each and immediately stored at -40°C until used.

Experimental Methods

Polyphenol Oxidase Inactivation

This part of the study was designed to determine the lowest processing temperature to heat-inactivate PPO in its native state. Strawberries were thawed overnight at ambient temperature, and puree was prepared using an Oster Juice extracter. Puree samples of ca. 300 ml were heated in a microwave oven (Litton Co., System 70/50) to different temperatures starting at 100°C and going down with 5°C intervals. Samples were held at each temperature for one minute. PPO was then extracted and assayed for remaining activity as described by Wesche-Ebeling (1981) with slight modification.

Polyphenol Oxidase Extraction

The procedure of Wesche-Ebeling (1981) for the extraction of PPO from strawberries using polyvinylpolypyrolidone (PVPP) was followed with slight modification. Six grams purified PVPP (Loomis, 1974), soaked overnight in 60 ml buffer pH 4.5 (0.1 M citrate-0.2 M phosphate) at 4°C, were mixed with 7 g puree and gently stirred for 4 min. The mixture was then centrifuged at 14,000 G at 0°C for 10 min. To remove floating debris, the supernatant was passed through Whatman No. 1 filter paper. This crude enzyme extract was kept in crushed ice and assayed without further purification.

Polyphenol Oxidase Assay

A polarographic procedure using Clark-type electrode, YSI Model 53 (Yellow Springs Co.) was used to measure the oxygen consumption and hence the enzyme activity. The reaction chamber contained 2.5 ml PPO extract, equilibrated to the reaction temperature of 30°C, and 0.5 ml freshly prepared 0.1 M 4-methylcatechol in 0.02 M citrate buffer pH 3.5. Oxygen consumption was recorded for at least 4 min.

Preliminary Study

After determining the lowest processing temperature to inactivate the PPO enzyme, it was desired to estimate the least amount of AA to be added during crushing the fruit in order to

retard its action during the early stages of processing. Therefore, AA at a concentration of 0.01, 0.02, 0.05, 0.1 and 0.5% were added and mixed with ca. 500 ml strawberry puree samples before heating in a microwave oven at 70°C for one minute. Samples were cooled in an ice bath and juice was prepared by passing through nylon cloth. The juice was depectinized by adding 0.2% (V/V) pectinol L (Rohm and Haas Co.) and incubating at 37°C for 3.5 hr. To further clarify the juice, it was filtered under vacuum through Whatman No. 1 filter paper lined with 1 cm layer of celite as filter aid. The juice was then stored in 500 ml glass stoppered flasks at 21°C for about two weeks and periodically analyzed for color changes.

Juice and Concentrate Processing

The basic procedure to prepare strawberry juice and concentrate is illustrated in Figure 2. Strawberries, ca. 20 kg, were thawed in a cold room at 1°C and were crushed using a hammer mill (Hammer Mill Model D, Comminuting Machine, the W.J. Fitzpatrick Co., Chicago) at about 500 rpm using a 5/8" screen. Whenever AA was added, a freshly prepared 0.5% solution was pumped during crushing at a rate so regulated to give a final concentration of 0.01%. The crushed strawberry was immediately transferred to a stainless steel steam-jacketed kettle and heated to 70°, 80° or 90°C, except for the control sample, and held for one minute at that temperature. The samples were immediately cooled in crushed

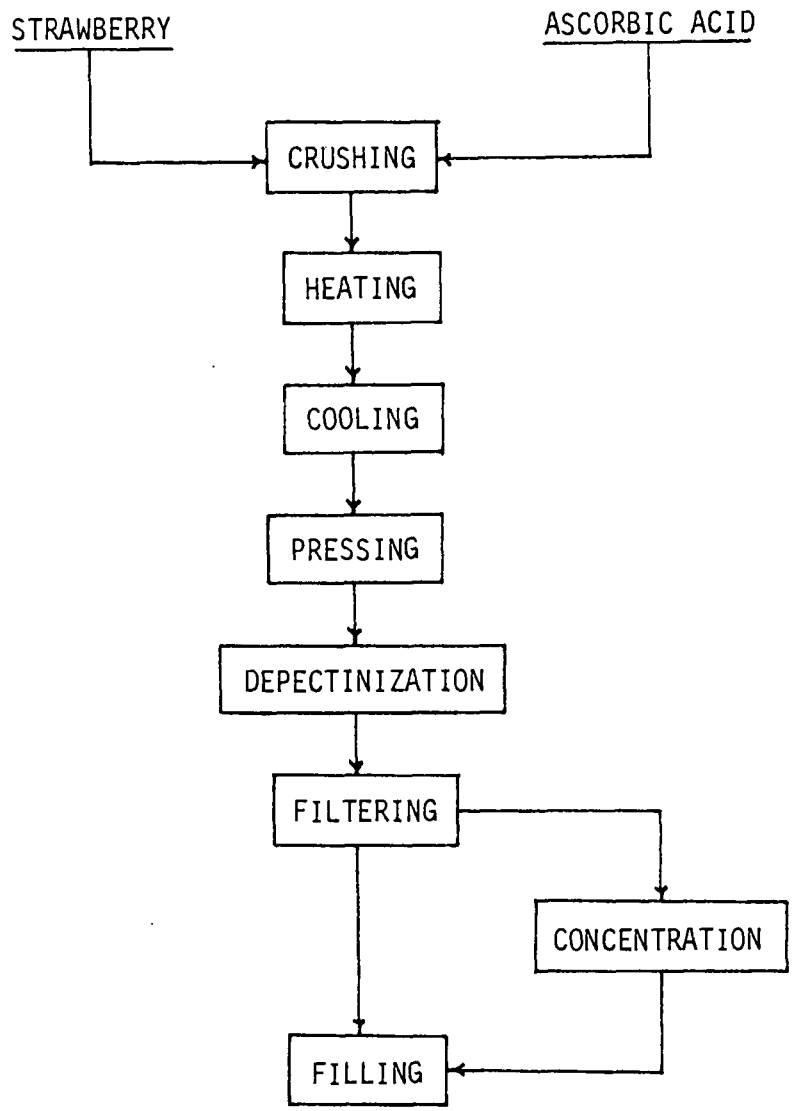


Figure 2. General Scheme used to prepare strawberry juice and concentrate.

bath to 40°C before pressing using a hydraulic rack-and-cloth type press, with maximum pressure 1200 psi. Pectinol L was added (0.2% V/W) and mixed and the juice incubated at 37°C for 3.5 hr for depectinization. The juice was then filtered under vacuum through Whatman No. 1 filter paper lined with 1 cm layer celite as a filter aid. The concentrate, 42° Brix, was prepared each time from the same batch using a vacuum evaporator; water bath 37°C, 29" Hg vacuum.

Potassium sorbate, at a concentration of 0.1% (W/V), was added as a preservative. Juice and concentrate were filled in 2 and 1 oz. sterile jars, respectively, fitted with parafilm lined screw caps, with minimum headspace. The jars were coded for easy identification and placed in boxes with dividers and stored in the dark at 1°, 21°, and 38°C. Random samples were drawn periodically throughout the study for analysis.

Analytical Methods

Samples were allowed to come to ambient temperature and briefly centrifuged to remove suspended particles before any analysis was made. All measurements were performed in duplicates, except for Hunter readings, and reported as the mean value. Spectrophotometric analyses were carried out on a Perkin-Elmer digital read-out spectrophotometer, Model 550, unless otherwise specified.

Anthocyanin Content

The pH differential method, as described by Wrolstad (1976), was used in the determination of ACN content. Measurements were taken at the aqueous absorbtion maximum of 500 nm at pH 1.0. The absorbtion at 700 nm, as a measurement of haze (Daravingas and Cain, 1968), was subtracted from that at 500 nm in computing the ACN content. Following the suggestion of Fuleki and Francis (1967) ACN content is reported in terms of the principle ACN pigment in strawberries. The molar absorbance and the molecular weight of Pel-3-G are reported to be 22,400 and 433.2 respectively (Wrolstad, 1976). Thus the formula used in computing ACN content would be as follows: ACN (mg/100 ml) =

$$\frac{(A \text{ pH } 1.0) - (A \text{ pH } 4.5)\ (df)\ (M.W.)\ (100)}{\varepsilon}$$

A = absorbance, corrected for haze

df = dilution factor

M.W. = molecular weight

ε = molecular absorbance

Average variation of the reported means was no more than 2.78%.

Abscorbic Acid

The spectrophotometric indophenol method of Loeffler and Ponting (1942) was used to determine AA content. A standard curve was prepared and results are reported as mg/100 ml juice or concentrate. This analysis was performed using a Bausch and Lomb

Spectronic 20 spectrophotometer. Average variation of the reported means was less than 3.81%, except for last day analysis on samples stored at 21°C where it was about 31%.

Flavanols and Leucoanthocyanins

The spectrophotometric technique developed by Swain and Hillis (1959) was applied in determining flavanols and leucoanthocyanins content. Results were reported as absorbance units per ml samples. Average variation of the reported means was less than 1.53%.

Total Phenolics

Total phenolics content were determined by the Folin-Ciocalteau reagent as described by Singleton and Rossi (1965). A standard curve was prepared using twice crystalized gallic acid and results were reported as mg gallic acid equivalents per ml samples. Average variation of the reported means was less than 4.57%.

Browning, Color Density, Polymeric Color and Percent Polymeric Color

Color density, polymeric color and percent polymeric color were determined from spectral analyses of potassium metabisulfite-treated samples as described by Somers (1971) and Wrolstad (1976). Color density, sum of the absorbances at 500 and 420 nm, measures the total sample color while polymeric color, sum of the absorb-

ances at 500 and 420 nm of the treated samples, measures the color contributed by tannins. Percent polymeric color is defined as the percent ratio of polymeric color to that of color density. The absorbance at 420 nm of the bisulfite-treated samples was recorded as a measurement of browning. In all cases, absorbance measurements were corrected for haze. Average variation of the reported means were less than 4.46, 0.38, 1.85 and 2.31% for browning, color density, polymeric color and percent polymeric color, respectively.

Colorimetric Measurements

Hunter L, a, and b color parameters were measured in the transmission mode using a Hunter Model D25 P-2 Color Difference Meter which was standardized against a white tile (No. DC 122, L=+94.02, a=-0.9, b=+1.2). All measurements were made with the light source pivoted and the specular component included (Arrangement III) using a 5 mm light path.

RESULTS AND DISCUSSION

Manufacturers of concentrates have known that certain strawberry varities would yield a product with better color qualities than would others. The Tioga variety was reported by Lee (1979) to have more PPO activity than the Hood variety. Moreover, Abers and Wrolstad (1979) reported that the high content of phenolics in the Tioga variety makes its products more susceptible to browning reactions. The Tioga variety was used in this study to magnify results which would be inferred, then, to other varieties. AA was added to counteract PPO activity in the early stages of processing.

BLANCHING STUDIES

Effect of Blanching on the Chemical Composition

Blanching of crushed strawberries was performed for 1 min at 70°, 80°, and 90°C. The lowest blanching temperature, 70°C, was found, in the preliminary study, to inactivate PPO in strawberry purees. Moreover, PPO was extracted from each batch and assayed; no activity was detected at any of the blanching temperatures investigated.

The effect of blanching on some of the chemical constitutents of strawberry concentrate and juice is shown in Tables 1 and 2,

Table 1. Effect of blanching on some chemical constituents in strawberry concentrate

Constituent	Blanching Temp.(°C)						
	70	70*	80	80*	90	90*	Control
Anthocyanins mg/100ml	89.84	87.10	98.84	94.65	96.44	91.65	85.37
Ascorbic Acid mg/100ml	16.65	19.76	19.62	23.71	18.49	22.01	10.16
Leucoantho-cyanins A**/ml	8.28	8.00	8.81	8.42	8.57	8.33	7.76
Flavanols A**/ml	30.49	29.58	31.98	30.94	31.53	30.62	20.06
Total Phenolics mg gallic acid/ml	8.79	8.60	9.36	9.06	9.16	8.90	8.43

*Added ascorbic acid (.01%).
**Absorbance units.

Table 2. Effect of blanching on some chemical constituents in strawberry juice

Constituent	Blanching Temp.(°C)						
	70	70*	80	80*	90	90*	Control
Anthocyanins mg/100ml	20.46	19.87	22.38	21.48	21.89	20.85	19.48
Ascorbic Acid mg/100ml	14.18	18.84	16.30	21.59	15.59	20.60	8.96
Leucoantho-cyanins A**/ml	1.87	1.81	1.98	1.90	1.93	1.88	1.76
Flavanols A**/ml	7.06	6.88	7.38	7.17	7.29	7.12	6.75
Total Phenolics mg gallic acid/ml	1.99	1.92	2.10	2.04	2.06	2.00	1.90

*Added ascorbic acid (.01%).
**Absorbance unit.

respectively. The chemicals investigated in this study are those, directly or indirectly, pertinent to color and color stability in strawberry concentrate and juice. As would be expected, blanching, at any temperature, showed a protective effect on all the chemical constituents tested. Blanching at 80°C showed the most protective effect, followed by those at 90° and 70°C. Although blanching at 70°C inactivated PPO, it would be reasonable to suggest that other degradative reactions took place at a much faster rate than on blanching at 90°C. The protective effect of blanching at 80°C corroborates very well with the results reported by Wrolstad et al. (1980) in their study of microwave blanched whole strawberries.

AA addition exerted an adverse effect on all other constituents when compared to blanched samples without added AA, although all samples showed higher values than the controls. It is evident that the protective effect of blanching was much higher than the degradative effect of AA. The most marked protective effect of blanching was observed with AA. AA content of the concentrate sample blanched at 80°C was almost double that of the control, being 19.62 and 10.16 mg/100 ml, respectively. Sistrunk et al. (1980) reported similar results with blanched strawberry puree. This protective effect of blanching, which was observed in both concentrate and juice samples, would largely be ascribed to the inactivation of PPO and other enzymes in the system.

Due to lack of information in the literature on the effect of the concentration process on the chemical constituents in strawberry juice, a modest contribution is in order. All chemical constituents tested experienced a loss of varying magnitude on concentration when compared to those of the single strength juice (Table 3). Once again, samples blanched at 80°C experienced the least loss followed by those blanched at 90° and 70°C. The control sample lost the most. The addition of AA aggravated the loss at any blanching temperature except in the case of total phenolics in samples blanched at 90° and 70°C. The greatest loss was observed with AA where all samples lost more than 74% of their AA content, which is in agreement with Wrolstad et al. (1980) who reported similar results.

Effect of Blanching on the Color Parameters

Effect on Browning, Color Density, Polymeric Color and Percent Polymeric Color

The effect of blanching on the initial color parameters in strawberry concentrate and juice are shown in Tables 4 and 5, respectively. As can be seen in the tables, blanching increased browning formation in the concentrate and juice samples. The increase in browning followed the increase in blanching temperatures, being highest on blanching at 90°C and lowest in the unblanched samples (control). Polymeric color, which is a measure of the contribution of tannins to color, followed the same

Table 3. Effect of the concentration process on some chemical constituents* in strawberry juice concentrated to 42°Brix.

Constituent	Blanching Temp.(°C)						
	70	70**	80	80**	90	90**	Control
Anthocyanins	5.91	6.07	5.36	5.58	5.59	5.81	6.09
Ascorbic Acid	74.84	77.53	74.21	74.47	74.59	77.10	75.70
Leucoantho-cyanins	5.12	5.29	4.65	5.04	4.85	5.05	5.52
Flavanols	7.46	7.87	7.14	7.53	7.32	7.85	7.75
Total Phenolics	5.35	4.02	4.49	4.73	4.72	4.64	4.92

*Percent loss.
**Added ascorbic acid (.01%).

Table 4. Effect of blanching on color parameters in strawberry concentrate

Blanching Temp.(°C)	Browning A*/ml	Polymeric Color A*/ml	Color Density A*/ml	%Polymeric Color
70	2.83	6.63	41.08	8.84
70+AA**	2.78	3.54	39.63	8.93
80	2.90	3.73	44.51	8.38
80+AA**	2.83	3.61	41.51	8.69
90	2.97	3.80	43.98	8.64
90+AA**	2.85	3.68	41.68	8.83
Control	2.58	3.43	37.88	9.05

*Absorbance unit.

**Added ascorbic acid (.01%).

Table 5. Effect of blanching on color parameters in strawberry juice

Blanching Temp.(°C)	Browning A*/ml	Polymeric Color A*/ml	Color Density A*/ml	%Polymeric Color
70	.55	.71	8.26	8.60
70+AA**	.54	.68	7.82	8.70
80	.56	.72	8.89	8.10
80+AA**	.53	.69	8.24	8.37
90	.57	.74	8.92	8.30
90+AA**	.54	.70	8.24	8.50
Control	.48	.64	7.11	9.00

*Absorbance units.

**Added ascorbic acid (.01%).

pattern. The addition of AA decreased both browning and polymeric color values when compared to samples blanched at the same temperature without AA, but all samples showed higher values than the controls.

Color density, which measures the total color, also increased on blanching. The highest increase was noticed in the concentrate sample blanched at 80°C, followed by that blanched at 90°C with the least increase noticed in concentrate sample blanched at 70°C. Color density in juice samples followed the pattern observed with browning and polymeric color. The different behaviour of color density in the concentrate and juice samples would be attributed to the effects of the concentration process. AA seems to exert a bleaching effect as manifested by the decreased color density whenever it was added.

Color density by itself would not be a good indicative factor of a product's color. It measures the absorbance at 500 nm and 420 nm, which would include both monomeric as well as polymeric colors. When color density is viewed along with polymeric color, we would have a better understanding of a product's color. Percent polymeric color, therefore, would be a better indicator of the type of color in a product. As shown in Tables 4 and 5, blanching decreased the percent polymeric color. The control samples showed the highest, while samples blanched at 80°C showed the lowest levels of percent polymeric color. Samples blanched

at 90° and 70°C were in between. Although the control samples showed the lowest values of browning and polymeric color, they showed the highest percent polymeric color which would suggest a PPO and other enzymes' involvement at this early stage. These findings corroborate very well with those reported earlier with the chemical constituents. Addition of AA increased the percent polymeric color in the same fashion it decreased the chemical constituents which would suggest AA role in the degradation reactions.

Effect on Colorimetric Parameters

Transmission colorimetric data in the Hunter L, a and b are widely used in the food industry and research institutes to measure the visual appearance of products as would be perceived by the human eye. "L" value is a measure of lightness, while "a" and "b" measure the chromaticity of a product. The hue angle is a widely used single-number function to describe hue in foods. Livingston et al. (1959) demonstrated that the hue angle had the most significant correlation with visual scores. $Tan^{-1}b/a$ would be used in this study as a measure of hue angle following the suggestion of Little (1975). It should be noted, though, that color measuring instruments are not sensitive enough, with dark-colored foods, to measure accurately the chromaticity of such dark foods (Eagerman et al., 1973). Chromaticity measurements for strawberry concentrate, therefore, are merely used in this

study for comparison reasons, and in no way should they be inferred as actual color parameters as perceived by the human eye.

The effect of blanching on "L", "a" and hue angle in strawberry concentrate and juice are shown in Tables 6 and 7, respectively. As reported by Wrolstad et al. (1980) blanching decreased "L" value, i.e., concentrate and juice samples became darker on heating. Browning formation would be the main cause of this darkening. This effect increased with the increase in blanching temperatures. AA aggravated this darkening effect in the concentrate samples which concurs with the results reported by Sistrunk and Cash (1970) in their study on strawberry puree. In juice samples, on the other hand, AA increased "L" value. This bleaching effect of AA was, also, reported by Poei-Langston and Wrolstad (1981) in an extensive study on a model system of strawberry ACN.

Hunter a value, redness, showed similar trends in both strawberry concentrate and juice samples; that is, decreased with the increase of blanching temperatures. Addition of AA aggravated this effect at any blanching temperature. This effect of blanching and AA on "a" value is in agreement with the literature (Sistrunk and Cash, 1970; Wrolstad et al., 1980; and Poei-Langston and Wrolstad, 1981).

By definition the hue angle, $\tan^{-1} b/a$, would relate yellowness to redness at certain lightness. It follows, therefore, that

Table 6. Effect of blanching on Hunter colorimetric parameters of strawberry concentrate

Blanching Temp. (°C)	L	a	Hue angle ($tan^{-1}b/a$)
70	25.4	44.0	20.0
70+AA*	24.5	44.0	20.9
80	24.8	44.6	20.5
80+AA*	24.0	43.9	21.6
90	24.3	44.1	21.1
90+AA*	23.6	43.5	21.9
Control	26.2	46.4	19.1

*Added ascorbic acid (.01%).

Table 7. Effect of blanching on Hunter colorimetric parameters of strawberry juice

Blanching Temp. (°C)	L	a	Hue angle ($\tan^{-1}$b/a)
70	50.6	48.8	19.8
70+AA*	52.4	47.6	20.8
80	49.2	48.1	20.5
80+AA*	50.9	47.3	21.5
90	47.7	47.6	21.0
90+AA*	49.4	46.8	21.8
Control	56.4	50.4	18.9

*Added ascorbic acid (.01%).

a greater hue angle would indicate a less red color. In this respect, hue angle followed a pattern similar to that of "a" value. All blanched samples had greater hue angle values than the control samples, and samples with added AA had even greater values.

STORAGE STUDIES

Effect of Storage on the Chemical Composition

Effect on Anthocyanins

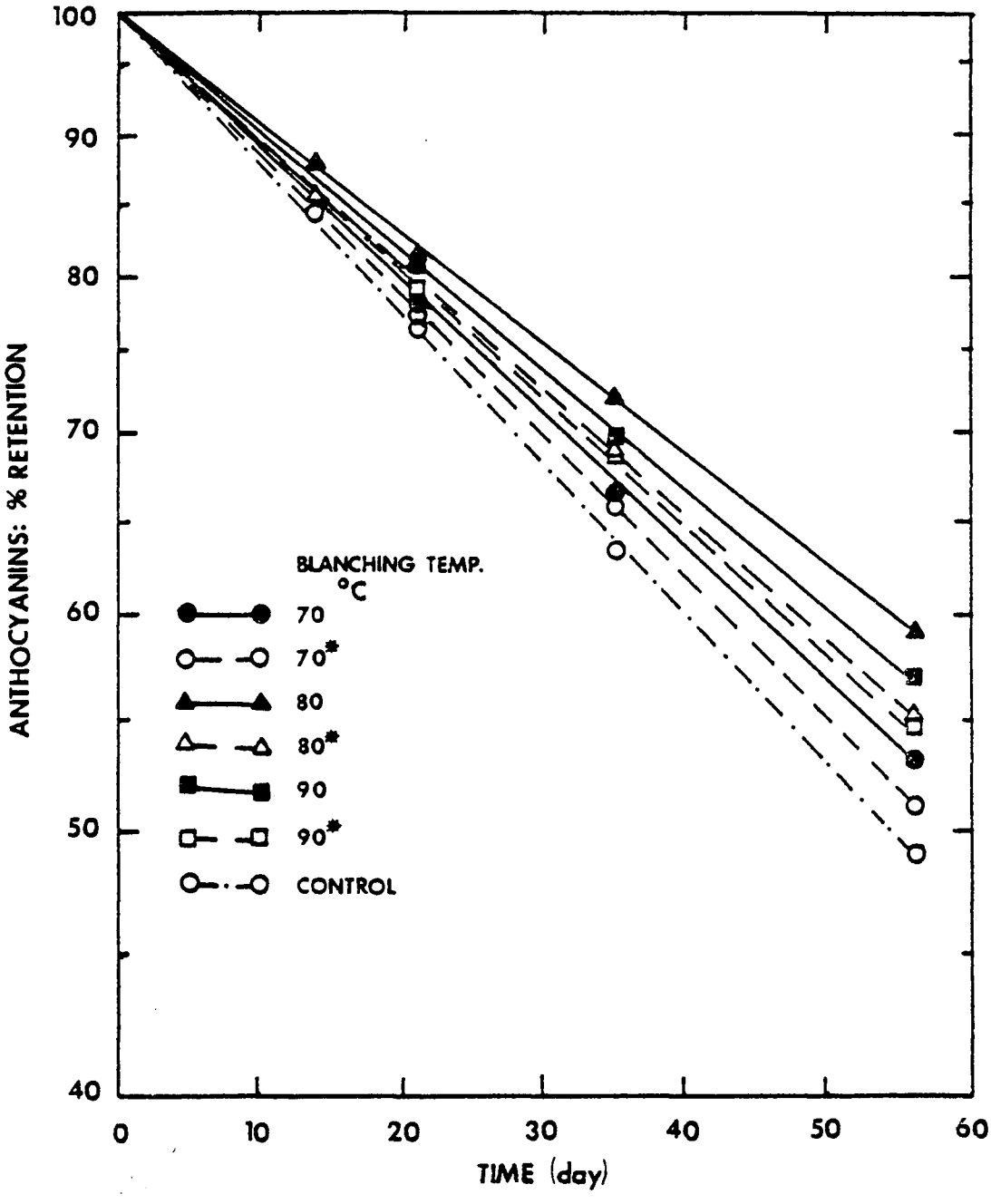
Strawberry concentrate and juice samples were stored at three different temperatures for 56 and 21 days, respectively. The high economical value of strawberry concentrate to the food industry, as well as the high instability of the ACN system in the single-strength juice, dictated that emphasis would be more on the concentrate rather than the juice. Therefore, 21 days of juice storage was deemed to be sufficient to give a better understanding of the color in this product.

Data obtained for the degradation of ACN, in samples stored at 1°C, followed first order kinetics. The resulting regression lines showed good linearity. First order rate constants and corresponding correlation coefficients are listed in Table 8, and the resulting regression lines for ACN degradation in strawberry concentrate and juice are depicted in Figures 3 and 4, respectively. It is evident that blanching provided a protective

Table 8. First order rate constants for the degradation of anthocyanins in strawberry concentrate and juice stored at 1°C

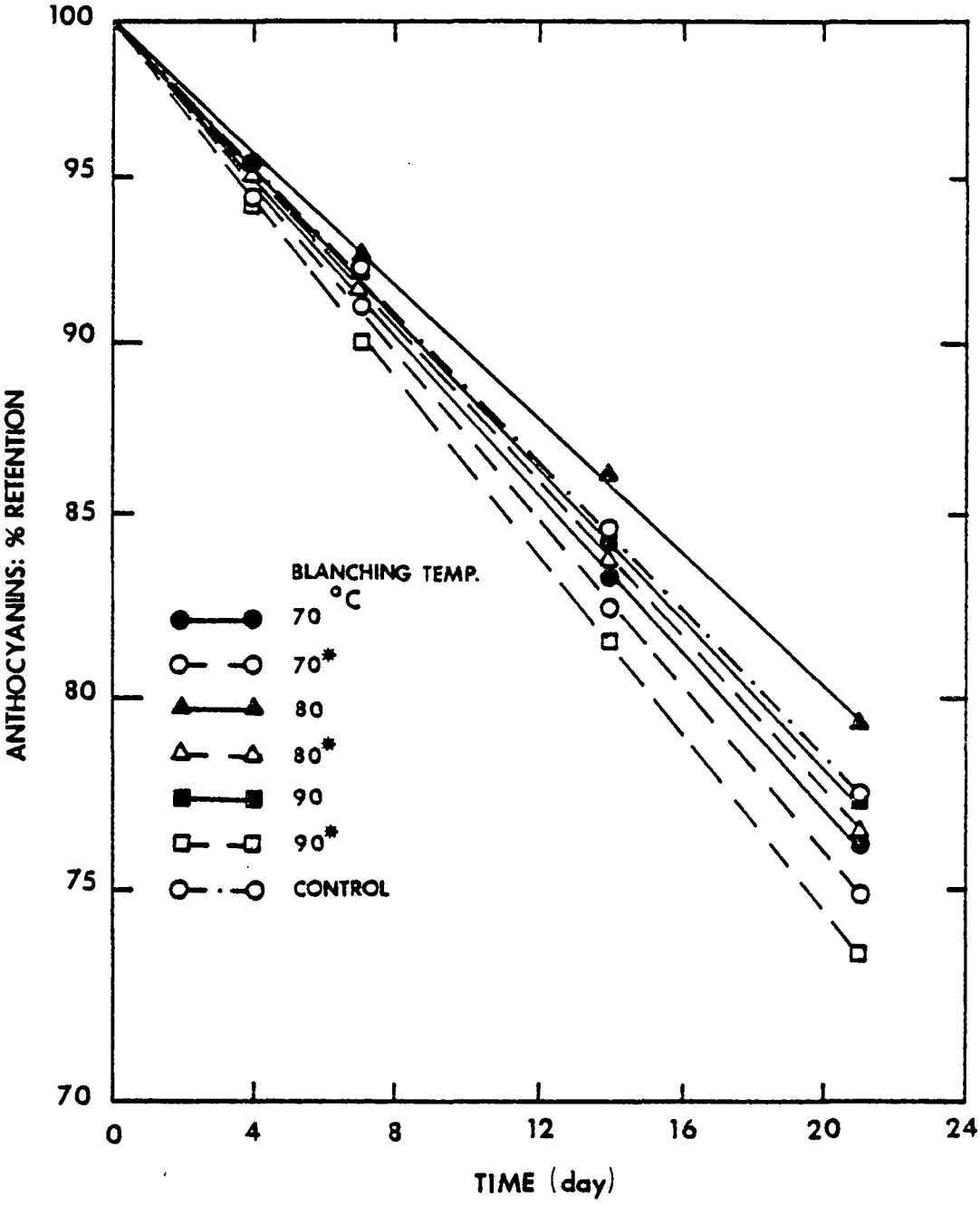
Blanching Temp.(°C)	Concentrate k(day^{-1})	corr. coeff.	Juice k(day^{-1})	corr. coeff.
70	1.22×10^{-2}	-.962	1.35×10^{-2}	-.951
70+AA*	1.38×10^{-2}	-.978	1.42×10^{-2}	-.965
80	9.46×10^{-3}	-.992	1.11×10^{-2}	-.957
80+AA*	1.12×10^{-2}	-.988	1.38×10^{-2}	-.970
90	1.06×10^{-2}	-.984	1.51×10^{-2}	-.936
90+AA*	1.14×10^{-2}	-.979	1.25×10^{-2}	-.973
Control	1.24×10^{-2}	-.984	1.23×10^{-2}	-.988

*Added ascorbic acid (.01%).



*Added ascorbic acid (.01%).

Figure 3. Regression lines for degradation of anthocyanins in strawberry concentrate stored at 1°C.



*Added ascorbic acid (.01%).

Figure 4. Regression lines for degradation of anthocyanins in strawberry juice stored at 1°C.

effect on ACN degradation rate. Blanching at 80°C, showed the highest protective effects. The higher blanching temperature of 90°C seemed to exert less protective effect than that at 80°C, which would be attributed to accelerated reactions at this high temperature. Wrolstad et al. (1980), on blanching whole strawberries in a microwave oven, demonstrated the protective effect of blanching on ACN in strawberry concentrate and juice, which corroborated well with Sistrunk and Cash (1970) results in studying strawberry puree. The higher ACN degradation rates observed in the controls would reflect the involvement of PPO and other enzymes in the destruction of ACN.

When AA was added to the system, it increased ACN degradation rates at any blanching temperature. Samples blanched at 70°C with added AA showed even greater degradation rates than the control. Reports by Starr and Francis (1968) and Shrikhande and Francis (1974) indicate that AA effect on the degradation of ACN was due to AA oxidation products, e.g., H_2O_2, interaction with ACN, while Poei-Langston and Wrolstad (1981) demonstrated a direct condensation of ACN and AA resulting in the loss of both. It is evident that AA is a major factor in the degradation of ACN in strawberry systems, a point that should be considered in the food industry in selecting strawberry varieties with less AA content.

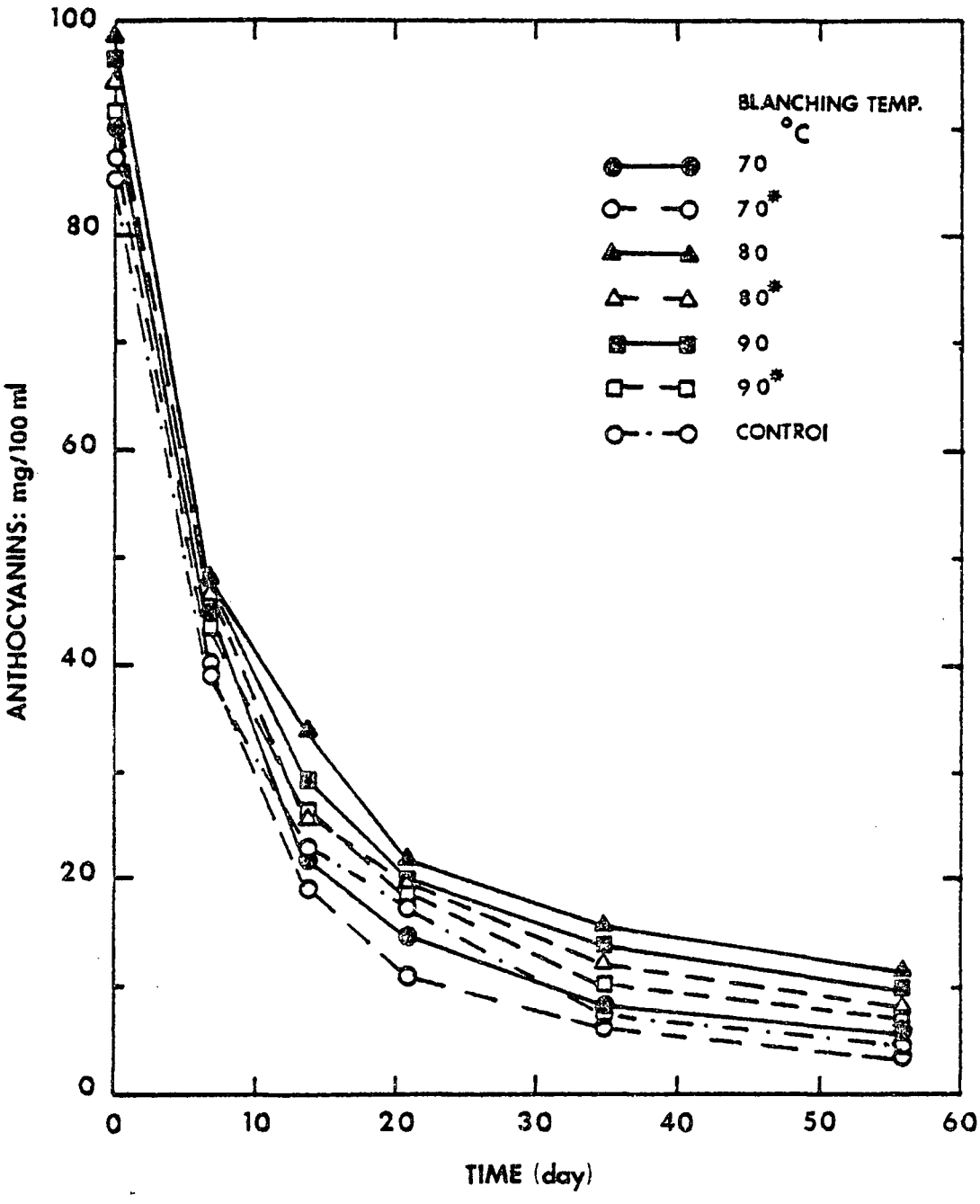
ACN degradation at 21° and 38°C storage temperatures did not

adhere to first order reaction kinetics. This was not considered unreasonable in this complex system. ACN degradation in strawberry concentrate and juice samples stored at 21°C are shown in Figures 5 and 6, respectively. Rapid loss of ACN was noticed at these temperatures. More than 50% ACN degradation took place within the first two weeks of storage at 21°C and well over 85% of ACN was lost by the end of the storage period. Throughout the storage period samples showed the same trend, and AA effect was similar to that observed on storage at 1°C.

Storage at 38°C showed identical effect on ACN with, not surprisingly, much faster degradation rates. Concentrate samples showed more than 75% degradation by the end of the first week of storage. A burnt flavor was observed by the end of the second week and ACN was totally undetectable by the end of the storage period (see Appendix 1). Juice samples showed the same trend, apart from the burnt flavor which was not observed. By the end of the storage period more than 75% degradation occurred (Appendix 1). This concurs with the results reported by Abers and Wrolstad (1979) on studying the effect of storage temperatures on ACN in strawberry preserves.

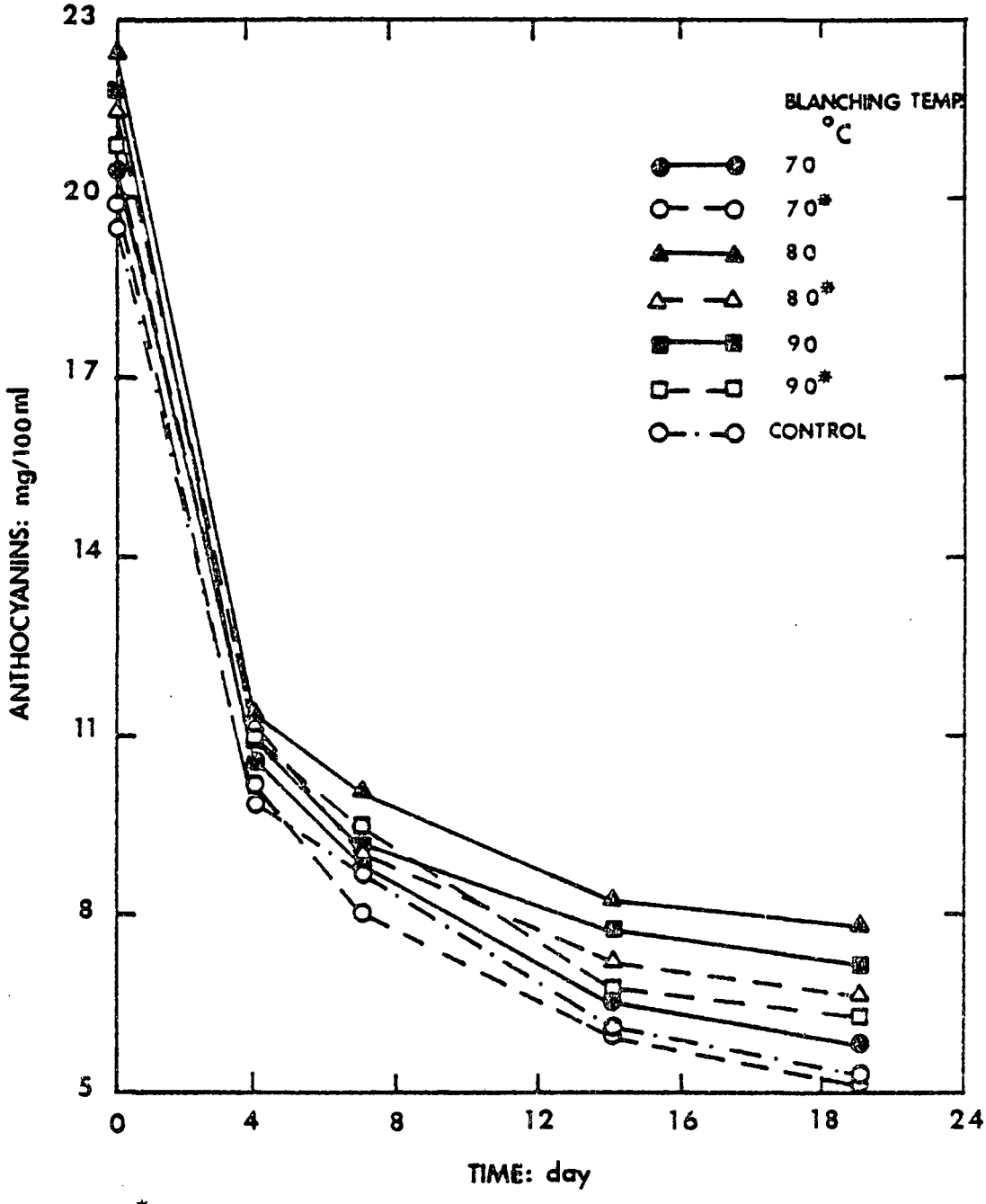
Effect on Ascorbic Acid

Many factors have been attributed to the oxidative destruction of AA in food systems. Oxidative enzymes, such as PPO, AA oxidase and peroxidase, have been reported to contribute to the



*Added ascorbic acid (.01%).

Figure 5. Anthocyanin retention in strawberry concentrate stored at 21°C.



*Added ascorbic acid (.01%).

Figure 6. Anthocyanin retention in strawberry juice stored at 21°C.

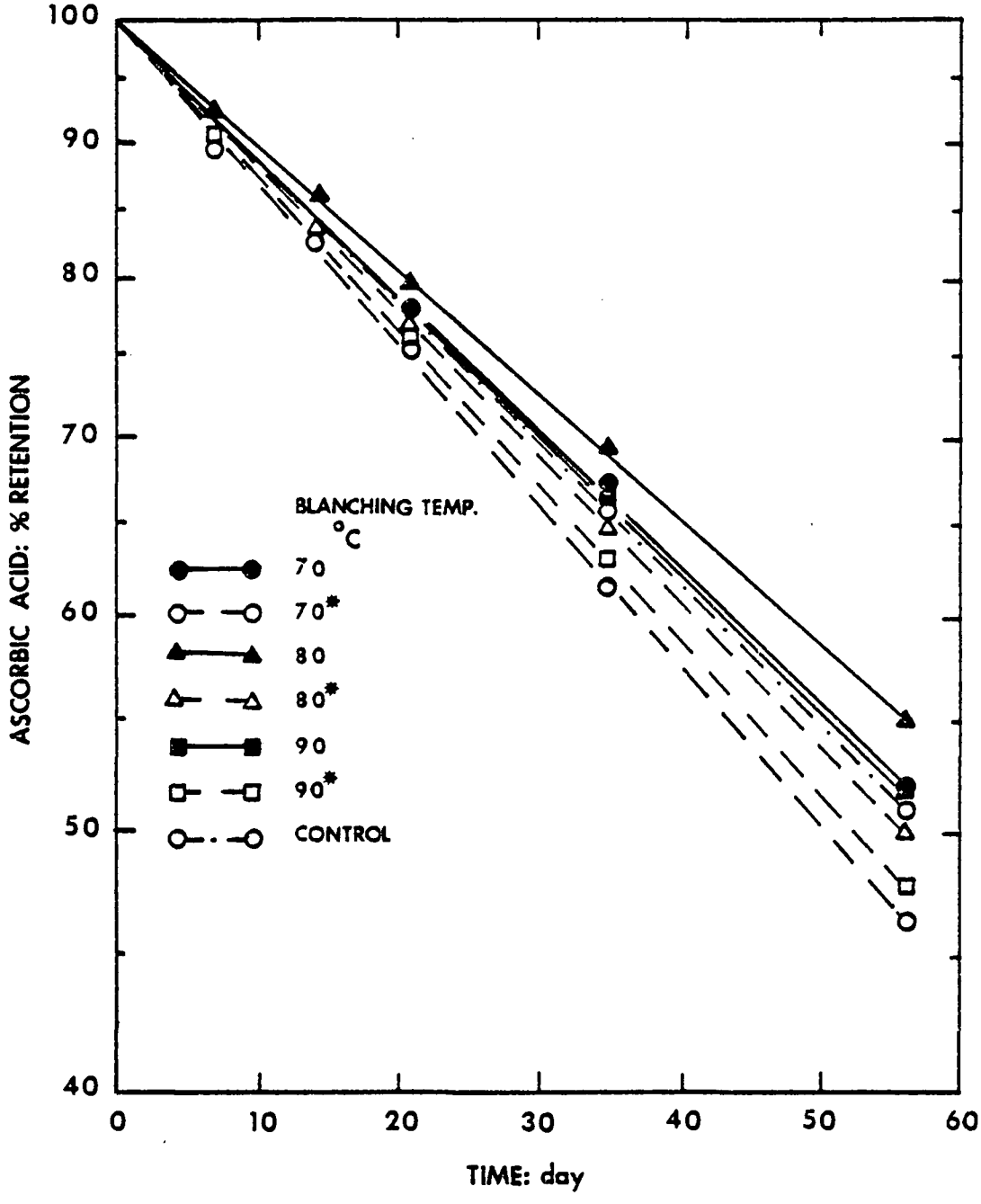
decomposition of AA in the presence of oxygen (Ponting and Joslyn, 1948; and Bauernfeind and Pinker, 1970). Only AA oxidase, of this group, would react directly degrading AA, and Green (1971) reported that the main oxidative loss of AA in soft fruits was due to the direct action of this enzyme. Non-enzymic degradation of AA was, also, reported (Kurata and Sakamura, 1967a, b).

AA degradation in strawberry concentrate and juice samples stored at 1°C showed a first order reaction kinetics. Table 9 lists the first order rate constants and corresponding correlation coefficients for the degradation of AA in strawberry concentrate and juice, and the resulting regression lines are depicted in Figures 7 and 8, respectively. As mentioned above, concentrate samples lost more than 75% of their AA content on concentration; nevertheless, AA degradation continued during storage. Blanched samples maintained higher AA content throughout the storage period. Samples with added AA maintained higher AA concentrations, although AA degradation rates in these samples was much higher than blanched samples without AA (Table 9). The higher initial AA contents in these samples may have caused the increased degradation rates of AA (Bauernfeind and Pinkert, 1970). The head-space and dissolved oxygen would, also, increase the degradation rate of AA. Blanching at 80°C provided the most protective effect on AA, followed by blanching at 90°C with blanching at 70°C showing the

Table 9. First order rate constants for the degradation of ascorbic acid in strawberry concentrate and juice stored at 1°C

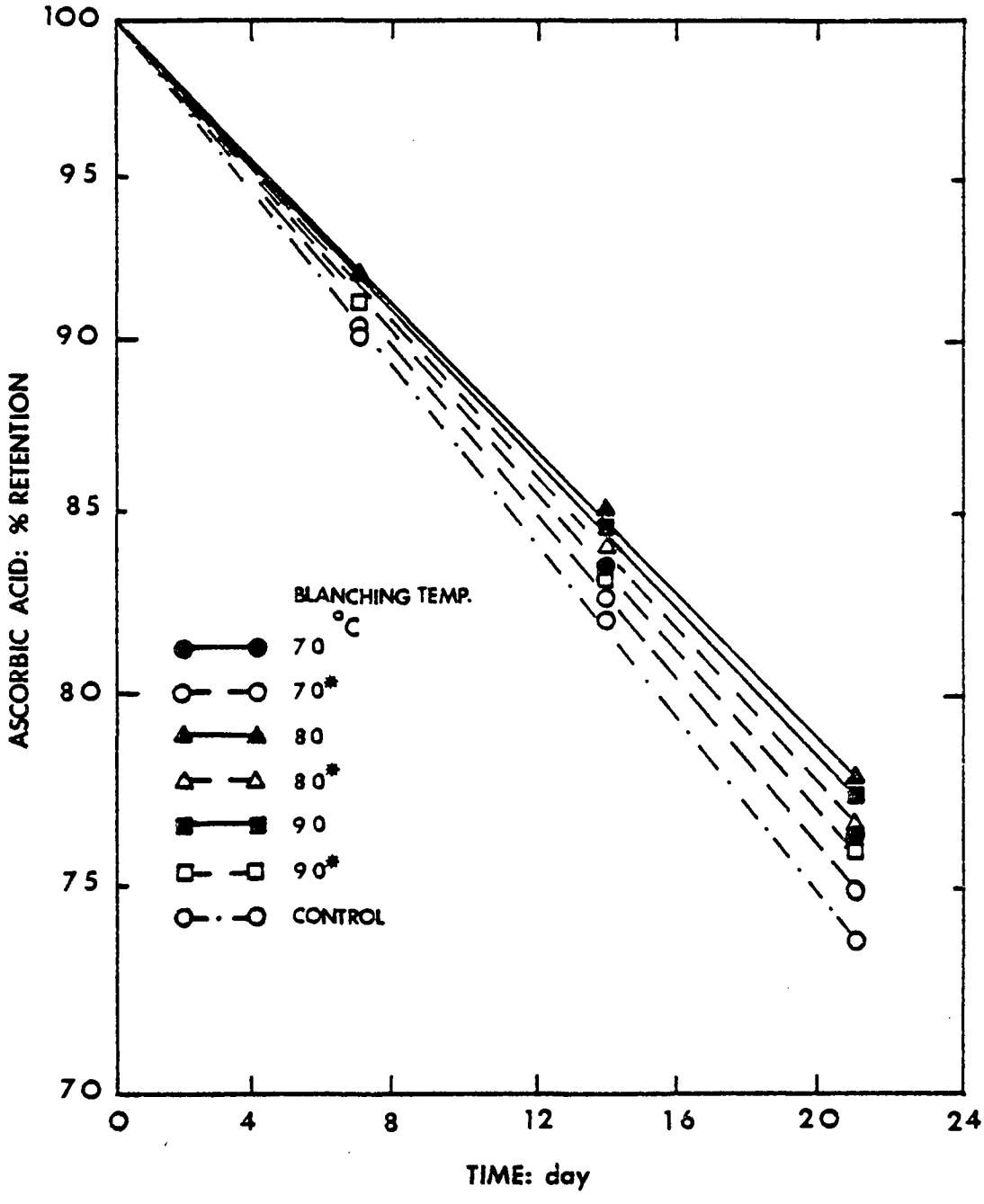
Blanching Temp.(°C)	Concentrate k(day^{-1})	Concentrate corr. coeff.	Juice k(day^{-1})	Juice corr. coeff.
70	1.22×10^{-2}	-.994	1.29×10^{-2}	-.997
70+AA*	1.46×10^{-2}	-.984	1.39×10^{-2}	-.999
80	1.10×10^{-2}	-.996	1.20×10^{-2}	-.995
80+AA*	1.31×10^{-2}	-.990	1.27×10^{-2}	-.997
90	1.24×10^{-2}	-.984	1.23×10^{-2}	-.997
90+AA*	1.40×10^{-2}	-.979	1.33×10^{-2}	-.996
Control	1.25×10^{-2}	-.992	1.48×10^{-2}	-.996

*Added ascorbic acid (.01%).



*Added ascorbic acid (.01%).

Figure 7. Regression lines for degradation of ascorbic acid in strawberry concentrate stored at 1°C.



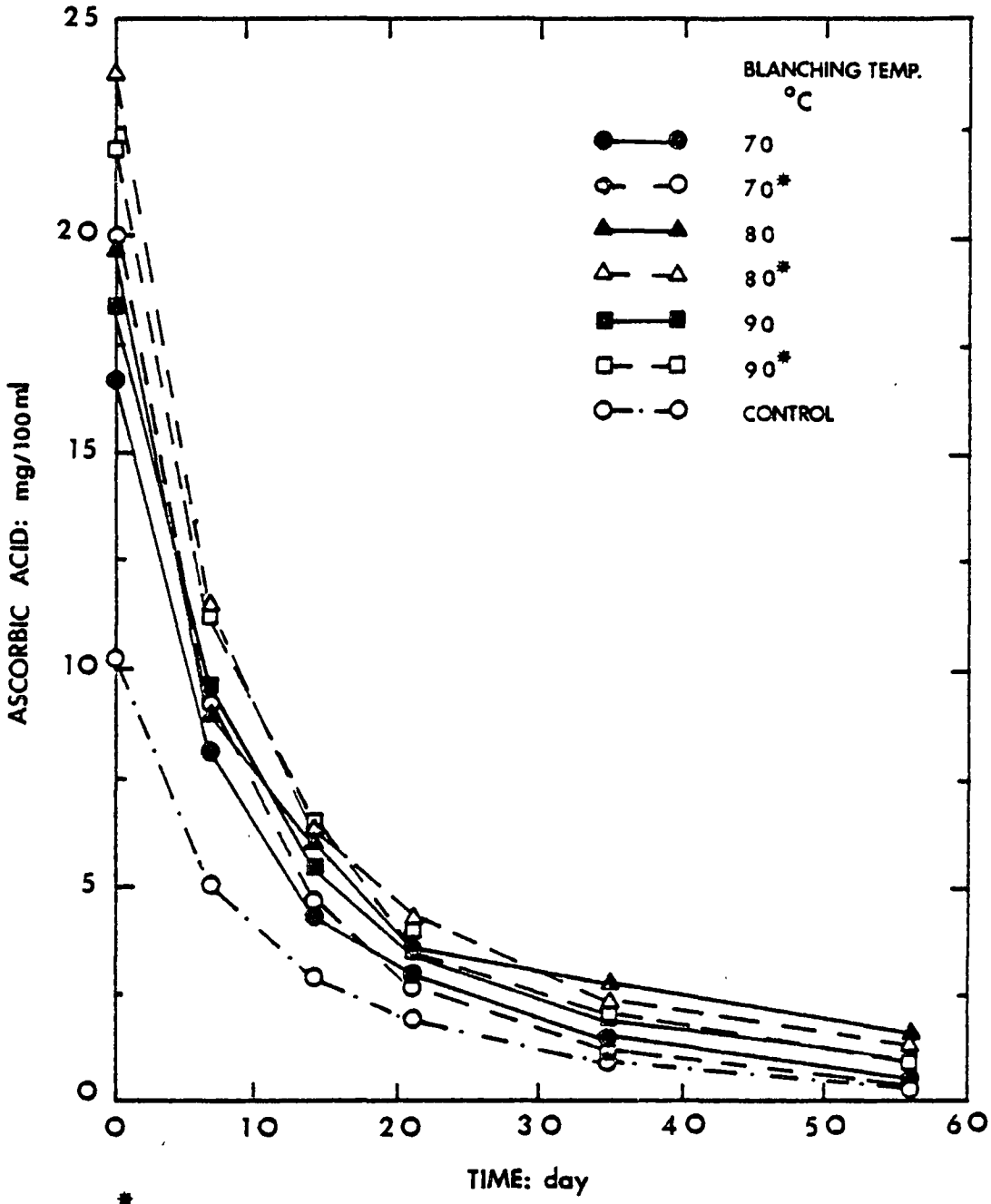
*Added ascorbic acid (.01%).

Figure 8. Regression lines for degradation of ascorbic acid in strawberry juice stored at 1°C.

least protective effect. Control samples showed the highest degradation rates, which would be expected in a system containing active oxidative enzymes.

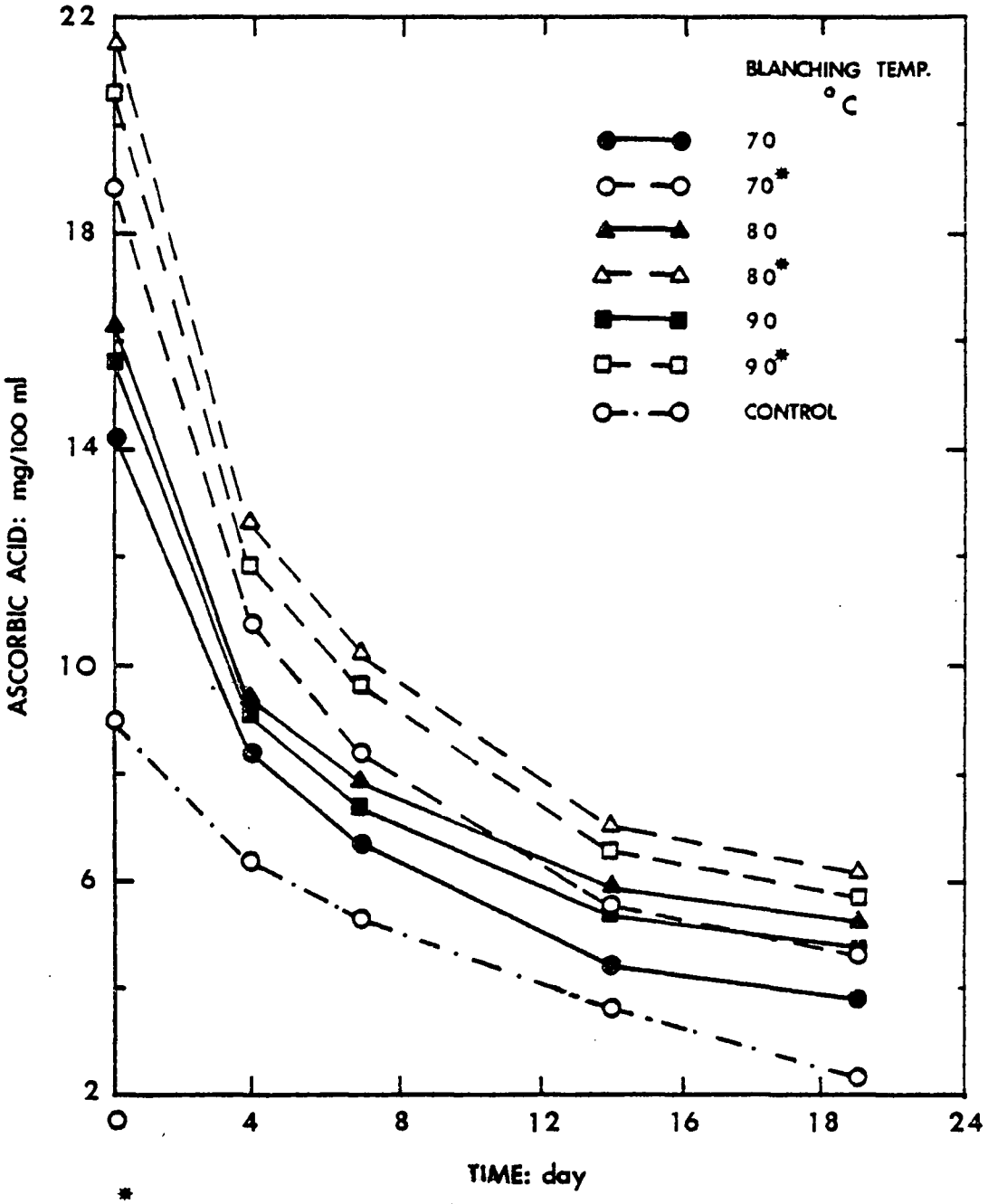
AA degradation in strawberry concentrate and juice stored at 21°C are shown in Figures 9 and 10, respectively. AA is, obviously, not a stable compound in strawberry systems. All samples lost about 50% of their AA content by the end of the first week and contained negligible amounts at the end of the storage period. It is evident that AA degradation occurred both enzymically, (control samples), and non-enzymically, (blanched samples). Nevertheless, blanched samples maintained higher AA levels than the control samples, which concurs with the results reported by Wrolstad et al. (1980) on a similar system. The striking similarity in the degradation of AA and ACN would suggest a major role of AA in the degradation of ACN. A direct condensation type of reaction between AA and ACN was reported by Jurd (1968) and was, later, demonstrated by Poei-Langston and Wrolstad (1981).

AA degradation in strawberry concentrate and juice samples stored at 38°C followed similar trends as those observed with samples stored at 21°C but with much faster degradation rates. Concentrate samples lost all their AA content by the end of the storage period (Appendix 2), while juice samples lost more than



* Added ascorbic acid (.01%).

Figure 9. Ascorbic acid retention in strawberry concentrate stored at 21°C.



* Added ascorbic acid (.01%).

Figure 10. Ascorbic acid retention in strawberry juice stored at 21°C.

80% of their AA. This increased AA degradation at higher storage temperatures concurs with the results of Beattie et al. (1943) reported in their study of AA degradation in different ACN containing fruit juices. AA degradation in other fruit juices was, also, reported to increase with increasing storage temperatures. Smoot and Nagy (1980) observed high AA losses in single-strength grapefruit juice with high storage temperatures.

Effect on Leucoanthocyanins, Flavanols and Total Phenolics

Leucoanthocyanins, flavanols and total phenolics degradation at various storage temperatures followed a similar pattern and, therefore, will be discussed collectively in this treatise. Both of the flavonoid compounds, along with some phenolics of the cinnamic acid derivative nature, are naturally found associated with ACN systems. Most of these phenolics, such as catechin and caffeic acid, contain o-hydroxy groups and may, therefore, serve as PPO substrates and contribute to the color loss of strawberry products.

Tables 10, 11, and 12 list the concentration of leucoanthocyanins, flavanols and total phenolics, respectively, in strawberry concentrate and juice at the end of the storage period. As would be expected, the degradation progressed at much faster rates as the storage temperatures increased. This was observed in

Table 10. Effect of storage temperatures on leucoanthocyanins* in strawberry concentrate and juice

Blanching Temp. °C	Concentrate			Juice		
	Temperature °C					
	1	21	38	1	21	38
70	7.46	5.90	4.30	1.71	1.47	1.19
70+AA**	7.27	5.53	3.84	1.64	1.64	1.12
80	7.73	6.50	4.85	1.82	1.61	1.34
80+AA**	7.52	6.05	4.46	1.73	1.51	1.23
90	7.64	6.23	4.67	1.77	1.55	1.27
90+AA**	7.43	5.90	4.32	1.68	1.47	1.19
Control	7.14	5.63	3.94	1.60	1.36	1.08

*Expressed as absorbance units per ml.

**Added ascorbic acid (.01%).

Table 11. Effect of storage temperatures on flavanols* in strawberry concentrate and juice

Blanching Temp. °C	Concentrate			Juice		
	Temperature °C					
	1	21	38	1	21	38
70	28.03	22.83	17.78	6.49	5.64	4.53
70+AA**	27.09	21.68	16.54	6.27	5.41	4.22
80	29.06	24.64	20.61	6.92	6.15	5.19
80+AA**	28.28	23.34	18.92	6.62	5.83	4.79
90	28.67	24.12	19.57	6.74	5.95	4.91
90+AA**	27.83	22.78	18.02	6.40	5.59	4.49
Control	27.20	21.94	16.59	6.11	5.30	4.24

*Expressed as absorbance units per ml.

**Added ascorbic acid (.01%).

Table 12. Effect of storage temperatures on total phenolics* in strawberry concentrate and juice

Blanching Temp. °C	Concentrate			Juice		
	Temperature °C					
	1	21	38	1	21	38
70	8.22	7.20	5.94	1.85	1.62	1.38
70+AA**	7.99	6.93	5.58	1.78	1.55	1.32
80	8.36	7.67	6.60	1.98	1.79	1.58
80+AA**	8.36	7.35	6.12	1.91	1.70	1.48
90	8.44	7.49	6.32	1.92	1.73	1.53
90+AA**	8.21	7.21	5.53	1.86	1.65	1.43
Control	7.84	6.86	5.60	1.75	1.52	1.34

*Expressed as mg gallic acid per ml.

**Added ascorbic acid (.01%).

concentrate and juice samples at any storage temperature (Appendices 3 through 8). Blanched samples contained higher concentrations, at the beginning of the study, and maintained higher values throughout the storage period when compared to the control samples. This is in agreement with the results reported by Wrolstad et al. (1980) on similar strawberry systems, and Poei-Langston and Wrolstad (1981) on model system. Whenever AA was added to the system, it increased the loss of these compounds. Samples blanched at 80°C maintained the highest level throughout the study, followed by those blanched at 90°C, samples blanched at 70°C were comparable to the controls. Although blanching at 70°C inactivated PPO, either other enzymes were not inactivated or the inactivation was not totally complete or could not be detected by the instrument. This would explain the higher phenolics degradation observed in samples blanched at 70°C.

Markakis (1974) reported that leucoanthocyanins would copolymerize with ACN forming new colored compounds. Catechin, a flavanol, was suggested by Timberlake and Bridle (1977) to interact with ACN contributing to the loss of the red color and the formation of browning products. A similar interaction between AA and catechin was reported by Poei-Langston and Wrolstad (1981) resulting in the loss of both. The degradation of these compounds, strikingly, followed similar patterns as ACN degradation, which would suggest their interaction with ACN with a net result of loss in color.

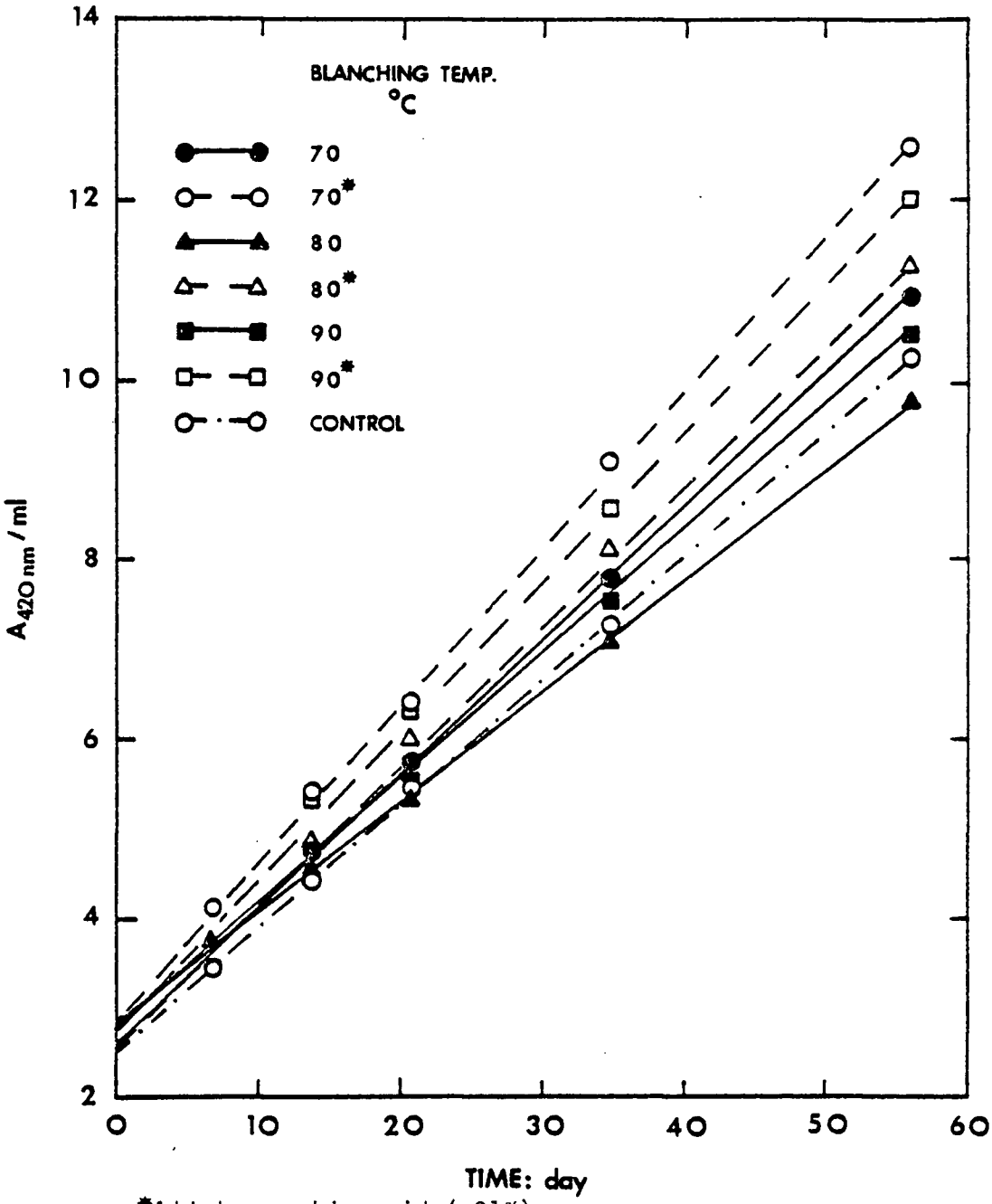
Effect of Storage on the Color Parameters

Effect on Browning

Browning measures the formation of the dark brown color which is resistant to bleaching by bisulfite. The formation of this brown color tends to mask the bright red color, associated with freshly prepared strawberry products, and is highly undesirable. Browning in strawberry concentrate and juice samples increased, as would be expected, during storage.

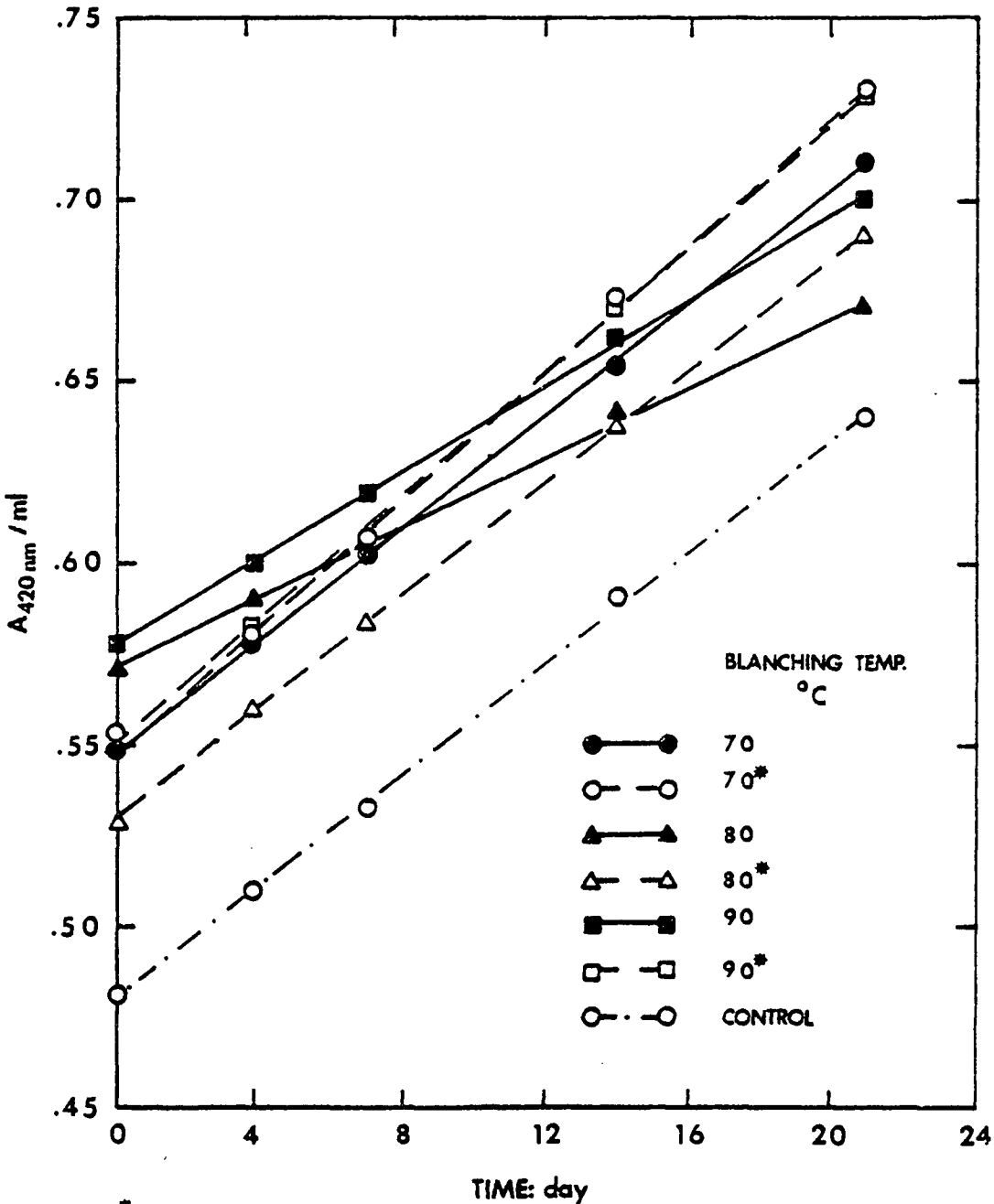
Browning formation, in samples stored at 1°C, followed zero order reaction kinetics. The resulting regression lines for browning in strawberry concentrate and juice are shown in Figures 11 and 12, respectively. At this low storage temperature browning formation proceeded at slow rates and the effect of blanching was not noticed. Blanched samples, at the beginning of the study, had higher browning values than the control samples, and maintained these high values till the end of the storage period. Samples blanched at 80°C showed lower browning values than those blanched at 90°C, with samples blanched at 70°C having the highest levels. When AA was added, it increased browning at any blanching temperature. Zero order rate constants with corresponding correlation coefficients for browning in strawberry concentrate and juice stored at 1°C are shown in Table 13.

A quick study of the rate constants reveals that browning progressed at much faster rates in the concentrate than the juice



*Added ascorbic acid (.01%).

Figure 11. Regression lines for browning formation in strawberry concentrate stored at 1°C.



* Added ascorbic acid (.01%).

Figure 12. Regression lines for browning formation in strawberry juice stored at 1°C.

Table 13. Zero order rate constants for browning formation in strawberry concentrate and juice stored at 1°C

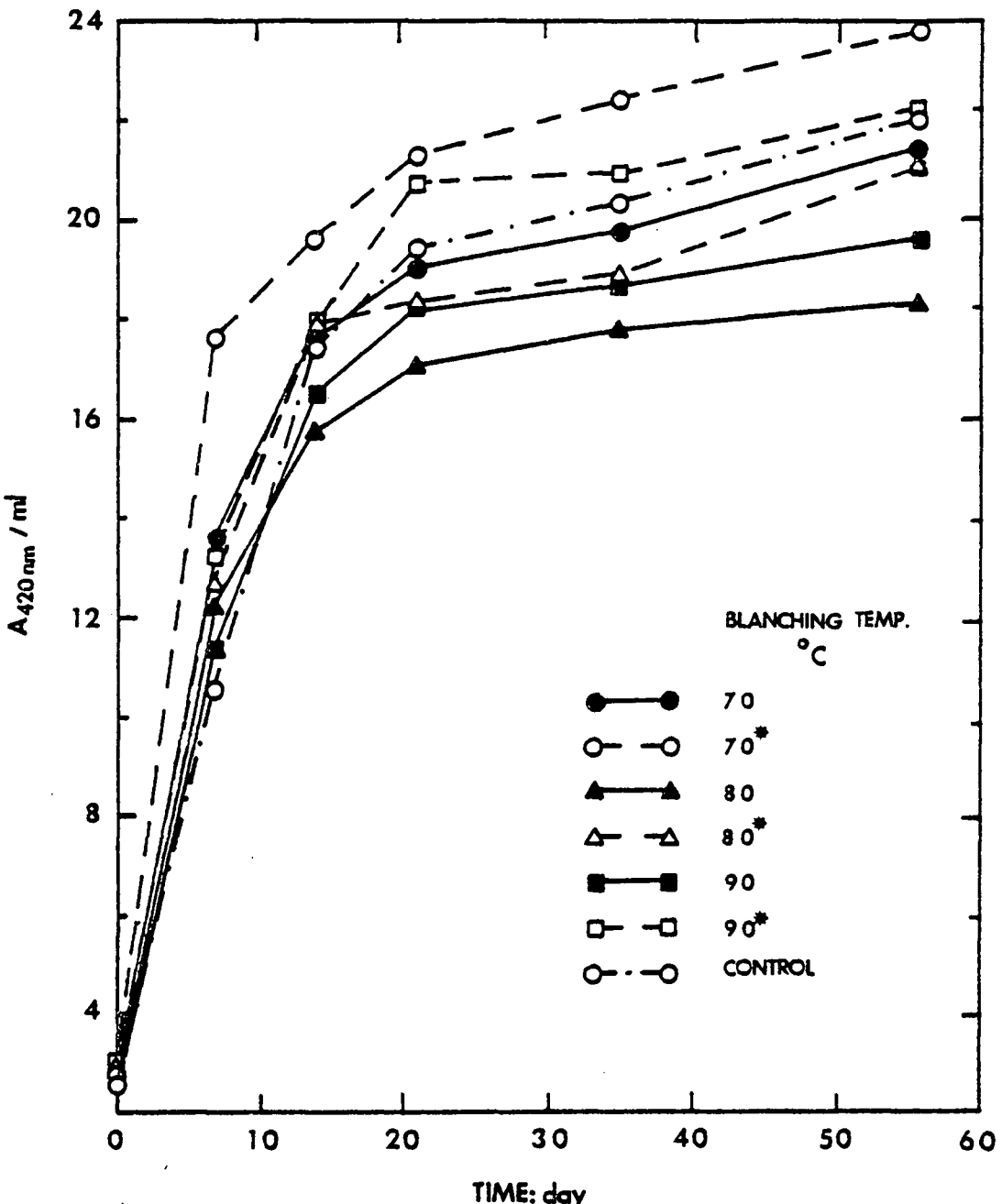
Blanching	Concentrate		Juice	
Temp.(°C)	K*	Corr. Coeff.	K*	Corr. Coeff.
70	.135	.989	7.60×10^{-3}	.969
70+AA**	.177	.986	9.22×10^{-3}	.980
80	.120	.995	5.60×10^{-3}	.990
80+AA**	.143	.995	7.60×10^{-3}	.989
90	.129	.994	6.42×10^{-3}	.981
90+AA**	.158	.994	9.22×10^{-3}	.985
Control	.134	.998	7.60×10^{-3}	.996

*Absorbance units per ml per day.

**Added ascorbic acid (0.01%).

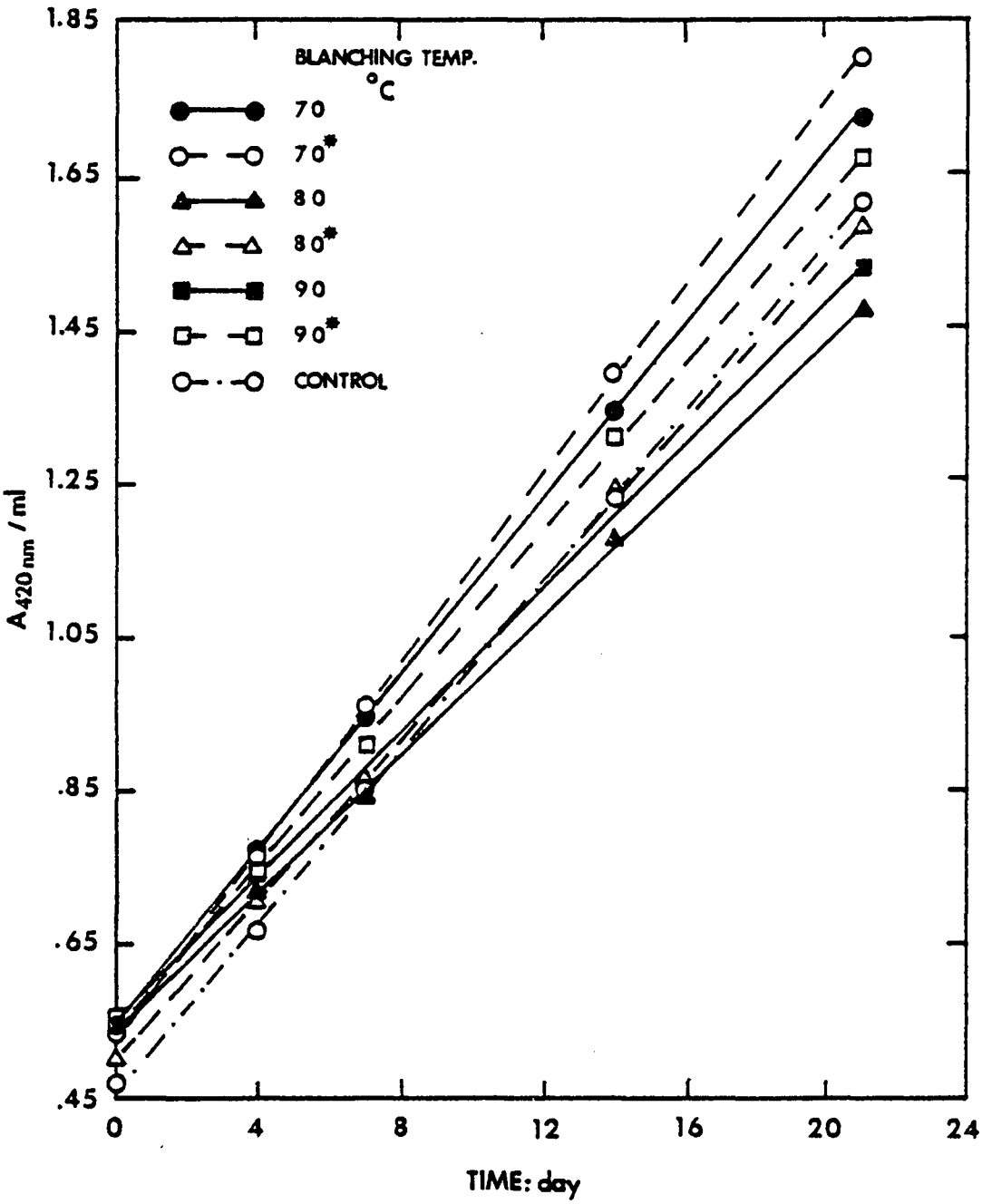
samples, which concurs with the results reported by Wrolstad et al. (1980). Blanched samples with added AA showed higher rate constants when compared to blanched samples without the addition of AA, which confirms the above mentioned observation. Although the control samples maintained the lowest browning values, both showed higher rate constants than samples blanched at 80° or 90°C. This would indicate a blanching protective effect, at these temperatures, on longer storage periods.

When samples were stored at 21°C, browning formation progressed at much faster rates, and only browning in juice samples followed zero order reaction kinetics. Browning formation in strawberry concentrate is shown in Figure 13 and the regression lines for browning in juice samples are shown in Figure 14. Blanching effect is evident at this storage temperature. Blanched concentrate samples showed less browning than the control. Only samples blanched at 90° and 70°C, with added AA, had higher browning than the control. In juice samples the same pattern was observed with the exception that the sample blanched at 70°C had higher browning value than the control. Once again, blanching at 80°C showed the most protective effect, followed by blanching at 90°C. AA addition had the same effect as noticed before. Browning zero rate constants in juice samples (Table 14) confirm the above findings. AA was reported by Poei-Langston and Wrolstad (1981) to exert similar effects on browning in model system of strawberry pigment.



* Added ascorbic acid (.01%).

Figure 13. Browning formation in strawberry concentrate stored at 21°C.



*Added ascorbic acid (.01%).

Figure 14. Regression lines for browning formation in strawberry juice stored at 21°C.

Table 14. Zero order rate constants for browning formation in strawberry juice stored at 21°C

Blanching Temp.(°C)	K*	Corr. Coeff.
70	5.56×10^{-2}	.991
70+AA**	5.96×10^{-2}	.998
80	4.28×10^{-2}	.993
80+AA**	4.92×10^{-2}	.992
90	4.43×10^{-2}	.993
90+AA**	5.36×10^{-2}	.998
Control	5.27×10^{-2}	.991

*Absorbance units per ml per day.

**Added ascorbic acid (0.01%).

The increased browning in the control samples would be attributed to the action of PPO and other enzyme systems present in strawberries. PPO would oxidize the naturally present o-hydroxy phenols into o-quinones. Although the formed o-quinones are themselves red to reddish-brown in color, the reaction rarely stops there (Mathew and Parpia, 1971). They take part in secondary reactions, bringing about the formation of intensely colored products.

Browning formation took much faster pace on storage at 38°C (Table 15). AA manifested its adverse effect in strawberry concentrate at this storage temperature; blanched samples with added AA showed higher browning levels than the control. In juice samples, only the sample blanched at 70°C with added AA showed higher browning than the control (Appendix 9). Other than that, the storage effect at this temperature was similar to that observed on storage at 21°C.

Although browning formation followed a pattern similar to that observed with the degradation of ACN, browning was reported to exert a more deleterious effect on the color deterioration of strawberry products (Mackinney and Chichester, 1952; and Abers and Wrolstad, 1979).

Table 15. Effect of storage at 38°C on browning* formation in strawberry concentrate and juice

Blanching Temp. (°C)	Concentrate		Juice	
	Days			
	0	56	0	21
70	2.83	23.64	.55	2.61
70+AA**	2.78	25.95	.54	2.76
80	2.90	21.86	.56	2.24
80+AA**	2.83	24.25	.53	2.51
90	2.97	23.39	.57	2.40
90+AA**	2.85	25.69	.54	2.58
Control	2.58	24.01	.48	2.66

*Expressed as absorbance units per ml.

**Added ascorbic acid (.01%).

Effect on Color Density

Color density would measure the total color of the samples including the portion of the color contributed by tannins. For this reason, the difference between the degradation rate of the monomeric color and the formation rate of the polymeric color would determine the measured color density. Since both processes take place simultaneoulsy, not much difference in color density would be expected in samples stored at one temperature.

The effect of storage temperatures on the color density in strawberry concentrate and juice is shown in Table 16 and Appendices 10 and 11. In the concentrate samples, color density decreased as the storage temperature increased. This would be attributed to the browning and polymerization reactions with subsequent precipitation and loss of color density. A different pattern was observed in the juice samples. Juice samples stored at 38°C showed higher color density than those stored at 21°C. This would be attributed to browning which was higher at this high storage temperature.

Effect on Polymeric Color

Polymeric color would measure the contribution of tannins, which are resistant to bisulfite bleaching and, therefore, would measure to what extent polymerization condensation reactions progressed. Somers (1971) introduced this measurement on his studies on the color of wine, and was later proved suitable for ACN con-

Table 16. Effect of storage temperatures on color density* in strawberry concentrate and juice

Blanching Temp. °C	Concentrate			Juice		
	Temperature °C					
	1	21	38	1	21	38
70	39.19	35.24	31.23	5.72	4.91	5.29
70+AA**	39.47	36.43	30.77	5.55	5.01	5.44
80	39.01	34.53	31.21	6.07	4.76	5.16
80+AA**	39.77	34.71	30.87	5.89	4.93	5.33
90	39.31	34.39	30.84	6.05	4.88	5.32
90+AA**	39.86	35.15	30.77	5.72	4.97	5.41
Control	39.01	35.14	30.91	5.72	4.81	5.35

*Expressed as absorbance units per ml.

**Added ascorbic acid (.01%).

taining systems (Poei-Langston and Wrolstad, 1981). The effect of storage temperatures on the polymeric color in strawberry concentrate and juice is shown in Table 17 and Appendices 12 and 13. As would be expected, polymeric color formation was faster as the storage temperature increased, which concurs with the results reported by Abers and Wrolstad (1979). In their study, on strawberry preserves, they demonstrated that higher polymeric color formation was associated with high initial total phenolics content, and postulated that phenolics play a major role in browning and polymerization reactions.

Polymeric color increased with time in all samples at any storage temperature. In samples stored at 1°C, blanching increased the polymeric color. In the concentrate samples, only the sample blanched at 80°C had lower polymeric color than the control, while blanched juice samples, all, showed higher polymeric color than the control. AA addition, at any blanching temperature, increased the polymeric color which, once again, demonstrates its adverse effect on the color of strawberry concentrate and juice.

Blanching showed a protective effect on the polymeric color in the samples stored at 21° and 38°C. Blanching at 80° and 90°C exerted a protective effect revealed by lower values of polymeric color. AA had the same adverse effect on polymeric color as observed in samples stored at 1°C. Effects of blanching and storage on the polymeric color was, not surprisingly, similar to

Table 17. Effect of storage temperatures on polymeric color* in strawberry concentrate and juice

Blanching Temp. °C	Concentrate			Juice		
	Temperature °C					
	1	21	38	1	21	38
70	12.51	26.66	28.53	.92	2.20	3.47
70+AA**	13.36	28.91	29.19	.94	2.34	3.67
80	11.75	23.62	26.67	.88	1.87	2.96
80+AA**	12.75	25.92	27.62	.93	2.08	3.28
90	12.40	24.70	27.35	.92	2.00	3.17
90+AA**	13.32	26.93	28.64	.95	2.17	3.43
Control	12.17	26.89	28.66	.86	2.18	3.56

*Expressed as absorbance units per ml.

**Added ascorbic acid (.01%).

that observed on browning.

Effect on Percent Polymeric Color

Percent polymeric color would measure the contribution of polymeric color as a percentage of the total color of a product. The effect of storage temperatures on the percent polymeric color in strawberry concentrate and juice is shown in Table 18 and Appendices 14 and 15. Percent polymeric color increased in a fashion similar to that observed with polymeric color. Since color density did not change very much with blanching, it is not unreasonable that percent polymeric color would follow the polymeric color formation.

In samples stored at 1°C, only samples blanched at 80°C had lower percent polymeric color than the control, with all other samples having much higher values than both. Blanching at 80°C, once more, showed the most protective effect on the color as revealed by lower values of percent polymeric color. This was followed by samples blanched at 90°C, with samples blanched at 70°C showing the highest values. AA increased the percent polymeric color at any blanching temperature. Similar AA adverse effect was, also, observed earlier with browning and the degradation of ACN which may indicate a major role AA had in the deterioration of strawberry concentrate and juice color.

Formation of percent polymeric color in samples stored at 21° and 38°C followed the same pattern, though it was much faster

Table 18. Effect of storage temperatures on percent polymeric color in strawberry concentrate and juice

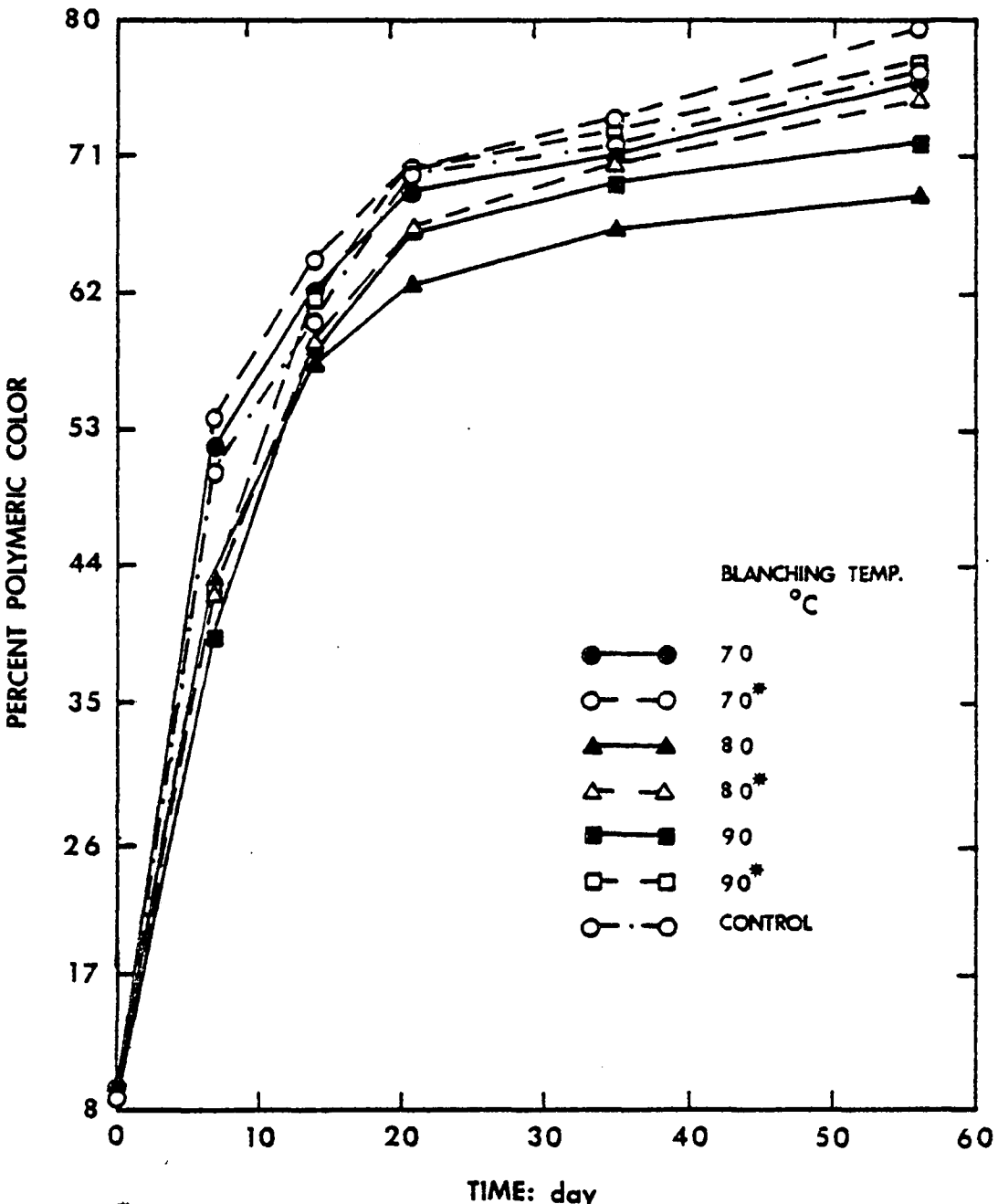
Blanching Temp. °C	Concentrate			Juice		
	Temperature °C					
	1	21	38	1	21	38
70	31.9	75.7	91.3	16.1	44.8	65.6
70+AA*	33.8	79.4	94.9	16.9	46.7	67.5
80	30.1	68.3	85.5	14.5	39.3	57.4
80+AA*	32.0	79.7	89.5	15.8	42.2	61.5
90	31.5	71.8	88.8	15.2	41.0	59.6
90+AA*	33.4	76.6	93.1	16.6	43.7	63.4
Control	31.2	76.5	92.7	15.1	45.7	66.5

*Added ascorbic acid (.01%).

at the high storage temperature, which concurs with the results reported by Abers and Wrolstad (1979) in their storage studies on strawberry preserves. Figures 15 and 16 depict the percent polymeric color progress in strawberry concentrate and juice stored at 21°C, respectively. Blanching provided a protective effect by reducing the formation rate of percent polymeric color, which corroborates well with the results reported by Wrolstad et al. (1980) in a similar system. Blanching at 80°C showed a profound effect in reducing percent polymeric color. Blanching at 90°C exerted a protective effect, though not as protective as blanching at 80°C. Blanching at 70°C did not show much effect. AA degradative effect surpassed the blanching protective effect at any temperature.

Effect on Colorimetric Parameters

The effect of storage temperatures on "L" value in strawberry concentrate and juice is shown in Table 19. "L" value, in concentrate samples, decreased with the increase of storage temperatures, i.e., color became darker. Juice samples, on the other hand, showed an increase in "L" value as the storage temperatures increased, with highest values observed in samples stored at 21°C. "L" value increased with time, color became lighter, in all samples stored at 1°C (Appendices 16 and 17). Concentrate samples showed an increase in "L" value up to the fifth week then started to decrease. The loss of color, ACN, and the steady browning



* Added ascorbic acid (.01%).

Figure 15. Percent polymeric color in strawberry concentrate stored at 21°C.

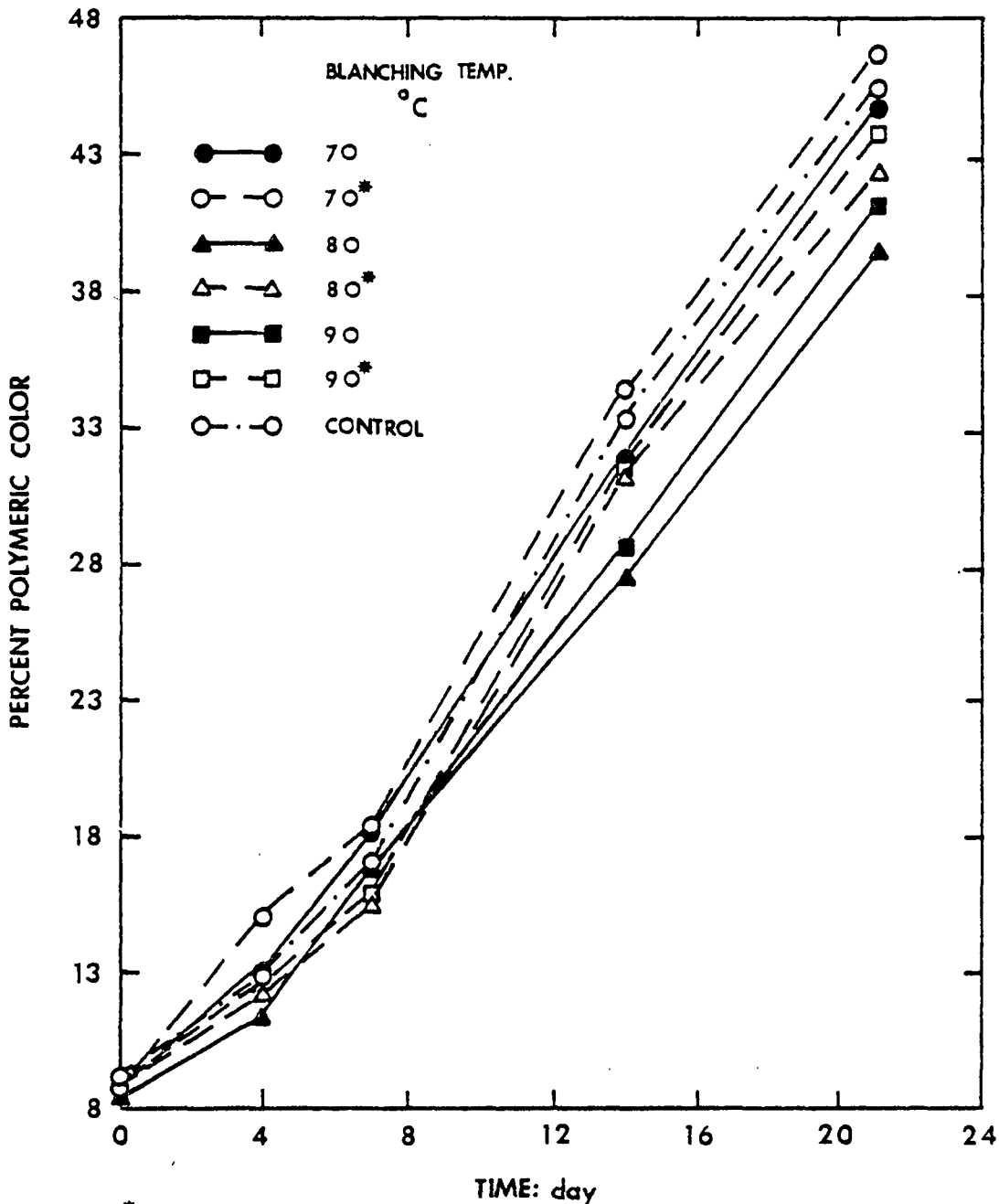


Figure 16. Percent polymeric color in strawberry juice stored at 21°C.

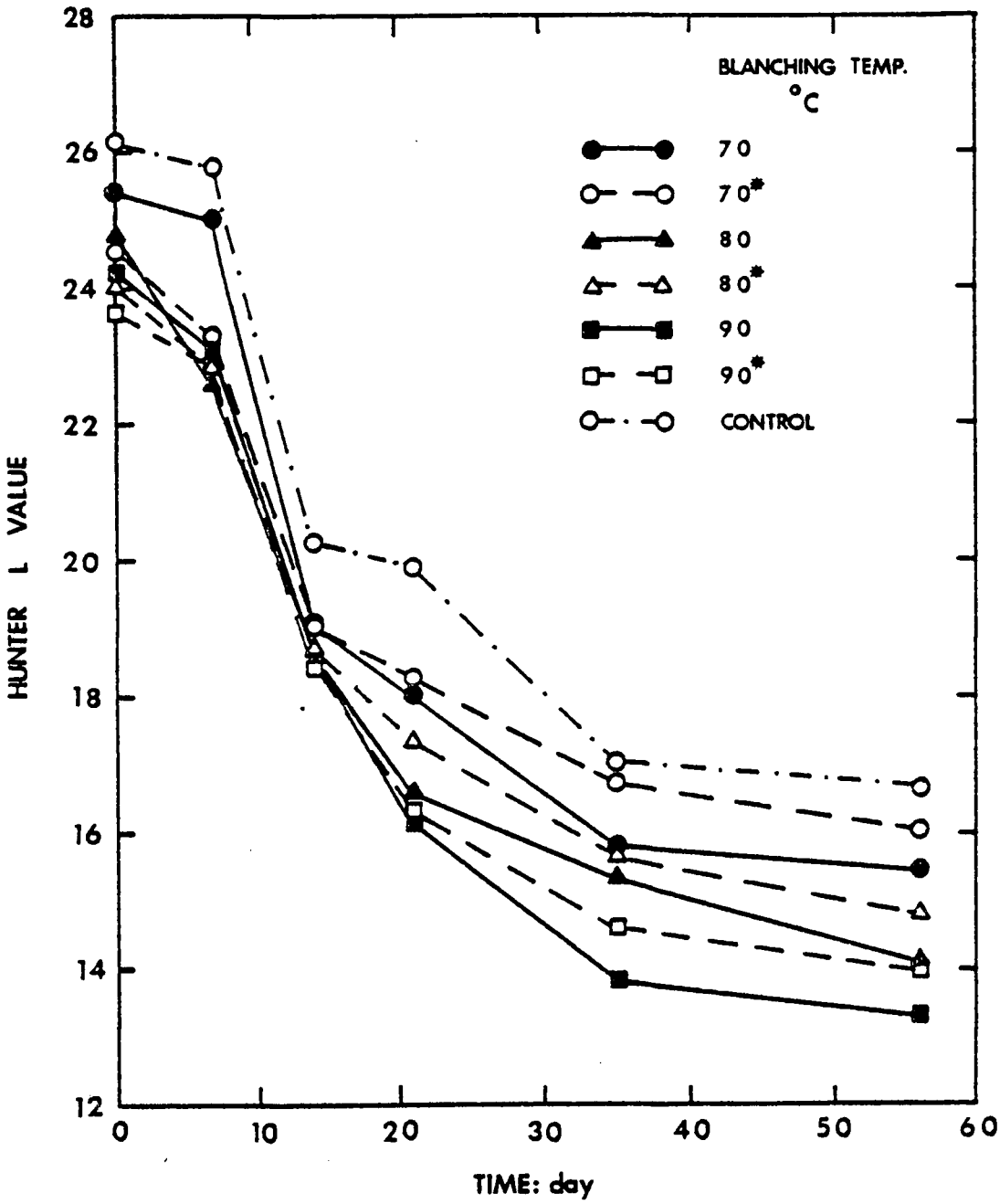
Table 19. Effect of storage temperatures on Hunter L value in strawberry concentrate and juice

Blanching Temp. °C	Concentrate			Juice		
	Temperature °C					
	1	21	38	1	21	38
70	27.3	15.4	11.0	56.9	66.2	61.8
70+AA*	26.6	16.0	11.6	59.1	69.7	66.8
80	26.4	14.0	10.1	55.2	60.7	56.8
80+AA*	25.9	14.8	10.8	57.4	64.8	60.9
90	26.0	13.3	9.6	53.9	61.5	57.3
90+AA*	25.6	13.9	10.0	56.0	65.4	61.5
Control	28.4	16.6	12.2	62.8	72.5	67.8

*Added ascorbic acid (.01%).

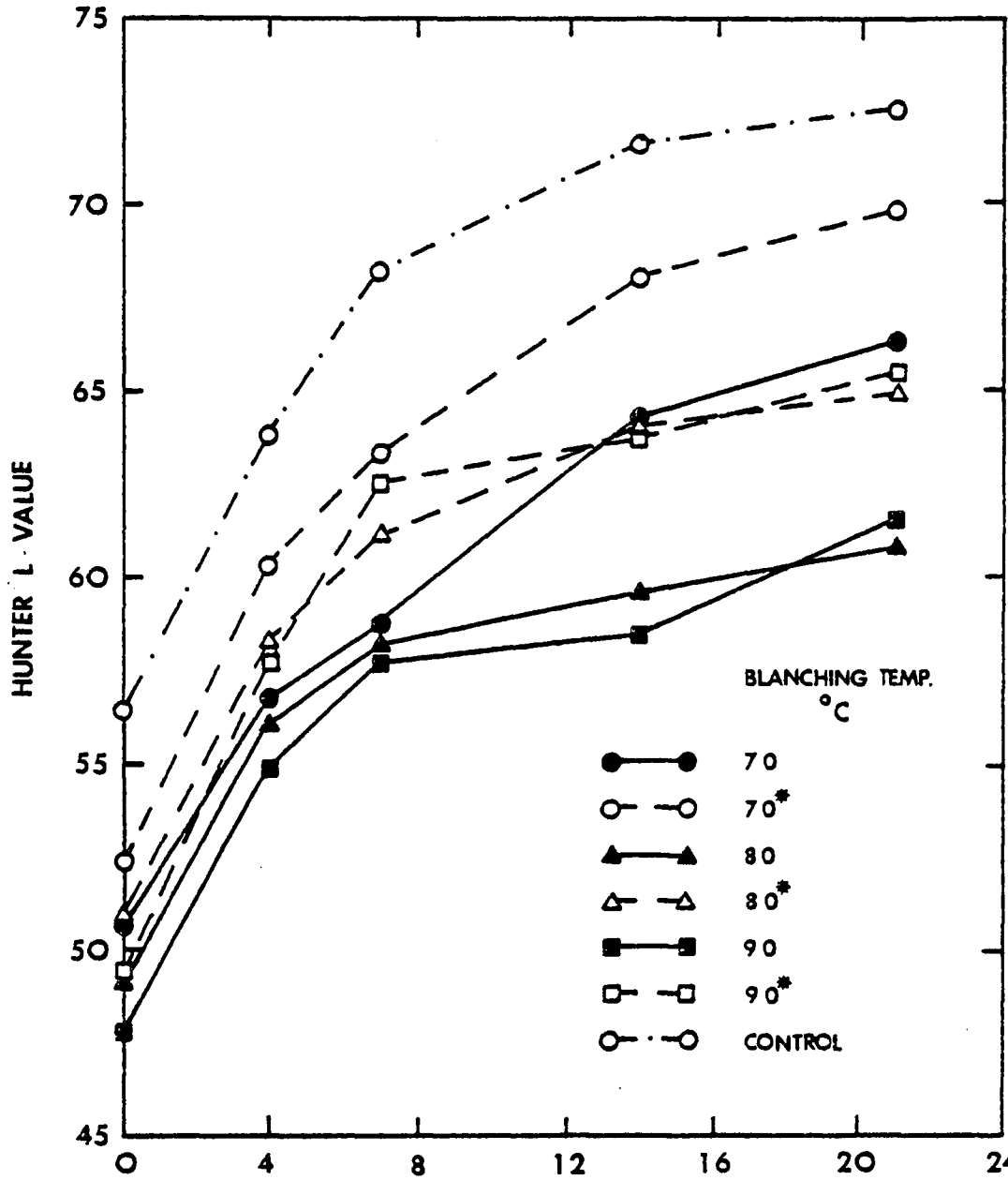
formation and precipitation would explain this fading of the color as revealed by increases in "L" value in both concentrate and juice samples. By the end of the storage period browning reactions, in the concentrate samples, were already advanced and surpassed the fading of the color causing "L" value to decrease. "L" value of the control samples was higher, at the beginning of the study, than the other samples and remained higher throughout the storage period. Blanching decreased "L" value and the effect was higher as the blanching temperature increased. AA addition increased "L" value at any blanching temperature which corroborates well with the results reported by Sistrunk and Cash (1970).

On storage at 21° and 38°C, "L" value followed similar patterns, only at higher rates with samples stored at 38°C. The effect of storage at 21°C on "L" value in strawberry concentrate is depicted in Figure 17 (see Appendix 16 for "L" value at 38°C). "L" value decreased with time which corresponds to increased browning and polymeric color, as mentioned above. On the other hand, "L" value increased in juice samples stored at 21° and 38°C (Figure 18 and Appendix 17, respectively). This effect on "L" value concurs with earlier reports (Sistrunk et al., 1980; and Wrolstad et al., 1980). The contradicting effect on "L" value between the concentrate and juice samples would be attributed to precipitation of polymerized compounds in the juice samples, whereas precipitation would take a longer time in the concentrate



*Added ascorbic acid (.01%).

Figure 17. Change of Hunter L value in strawberry concentrate stored at 21°C.



*Added ascorbic acid (.01%).

Figure 18. Change of Hunter L value in strawberry juice stored at 21°C.

samples due to their high viscosity.

Samples blanched with AA showed higher "L" values than samples blanched without AA at any storage temperature. This is in agreement with the results reported by Sistrunk and Cash (1970) and Poei-Langston and Wrolstad (1981).

As would be expected, "a" value, which measures redness, decreased on storage at any temperature. The effect of storage temperatures on "a" value in strawberry concentrate and juice is shwon in Table 20. Concentrate samples stored at 1°C exhibited initial increase in "a" values, which might be caused by the initial increase in "L" value. Control samples, which had higher "a" values, at the start of this study, than blanched samples maintained higher values throughout the storage period except for the juice sample blanched at 80°C (Appendices 18 and 19). Storage at this low temperature would not be expected to show much effect on the color. Blanching at 80°C exerted the most observed protective effect when compared to blanching at 90° or 70°C. Once again, AA addition showed a deleterious effect on the color at any blanching temperature. AA adverse effect on the color of ACN containing products has long been observed (Sistrunk and Cash, 1970; Starr and Francis, 1968; Shrikhande and Francis, 1974; Sistrunk et al., 1980; and Poei-Langston and Wrolstad, 1981).

Samples stored at 21° and 38°C showed similar "a" value decreasing patterns, with much faster rates in samples stored at

Table 20. Effect of storage temperatures on Hunter a value in strawberry concentrate and juice

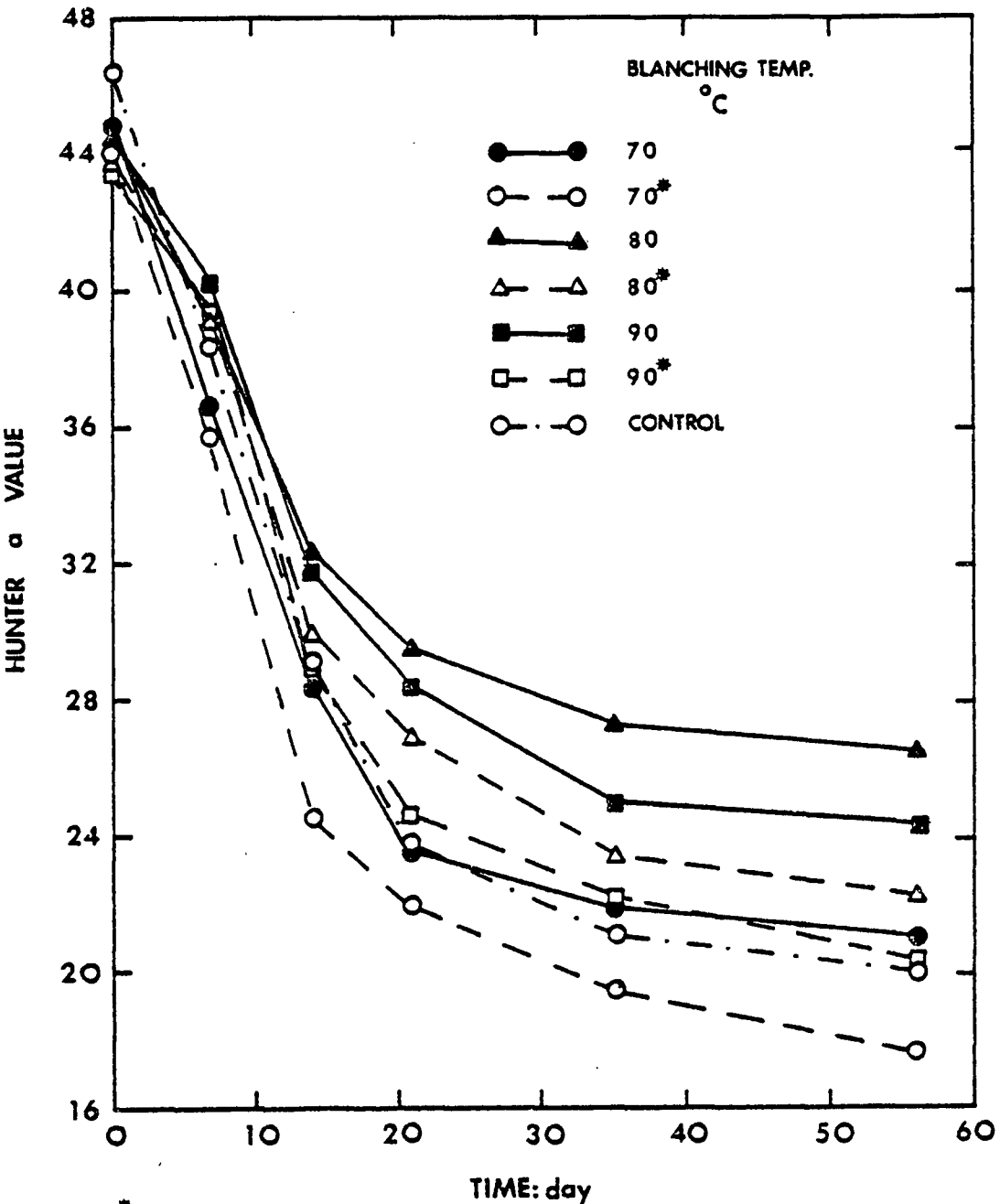
Blanching Temp. °C	Concentrate			Juice		
	Temperature °C					
	1	21	38	1	21	38
70	42.7	20.8	12.2	37.6	23.2	10.8
70+AA*	41.4	17.7	10.5	34.5	19.4	7.4
80	43.5	26.4	16.6	40.2	31.1	16.8
80+AA*	41.7	22.0	12.4	36.5	25.4	12.6
90	42.8	24.1	14.9	38.4	28.5	14.4
90+AA*	41.2	20.3	11.3	34.8	23.6	11.6
Control	44.1	19.8	11.8	38.8	23.0	8.2

*Added ascorbic acid (.01%).

38°C. The effect of storage temperatures on "a" value in strawberry concentrate and juice stored at 21°C is shown in Figures 19 and 20, respectively, and at 38°C in Appendices 18 and 19, respectively. Blanched samples exhibited higher "a" values than the controls. This would be due to higher levels of ACN and less browning in these samples, as noticed before. Blanching at 80°C showed higher protective effect on "a" value than blanching at 90°C, with blanching at 70°C showing the least effect. Wrolstad et al. (1980) and Sistrunk and Cash (1970) observed similar blanching effect in strawberry systems. AA exerted similar effect as mentioned above.

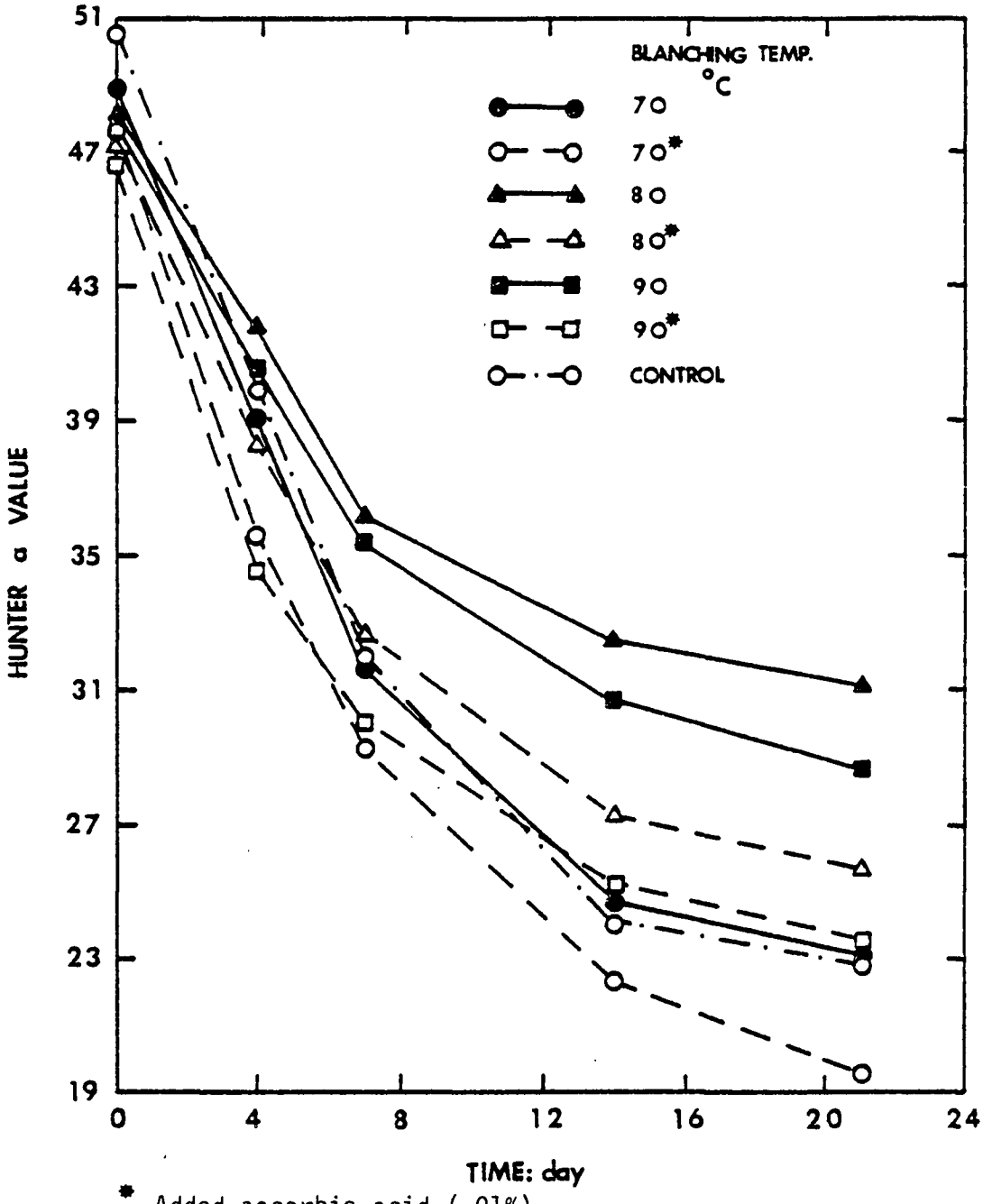
The hue angle ($\tan^{-1}b/a$) increased on storage at any temperature investigated, i.e., the color decreased in redness, accompanied by increase in yellowness. The effect of storage temperatures on the hue angle is shown in Table 21. As would be expected, hue angle increased as the storage temperature increased. In samples stored at 1°C, the control samples showed the lowest hue angle, a better red color, than blanched samples. Blanching at 80°C had more protective effect on hue angle than blanching at 90° or 70°C. AA addition, to blanched samples, increased the hue angle (Appendices 20 and 21) which was, also, observed with "a" value.

Samples stored at 21° and 38°C showed similar trends in the hue angle. The increase was much faster in samples stored at 38° than at 21°C, which concurs with the results reported by Abers and



* Added ascorbic acid (.01%).

Figure 19. Change of Hunter a value in strawberry concentrate stored at 21°C.



* Added ascorbic acid (.01%).

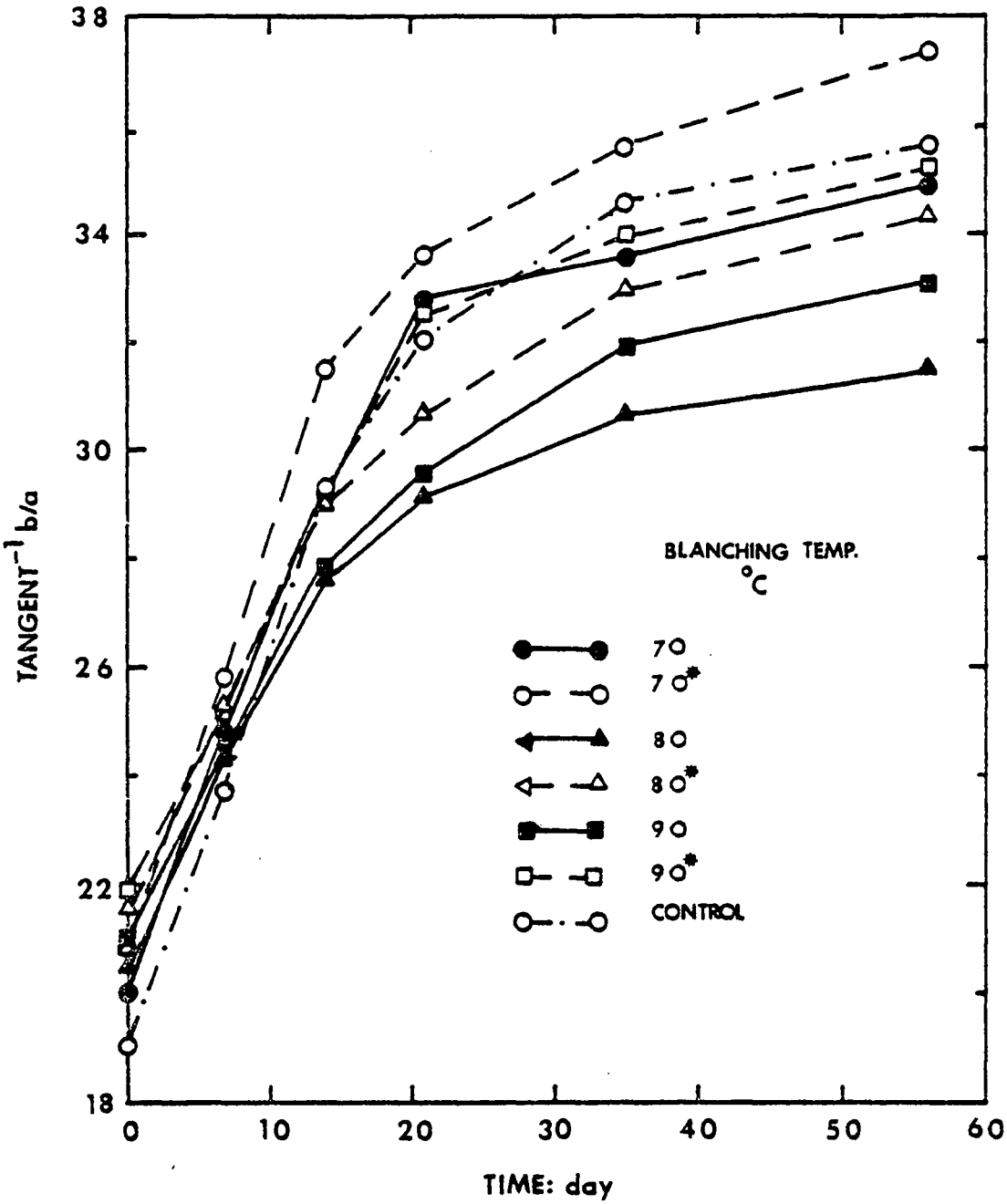
Figure 20. Change of Hunter a value in strawberry juice stored at 21°C.

Table 21. Effect of storage temperatures on the hue angle ($tan^{-1}b/a$) in strawberry concentrate and juice

Blanching Temp. °C	Concentrate			Juice		
	Temperature °C					
	1	21	38	1	21	38
70	23.1	34.9	45.0	22.1	46.0	68.6
70+AA*	24.4	37.3	46.6	24.3	51.3	75.3
80	22.1	31.4	41.3	21.7	36.2	58.5
80+AA*	24.0	34.3	44.8	24.2	42.9	65.8
90	23.0	32.4	42.4	22.9	39.3	62.5
90+AA*	24.6	35.2	46.0	25.2	45.6	67.7
Control	21.1	35.6	46.4	21.0	46.1	73.3

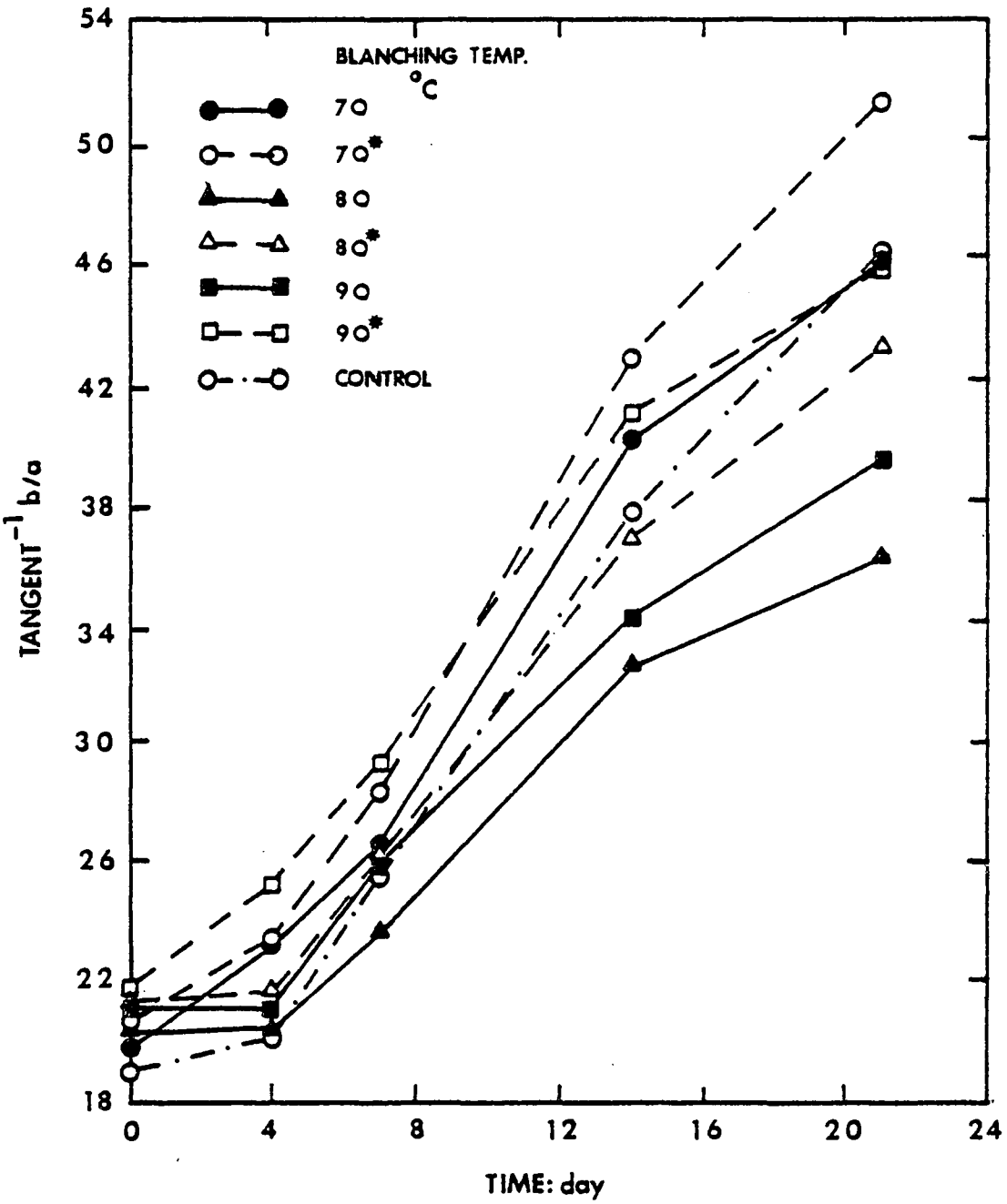
*Added ascorbic (.01%).

Wrolstad (1979). The effect of storage at 21°C, on the hue angle in strawberry concentrate and juice is shown in Figures 21 and 22, respectively, and at 38°C in Appendices 20 and 21, respectively. It is evident that blanching, particularly at 80°C and to a lesser extent at 90°C, had a protective effect on hue angle, while AA addition had an adverse effect. This effect of blanching and AA addition on the hue angle is, not surprisingly, similar to their effect on "a" value.



*Added ascorbic acid (.01%).

Figure 21. Change of hue angle ($tan^{-1}b/a$) in strawberry concentrate stored at 21°C.



*Added ascorbic acid (.01%).

Figure 22. Change of hue angle ($\tan^{-1} b/a$) in strawberry juice stored at 21°C.

SUMMARY AND CONCLUSIONS

Crushed strawberries were blanched at 70°, 80° and 90°C for 1 min. Another batch was similarly prepared with added AA (0.01%). Juice and concentrate (42° Brix) were then prepared and stored at 1°, 21° and 38°C. Blanching at 70°C proved adequate to heat inactivate PPO in strawberry puree and in all blanched samples.

Blanching provided a protective effect on protecting such color important chemicals as ACN, AA, leucoanthocyanins, flavanols and total phenolics. Blanching at 80°C exhibited the most protective effect followed by blanching at 90°C. Blanching at 70°C did not show much effect. On the other hand, blanched samples became darker in color. When AA was added it diminished the blanching protective effect on the chemical constituents. Moreover, it bleached the color, slightly, of the juice and concentrate as demonstrated by higher "L" values.

On concentration, the single-strength juice lost varying amounts of its chemical constituents. Blanched samples retained more chemical constituents than the controls, and samples with added AA lost the most. AA suffered the most loss on concentration. Well over 74% of the vitamin was lost during concentration. Samples blanched at 80°C suffered the least loss.

As would be expected, samples stored at the low temperature of 1°C experienced the least changes in chemical constituents or color changes when compared to samples stored at 21° and 38°C. Storage at 38°C, which might be encountered during hot summer days in some warehouses, is the major factor in the deterioration of color, chemical constituents and overall quality of strawberry concentrate and juice. After the third week of storage at 38°C, concentrate samples were very dark in color and developed a burnt flavor. Juice samples lost their color and faded to a yellowish color.

Nevertheless, blanched samples, at any storage temperature, retained more chemical constitutents and were superior in color when compared with the controls. Blanching at 80°C was more effective in protecting the color of strawberry concentrate and juice at any storage temperature. AA, whenever added, aggravated the loss of both color and the chemical constituents. ACN and AA degradation in concentrate and juice samples stored at 1°C were found to obey first order reaction kinetics. While browning formation in these samples and in juice samples stored at 21°C followed zero order reaction kinetics. Reaction rate constants suggest a major role of AA in ACN degradation and general color deterioration.

It was concluded that blanching at 80°C for 1 min would be the optimum blanching process if color of strawberry concentrate

and juice is to be protected. Blanching at 90°C would result in adverse heating effect, while at 70°C even greater adverse effect would be encountered. Enzymes present in strawberry system would contribute, immensely, to the loss of color and overall quality of strawberry concentrate and juice. Although AA is a valuable nutrient, its deleterious effect on the color of strawberry concentrate and juice should be considered. Its addition ought to be avoided and selection of strawberry varieties with low AA content would be desirable to prepare better color quality product. Storage temperature is the major factor in color stability.

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APPENDICES

Appendix 1

Anthocyanins* retention in strawberry concentrate and juice stored at 38°C

System	Days	Blanching Temp. (°C)						
		70	70**	80	80**	90	90**	Control
Concentrate	0	89.84	87.10	98.84	94.65	96.44	91.65	85.37
	7	13.99	12.28	14.13	12.71	14.20	13.12	12.81
	14	4.11	3.27	4.87	3.59	4.11	4.22	3.17
	21	2.28	2.20	3.66	2.51	3.61	2.43	2.27
	35	1.71	1.52	2.26	1.87	2.00	1.82	1.52
	56	00	00	00	00	00	00	00
Juice	0	20.46	19.87	22.38	21.48	21.89	20.85	19.48
	4	5.48	5.60	7.16	6.34	6.07	7.06	6.16
	7	4.71	4.58	6.58	5.58	5.88	5.10	5.57
	14	3.47	2.95	5.60	4.93	5.11	4.66	3.41
	21	3.35	2.61	5.28	4.11	4.68	3.63	2.96

*Expressed as mg/100ml.

**Added ascorbic acid (.01%).

Appendix 2

Ascorbic acid* retention in strawberry concentrate and juice stored at 38°C

System	Days	Blanching Temp. (°C)						
		70	70**	80	80**	90	90**	Control
Concentrate	0	16.65	19.76	19.62	23.71	18.49	22.01	10.16
	7	2.40	2.96	3.25	4.09	2.82	2.96	1.83
	14	1.27	1.27	1.69	2.00	1.55	1.69	.99
	21	.56	.60	1.13	1.13	.84	.85	.56
	35	.42	.42	.85	.85	.71	.71	.14
	56	00	00	00	00	00	00	00
Juice	0	14.18	18.86	16.30	21.59	15.59	20.60	8.96
	4	4.40	5.81	5.24	6.52	4.75	6.19	2.70
	7	3.55	4.54	4.42	5.27	3.99	4.07	2.14
	14	2.14	2.14	3.08	3.46	2.82	3.13	1.20
	21	1.51	1.43	2.52	2.54	2.23	2.26	.82

*Expressed as mg/100ml.

**Added ascorbic acid (.01%).

Appendix 3

Effect of storage temperatures on leucoanthocyanins* retention in strawberry concentrate

Temp(°C)	Days	Blanching Temp. (°C)						
		70	70**	80	80**	90	90**	Control
1	0	8.28	8.00	8.81	8.42	8.57	8.33	7.76
	7	7.98	7.86	8.15	8.09	8.15	7.94	7.63
	14	7.89	7.73	7.95	7.89	7.94	7.88	7.55
	21	7.70	7.60	7.88	7.76	7.85	7.67	7.46
	35	7.62	7.44	7.79	7.64	7.73	7.58	7.26
	56	7.46	7.27	7.73	7.52	7.64	7.43	7.14
21	7	7.55	7.28	7.55	7.43	7.47	7.31	7.33
	14	7.37	6.95	7.25	7.01	7.04	6.98	7.16
	21	6.83	6.38	6.98	6.63	6.89	6.62	6.47
	35	6.32	5.77	6.75	6.38	6.65	6.32	5.84
	56	5.90	5.53	6.50	6.05	6.23	5.90	5.63
38	7	6.20	5.87	6.50	6.32	6.80	6.45	5.98
	14	5.54	5.51	6.41	5.69	6.35	5.69	5.46
	21	5.10	4.76	5.97	5.00	5.63	5.09	5.01
	35	4.55	4.33	5.36	4.79	5.25	4.73	4.38
	56	4.30	3.84	4.85	4.46	4.67	4.32	3.94

*Expressed as absorbance unit per ml.

**Added ascorbic acid (.01%).

Appendix 4

Effect of storage temperatures on leucoanthocyanins* retention in strawberry juice

Temp(°C)	Days	Blanching Temp. (°C)						
		70	70**	80	80**	90	90**	Control
1	0	1.87	1.81	1.98	1.90	1.93	1.88	1.76
	4	1.84	1.78	1.94	1.87	1.90	1.82	1.72
	7	1.80	1.74	1.91	1.83	1.86	1.79	1.69
	14	1.76	1.69	1.86	1.78	1.81	1.74	1.65
	21	1.71	1.64	1.82	1.73	1.77	1.68	1.60
21	4	1.70	1.60	1.80	1.75	1.78	1.74	1.62
	7	1.67	1.50	1.73	1.72	1.76	1.62	1.56
	14	1.56	1.48	1.67	1.61	1.63	1.52	1.40
	21	1.47	1.39	1.61	1.51	1.55	1.47	1.36
38	4	1.51	1.49	1.68	1.64	1.60	1.53	1.47
	7	1.45	1.38	1.54	1.55	1.56	1.42	1.36
	14	1.28	1.23	1.41	1.31	1.38	1.26	1.19
	21	1.19	1.12	1.34	1.23	1.27	1.19	1.08

*Expressed as absorbance units per ml.

**Added ascorbic acid (.01%).

Appendix 5

Effect of storage temperatures on flavanols* retention in strawberry concentrate

Temp(°C)	Days	Blanching Temp. (°C)						
		70	70**	80	80**	90	90**	Control
1	0	30.49	29.58	31.98	30.94	31.53	30.62	29.06
	7	29.77	28.80	30.01	30.29	30.42	29.51	28.47
	14	29.45	28.41	30.55	30.03	29.90	29.19	28.34
	21	28.86	27.87	30.23	29.38	29.58	28.80	28.02
	35	28.50	27.66	29.90	29.06	29.19	28.47	27.76
	56	28.03	27.09	29.06	28.28	28.67	27.83	27.20
21	7	28.67	26.91	28.41	27.89	28.08	27.76	27.69
	14	27.43	25.81	27.63	26.65	27.37	26.13	26.39
	21	26.13	26.91	26.85	25.87	26.52	25.42	24.57
	35	24.65	23.14	25.68	25.03	25.29	24.25	23.79
	56	22.83	21.68	24.64	23.34	24.12	22.78	21.94
38	7	28.21	24.70	28.21	27.37	27.37	26.78	26.59
	14	24.05	24.18	24.90	24.18	25.16	24.64	22.49
	21	22.10	21.37	25.35	23.66	24.38	22.69	21.52
	35	19.29	18.04	23.60	20.87	23.20	20.54	18.59
	56	17.78	16.54	20.61	18.92	19.57	18.02	16.58

* Expressed as absorbance units per ml.

** Added ascorbic acid (.01%).

Appendix 6

Effect of storage temperature on the retention of flavanols* in strawberry juice

Temp(°C)	Days	Blanching Temp. (°C)						
		70	70**	80	80**	90	90**	Control
1	0	7.06	6.88	7.38	7.17	7.29	7.12	6.75
	4	6.94	6.73	7.36	7.06	7.18	6.86	6.48
	7	6.78	6.58	7.22	6.79	7.08	6.78	6.37
	14	6.65	6.40	7.07	6.71	6.88	6.48	6.24
	21	6.49	6.27	6.92	6.62	6.72	6.40	6.11
21	4	6.59	6.29	6.87	6.50	6.77	6.47	5.92
	7	6.32	6.01	6.64	6.32	6.60	6.25	5.77
	14	5.92	5.80	6.38	6.06	6.24	5.85	5.44
	21	5.64	5.41	6.15	5.83	5.95	5.59	5.30
38	4	5.80	5.43	6.31	5.90	5.93	5.74	5.35
	7	5.53	5.12	6.03	5.64	5.67	5.45	4.95
	14	5.04	4.69	5.57	5.27	5.38	4.96	4.57
	21	4.53	4.22	5.19	4.79	4.91	4.49	4.24

*Expressed as absorbance unit per ml.

**Added ascorbic acid (.01%).

Appendix 7

Effect of storage temperature on the retention of total phenolics* in strawberry concentrate

Temp.(°C)	Days	Blanching Temp.(°C)						
		70	70**	80	80**	90	90**	Control
1	0	8.79	8.60	9.36	9.07	9.16	8.90	8.43
	7	8.56	8.46	9.03	8.53	8.76	8.70	8.30
	14	8.38	8.33	8.96	8.64	8.70	8.61	8.30
	21	8.54	8.19	8.87	8.56	8.67	8.50	8.10
	35	8.28	8.06	8.70	8.47	8.47	8.36	7.95
	56	8.22	7.99	8.61	8.36	8.44	8.21	7.84
21	7	8.23	8.04	8.79	8.47	8.59	8.33	8.13
	14	7.90	7.88	8.53	8.15	8.47	8.26	7.61
	21	7.82	7.73	8.47	8.18	8.24	7.98	7.68
	35	7.47	7.34	8.33	7.90	8.18	7.70	7.29
	56	7.20	6.93	7.67	7.35	7.49	7.21	6.86
38	7	8.14	7.65	8.61	8.01	8.07	7.87	7.81
	14	7.77	7.45	8.07	7.72	7.75	7.21	7.64
	21	7.08	6.83	7.78	7.12	7.44	6.35	6.99
	35	6.48	6.18	7.41	6.60	7.01	6.03	6.25
	56	5.94	5.58	6.60	6.12	6.32	5.54	5.60

*Expressed as mg gallic acid per ml.

**Added ascrobic acid (.01%).

Appendix 8

Effect of storage temperature on the retention of total phenolics* in strawberry juice

Temp.(°C)	Days	Blanching Temp.(°C)						
		70	70**	80	80**	90	90**	Control
1	0	1.99	1.92	2.10	2.04	2.06	2.00	1.90
	4	1.95	1.88	2.07	2.02	2.01	1.96	1.84
	7	1.91	1.84	2.04	1.99	1.99	1.93	1.80
	14	1.88	1.81	2.01	1.94	1.96	1.90	1.77
	21	1.85	1.78	1.98	1.91	1.92	1.86	1.75
21	4	1.78	1.76	1.91	1.79	1.85	1.76	1.72
	7	1.72	1.71	1.88	1.76	1.82	1.74	1.67
	14	1.67	1.66	1.84	1.75	1.78	1.70	1.61
	21	1.62	1.55	1.79	1.70	1.73	1.65	1.52
38	4	1.63	1.52	1.74	1.58	1.71	1.61	1.65
	7	1.53	1.50	1.72	1.56	1.67	1.57	1.52
	14	1.45	1.39	1.65	1.52	1.59	1.48	1.44
	21	1.38	1.32	1.58	1.48	1.53	1.43	1.34

*Expressed as mg gallic acid per ml.

**Added ascorbic acid (.01%).

Appendix 9

Effect of storage (38°C) on browning* in strawberry concentrate and juice

System	Days	Blanching Temp.(°C)						
		70	70**	80	80**	90	90**	Control
Concentrate	0	2.83	2.78	2.90	2.83	2.97	2.85	2.58
	7	20.19	21.00	19.07	20.72	21.30	21.46	19.14
	14	20.49	21.57	19.30	21.60	21.51	22.86	20.08
	21	22.54	24.38	19.41	23.16	22.17	23.46	22.70
	35	23.16	25.09	19.71	23.76	22.61	24.07	23.21
	56	23.64	25.95	21.86	24.25	23.39.	25.69	24.01
Juice	0	.55	.54	.56	.53	.57	.54	.48
	4	1.26	1.18	1.11	.98	1.23	1.04	.83
	7	1.90	2.08	1.47	1.67	1.82	1.72	.98
	14	2.30	2.51	2.14	2.21	2.16	2.26	2.33
	21	2.61	2.76	2.24	2.51	2.40	2.58	2.66

*Expressed as absorbance units per ml.

**Added ascorbic acid (.01%).

Appendix 10

Effect of storage temperature on color density* in strawberry concentrate

Temp.(°C)	Days	Blanching Temp.(°C)						
		70	70**	80	80**	90	90**	Control
1	0	41.08	39.63	44.51	41.56	43.98	41.68	37.88
	7	40.48	39.54	43.26	41.10	42.76	41.15	38.16
	14	40.18	39.58	42.30	40.85	42.04	40.85	38.25
	21	39.97	39.56	41.88	40.43	41.15	40.37	38.59
	35	39.49	39.54	40.02	40.02	40.04	40.10	38.85
	56	39.19	39.47	39.01	39.77	39.31	39.86	39.01
21	7	35.58	36.62	35.37	35.41	35.50	36.65	35.33
	14	35.42	36.52	34.85	34.96	34.71	35.26	35.24
	21	35.31	36.48	34.68	34.82	34.50	35.12	35.19
	35	35.28	36.46	34.62	34.75	34.43	35.09	35.17
	56	35.24	36.43	34.57	34.71	34.39	35.15	35.14
38	7	31.42	30.89	31.37	31.05	31.03	30.87	31.05
	14	31.33	30.84	31.30	30.96	30.94	30.77	30.98
	21	31.28	30.81	31.28	30.89	30.91	30.80	30.94
	35	31.26	30.80	31.26	30.89	30.89	30.75	30.91
	56	30.23	30.77	31.21	30.87	30.84	30.77	30.91

*Expressed as absorbance units per ml.

**Added ascorbic acid (.01%).

Appendix 11

Effect of storage temperature on color density* in strawberry juice

Temp.(°C)	Days	Blanching Temp.(°C)						
		70	70**	80	80**	90	90**	Control
1	0	8.26	7.82	8.89	8.24	8.92	8.24	7.11
	4	7.17	6.95	7.38	7.28	7.43	6.95	6.38
	7	6.77	6.64	7.13	7.07	7.00	6.75	5.87
	14	6.38	6.08	6.52	6.54	6.59	6.11	6.06
	21	5.72	5.55	6.07	5.89	6.05	5.72	5.70
21	4	7.48	6.35	7.26	6.45	7.39	6.72	5.94
	7	6.26	5.35	6.08	6.62	6.33	6.39	5.50
	14	5.39	4.93	5.35	4.85	5.37	5.16	4.88
	21	4.91	5.01	4.76	4.93	4.88	4.97	4.81
38	4	7.03	6.11	7.36	6.44	7.16	6.32	5.48
	7	6.53	6.42	5.84	5.94	5.79	6.18	5.77
	14	5.59	5.74	5.67	5.43	5.65	5.51	5.43
	21	5.29	5.44	5.16	5.33	5.32	5.41	5.35

*Expressed as absorbance units per ml.

**Added ascorbic acid (.01%).

Appendix 12

Effect of storage temperature on the polymeric color* in strawberry concentrate

Temp.(°C)	Days	Blanching Temp.(°C)						
		70	70**	80	80**	90	90**	Control
1	0	3.63	3.54	3.73	3.61	3.80	3.68	3.43
	7	4.67	5.43	4.32	4.46	4.53	4.37	4.28
	14	5.45	6.30	4.99	5.06	5.11	5.20	4.46
	21	6.33	8.60	5.38	6.56	6.28	7.41	5.97
	35	9.27	10.14	8.21	9.36	8.79	9.68	8.30
	56	12.51	13.36	11.75	12.75	12.40	13.32	12.17
21	7	18.47	19.62	15.20	14.84	13.80	15.09	17.64
	14	21.86	23.41	19.92	20.54	20.13	21.44	21.00
	21	24.31	25.51	21.67	23.12	22.79	24.82	24.54
	35	24.93	26.75	22.96	24.59	23.90	25.46	25.21
	56	26.66	28.91	23.62	25.92	24.70	26.93	26.89
38	7	24.75	26.22	24.13	24.13	24.52	25.69	24.36
	14	26.59	27.35	25.14	25.85	25.81	27.30	26.36
	21	27.23	27.92	25.62	26.61	26.24	27.46	27.60
	35	27.92	28.50	26.02	27.12	26.82	27.99	28.24
	56	28.53	29.19	26.67	27.62	27.35	28.64	28.66

*Expressed as absorbance units per ml.

**Added ascorbic acid (.01%).

Appendix 13

Effect of storage temperature on the polymeric color* in strawberry juice

Temp.(°C)	Days	Blanching Temp.(°C)						
		70	70**	80	80**	90	90**	Control
1	0	.71	.68	.72	.69	.74	.70	.64
	4	.76	.73	.76	.75	.78	.73	.67
	7	.84	.81	.82	.82	.84	.85	.71
	14	.88	.90	.86	.89	.87	.88	.83
	21	.92	.94	.88	.93	.92	.95	.86
21	4	.95	.94	.83	.78	.85	.84	.76
	7	1.24	1.06	1.04	.98	1.07	.99	.94
	14	1.67	1.69	1.46	1.49	1.54	1.54	1.62
	21	2.20	2.34	1.87	2.08	2.00	2.17	2.18
38	4	1.54	1.49	1.36	1.30	1.49	1.47	1.08
	7	2.58	2.75	1.98	2.12	1.90	2.25	2.43
	14	3.04	3.34	2.74	2.91	2.88	2.93	3.08
	21	3.47	3.67	2.96	3.28	3.17	3.43	3.56

*Expressed as absorbance units per ml.

**Added ascorbic acid (.01%).

Appendix 14

Effect of storage temperature on the percent polymeric color in strawberry concentrate

Temp.(°C)	Days	Blanching Temp. (°C)						
		70	70*	80	80*	90	90*	Control
1	0	8.4	8.9	8.4	8.7	8.6	8.8	9.1
	7	11.5	13.7	10.0	10.9	10.6	10.6	11.2
	14	13.6	15.9	11.8	12.4	12.2	12.7	11.7
	21	15.8	21.7	12.8	16.2	15.3	18.4	15.5
	35	23.5	25.6	20.5	23.4	22.0	24.1	21.4
	56	31.9	33.8	30.1	32.0	31.5	33.4	31.2
38	7	78.8	84.9	76.9	77.7	79.0	83.2	78.5
	14	84.9	88.7	80.3	83.5	83.4	88.7	85.1
	21	87.1	90.6	81.9	86.1	84.9	89.2	89.2
	35	89.3	92.5	83.2	87.8	86.8	91.0	91.4
	56	91.3	94.9	85.5	89.5	88.8	93.1	92.7

*Added ascorbic acid (.01%).

Appendix 15

Effect of storage temperature on the percent polymeric color in strawberry juice

Temp.(°C)	Days	Blanching Temp. (°C)						
		70	70*	80	80*	90	90*	Control
1	0	8.6	8.7	8.1	8.4	8.3	8.5	9.0
	4	10.6	10.5	10.3	10.3	10.5	10.5	10.5
	7	12.4	12.2	11.5	11.6	12.0	12.6	12.1
	14	13.8	14.8	13.2	13.6	13.2	14.4	13.7
	21	16.1	16.9	14.5	15.8	15.2	16.6	15.1
38	4	21.9	24.4	18.5	20.2	20.8	23.3	19.7
	7	39.5	42.8	33.9	35.7	32.8	36.4	42.1
	14	54.4	58.2	48.3	52.6	51.0	53.2	56.7
	21	65.6	67.5	57.4	61.5	59.6	63.4	66.5

*Added ascorbic acid (.01%).

Appendix 16

Effect of storage temperature on Hunter L value in strawberry concentrate.

Temp.(°C)	Days	Blanching Temp. (°C)						
		70	70*	80	80*	90	90*	Control
1	0	25.4	24.5	24.8	24.0	24.3	23.6	26.2
	7	27.6	26.2	26.3	26.1	25.7	25.2	27.7
	14	28.1	27.1	26.7	26.6	25.9	25.7	29.0
	21	28.8	28.1	27.0	27.1	26.1	26.0	30.3
	35	29.3	28.8	27.3	27.0	26.7	26.5	31.2
	56	27.3	26.6	26.4	25.9	26.0	25.6	28.4
38	7	16.1	15.6	13.9	15.4	13.1	16.0	16.7
	14	13.7	13.5	12.3	12.8	11.8	12.4	14.3
	21	12.4	12.8	10.9	12.3	10.6	11.3	13.8
	35	11.6	11.9	10.4	11.3	10.1	10.6	12.6
	56	11.0	11.6	10.1	10.8	9.6	10.0	12.2

*Added ascorbic acid (.01%).

Appendix 17

Effect of storage temperature on Hunter L value in strawberry juice.

Temp.(°C)	Days	Blanching Temp. (°C)						
		70	70*	80	80*	90	90*	Control
1	0	50.6	52.4	49.2	50.9	47.7	49.4	56.4
	4	54.7	54.4	50.4	54.9	50.7	53.3	58.2
	7	55.3	57.8	54.0	55.6	51.3	54.0	59.1
	14	56.0	58.2	54.8	56.6	53.3	54.9	61.4
	21	56.9	59.1	55.2	57.4	53.9	56.0	62.8
38	4	68.4	71.1	62.4	65.9	63.1	67.3	74.4
	7	65.9	70.6	61.6	63.7	62.0	65.4	73.8
	14	62.7	68.2	58.1	62.5	59.1	62.4	70.2
	21	61.8	66.8	56.8	60.9	57.3	61.5	67.8

*Added ascorbic acid (.01%).

Appendix 18

Effect of storage temperature on Hunter a value in strawberry concentrate.

Temp.(°C)	Days	Blanching Temp. (°C)						
		70	70*	80	80*	90	90*	Control
1	0	44.9	44.0	44.6	43.9	44.1	43.5	46.4
	7	45.8	45.3	45.7	44.8	45.0	44.5	47.3
	14	46.0	45.4	46.0	45.2	45.9	44.7	47.5
	21	46.3	45.7	46.3	45.9	46.2	44.9	47.8
	35	44.6	43.9	45.7	44.2	45.2	43.6	46.3
	56	42.7	41.4	43.5	41.7	42.8	41.2	44.1
38	7	20.5	17.7	23.4	20.7	20.8	21.1	20.2
	14	16.6	16.2	19.3	15.8	17.4	15.6	15.8
	21	15.1	14.1	18.3	15.5	16.1	14.5	14.9
	35	13.4	11.4	17.6	13.8	15.7	12.1	13.1
	56	12.2	10.5	16.6	12.4	14.9	11.3	11.8

*Added ascorbic acid (.01%).

Appendix 19

Effect of storage temperature on Hunter a value in strawberry juice.

Temp.(°C)	Days	Blanching Temp. (°C)						
		70	70*	80	80*	90	90*	Control
1	0	48.8	47.6	48.1	47.3	47.6	46.8	50.4
	4	43.7	41.8	43.2	42.6	42.6	39.8	44.7
	7	41.6	38.6	42.2	41.1	41.7	38.5	43.7
	14	38.6	37.0	41.1	38.5	39.8	36.6	40.5
	21	37.6	34.6	40.2	36.5	38.4	34.8	38.8
38	4	28.9	27.4	33.1	29.8	32.3	27.8	29.3
	7	16.7	17.0	19.3	17.6	18.2	17.0	14.8
	14	14.9	11.0	18.2	16.6	17.4	15.5	12.7
	21	10.8	.7.4	16.8	12.6	14.4	11.6	8.2

*Added ascorbic acid (.01%).

Appendix 20

Effect of storage temperature on the hue angle ($\tan^{-1}b/a$) in strawberry concentrate

Temp.(°C)	Days	Blanching Temp. (°C)						
		70	70*	80	80*	90	90*	Control
1	0	20.0	20.9	20.5	21.6	21.1	21.9	19.1
	7	21.1	22.0	21.3	22.4	22.0	23.0	19.6
	14	21.7	22.4	21.4	22.6	21.8	23.5	19.4
	21	21.8	23.5	21.5	23.0	22.5	23.6	19.7
	35	22.6	23.8	21.7	23.6	23.0	24.5	20.6
	56	23.1	24.4	22.1	24.0	23.0	24.6	21.1
38	7	33.9	35.4	33.9	34.4	35.8	34.7	34.0
	14	38.3	37.4	38.0	39.2	39.6	40.4	40.5
	21	40.3	39.7	39.2	39.1	40.8	40.8	41.1
	35	42.5	44.7	40.1	42.6	41.1	44.5	44.3
	56	45.0	46.6	41.3	44.8	42.4	46.0	46.4

*Added ascorbic acid (.01%).

Appendix 21

Effect of storage temperature on the hue angle ($\tan^{-1}b/a$) in strawberry juice

Temp.(°C)	Days	Blanching Temp. (°C)						
		70	70*	80	80*	90	90*	Control
1	0	19.8	20.8	20.5	21.5	21.0	21.8	18.9
	4	20.4	21.7	21.3	22.6	21.8	23.6	20.4
	7	21.0	22.6	21.2	22.8	21.9	23.8	20.0
	14	21.5	23.1	21.6	23.4	22.5	24.7	20.8
	21	22.1	24.3	21.7	24.2	22.9	25.2	21.0
38	4	30.6	33.0	28.0	32.5	29.3	35.0	27.3
	7	54.7	55.7	51.1	55.0	53.2	56.4	53.4
	14	60.6	68.0	55.9	58.8	57.2	60.9	63.5
	21	68.6	75.3	58.5	65.8	62.5	67.7	73.3

*Added ascorbic acid (.01%).