AN ABSTRACT OF THE THESIS OF

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Title THE EFFECT OF PHYSICAL AND CHEMICAL AGENTS ON THE STORAGE CHARACTERISTICS OF RAW VEGETABLES AND FRUITS

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This investigation was concerned with the reduction of waste in raw vegetables and fruits between the times of harvest and consumption. Reduction of spoilage in produce was attempted by means of chemical and physical agents as well as a combination of both.

The first phase of the work consisted of an evaluation of a number of chemical compounds with respect to their effectiveness in reducing post-harvest spoilage. The second part dealt with an evaluation of several transparent films applied to raw produce as wrappers and their effect on the keeping quality of the plant material until consumed. Finally combinations of surface disinfection and overwrapping were evaluated for effectiveness against raw produce spoilage.

1. Disinfection

Approximately 26 compounds were tested as aqueous dips using 3 concentrations of each on 7 major vegetables and 2 fruits. The following types of compounds were studied.

1. Quaternary ammonium compounds (chlorides, bromides and pyridinium derivatives)
2. Chlorine liberators (organic and inorganic)
3. Phenols (simple and poly-phenols)
4. Quinones and hydroquinones
5. Salts of fatty acids
6. SO_2 liberators
7. Benzoates

The chemical treatments were evaluated for each produce by comparison with untreated controls using duplicate tests with triplicate samples for each chemical and concentration. Promising treatments were found for all but one produce (strawberries).

The treatments showing promise for each of Pascal celery and Emperor grapes were further tested on a larger scale using commercial size units of produce as test samples and long term cold storage. Three chemical treatments for each product were judged satisfactory enough to warrant further testing by means of field trials. The chemicals found most promising for celery were Onyxide, Cetab and Decco while Roccal, Dowicide C and Phygon were selected for grapes.

A field test of the three above mentioned treatments for Pascal celery was completed. One thousand bunches per chemical were tested under commercial conditions of dipping and storing. An equal number of untreated bunches was also tested. Half-lots of each treatment were evaluated on each bunch for 11 subjective characteristics and standard mold and bacterial counts of each crate of celery were made after 8 and 14 weeks of storage.

On the basis of a statistical analysis of the results, 0.1% Decco of pH=5 can be recommended for the reduction of general rot development in cold storage Pascal celery. Onyxide and Cetab significantly reduce the development of mold but commercial application cannot be recommended because the amount of visible stalk injury was significantly increased over that shown by corresponding untreated or Decco treated celery.

2. Prepackaging

The following films were compared for their merit in prolonging the salable life of raw produce. Pliofilm 75FF, Pliofilm 75N2, Pliofilm 75P6A, Cellophane 300LSAT, Cellophane 300MSAT-86, Lumarith P-912, Dupont Acetate 100CA48, Polythene and Kodapak II-130.

Wrapping techniques were also evaluated using the following variations; Complete seals, tent-flap closures, single hole punctures, multiple punctures and windo bags.

The following products were studied: celery, tomatoes, carrots, lettuce, cauliflower, chopped salad mix, spinach, strawberries, raspberries, blackberries, and boysenberries.

Harvested produce was packaged both before and after the removal of field heat. Behavior of the pre-packaged products in both 33°F storage and subsequent 80°F storage was studied. Cold storage was extended as long as 120 days while subsequent holding at room temperature varied widely from produce to produce. Observations were made at regular intervals for each product. Several hundred uniform samples were evaluated for most products using duplicates of each treatment for every observation period. Evaluation of most samples included weightloss, CO_2 (and sometimes O_2) of the container

atmosphere, mold and decay development, flavor, color, odor, wilting and shriveling.

The following conclusions were drawn:

All films and wrapping methods affect produce quality. For each produce, treatments could be singled out which were superior to unwrapped controls. However any particular film and type of seal found to be superior for one produce was often not acceptable for another fruit or vegetable. Among the factors found to be critical for the proper choice of treatment were type of produce, produce temperature when packed, length of storage, and temperature of storage.

A. Cold Storage

For most products, the partially sealed, low permeability MSAT containers and the completely sealed Polythene wraps scored highest for overall product quality. These treatments prevented the accumulation of undesirable CO_2 while at the same time protecting the produce against weightloss and consequent wilting. For some produce, especially berries, wilting was not apparent even in high permeability films such as acetates.

B. Warm Storage

For produce with high respiration rates (spinach, and berries) only acetate films were acceptable as wraps.

The partially sealed low permeability films maintained good quality in warm storage but the high humidity within the package was conducive to micro-organism activity. Thus, in many cases samples disinfected prior to packaging in those films improved the warm storage quality.

Disinfection also improved the quality of tomatoes and chopped salad mix in acetate wraps.

Of the high permeability films, no significant difference was found among the Dupont acetate, Lumarith and Kodapak II.

The type of seal also did not affect the characteristics of these wraps. The low permeability films differed principally in the amount of CO_2, retained by the container during storage. The Pliofilms retained the highest CO_2, levels followed by LSAT and then MSAT Cellophane.

The sealed polyethylene, the single puncture and tent flap MSAT wraps exhibited similarity, especially with respect to CO_2 accumulation.

The multiple puncture low permeability wraps showed characteristics between acetates and the last mentioned group.

Correlation between CO_2 accumulation and off-flavor formation could be determined for most products. Higher CO_2 levels were tolerated at short storage intervals without off-flavor formation by most products but the rate of change in CO_2 tolerance varied from produce to produce. Correlation between % weightloss and degree of wilting could also be expressed as a function of the pre-packaging treatments used.

Storage infection was eliminated by all films independent of the type of seal used.

It should be emphasized that only a study of the results and relationships discussed under each product can serve as a basis for future work and commercial application of the methods presented in this work.

THE EFFECT OF PHYSICAL AND CHEMICAL AGENTS ON THE STORAGE CHARACTERISTICS OF RAW VEGETABLES AND FRUITS

by

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TABLE OF CONTENTS

TABLE OF TABLES

TABLE OF FIGURES

TABLE OF ILLUSTRATIONS

THE EFFECT OF PHYSICAL AND CHEMICAL AGENTS ON THE STORAGE CHARACTERISTICS OF RAW VEGETABLES AND FRUITS

PURPOSE OF STUDY

The sharp rise of the frozen food industry has precipitated an intensive search for better methods of merchandizing on the part of the fresh produce distributors. Considerable effort has been expended to prolong the market life of fresh produce to improve quality and reduce waste (54).

The food technologist is principally concerned with three of the factors responsible for the deterioration of produce between harvest and consumption. These factors include: (a) decay produced by micro-organisms acquired by the plant in the field or during storage, (b) evaporation of water from the plant causing wilt or shrinkage and (c) abnormal enzymatic activities of the harvested plant associated with off-flavor, color, odor and general aging (53) (17).

The purpose of this study was to determine the possibilities of chemical agents in reducing decay, of physical agents in retarding wilting and of a combination of both physical and chemical agents in improving flavor, odor, color and general quality of seven vegetables and five fruits between the times of harvest and consumption.

REVIEW OF LITERATURE

The causative factors of storage and market diseases in vegetables and fruits have been discussed in many investigations especially by the agencies of the United States Department of Agriculture (42) (43) (44) (45). While it is generally agreed that micro-organisms such as molds and bacteria play an important role in the decay producing post-harvest diseases of vegetables and fruits, only a limited amount of work has been reported on the control of micro-biological spoilage through the surface-application of disinfection solutions.

During the last decade a number of compounds have been reported as having potent bacterio - and/or mycocidal properties. Almost all of these studies, however, were carried out "in vitro" and were based on a few isolated test organisms. Such information, while important as a starting point, cannot be directly applied to the surface disinfection of fruits and vegetables. Factors such as compatibility of chemical and produce, effectiveness against the mixed flora characteris tic for each vegetable or fruit under average commercial operating conditions, stability, wetting and penetrating power, toxicity at the effective level of concentration, flavor, odor and appearance all have to be evaluated before any germicide can be

chosen for the surface disinfection of produce.

There are a few sporadic tests, (29) (62) (3) (7) (36), in which the effectiveness of a particular compound on a specific fruit or vegetable was studied. Somewhat more comprehensive studies are reported for animal products where a number of germicides were tested on a comparative basis against mixed cultures such as fish slime (55). Systematic comparative studies of the many types of compounds having "in vitro" germicidal potency are often found to be lacking for "in vivo" conditions.

Among the compounds of interest are:

1. The chlorine liberating compounds such as the inorganic hypochlorites or organic chloramines such as -N-N'-dichloro-azo-dicarbonamidine. These have been reviewed by Levine (60) (47), Schmelkes (48) and more recently by Bartlett (4).

2. The quaternary ammonium salts which were reviewed by Hucker (59) (21) (22) and Hoogerheide (20).

3. The phenols, phenyl-phenols and their chloride derivatives (9) (50).

4. The fatty acid salts (19) (23).

5. The naphtho-quinones (28).

6. The benzoates (63).

7. The sulfur dioxide liberating compounds such as potassium metabisulfite (34) (35). The literature cited

reviews the relative potency of the various compounds of the same group such as the quaternaries by Hucker (21) or the benzoates by Wyss (63). Phenol coefficients and relative rate of kill of specific isolates of micro-organisms are generally used as a basis of comparison while in a few cases the inhibitory effect of organic media such as blood serum are also reported. A few authors report the relative "in vitro" potency of a number of the above groups of compounds against specific organisms (28). Finally, several studies deal with the effect of a specific compound or group of compounds against a particular organism using commercial produce as a basis of comparison. Outstanding studies along this line have been reported by Pentzer (35) on grapes and Klotz (27) on citrus products.

Toxicity studies have been reported by manufacturers such as the U. S. Rubber Company for phygon as well as by several authors such as Harshbarger for quaternaries, benzoates and propionates (13). Other reports deal with the toxicity of phenyl-phenols (30) or quaternaries (51).

The use of transparent plastic films for the packaging of raw produce prior to storage and merchandizing is a rather recent development. Unfortunately commercial application preceded thorough technical evaluation of the suitability of various films and wrapping techniques.

Again, as in the case of chemical agents, good information is available for such physical properties as moisture-vapor transmission and oxygen or carbon dioxide permeability for most films and wrapping techniques (1) (8). This information is of only limited value since the proper choice of wrapping material will depend upon the transpiration, respiration and decay characteristics of each produce and will vary with each set of storage and merchandizing conditions. Produce weight losses, accumulation of carbon dioxide and depletion of oxygen within the packages, susceptibility to decay and injury are all related to the type of film and wrapping technique employed. In addition storage times and temperatures, produce type, temperature, and contamination at the time of wrapping affect the ultimate quality of the product to varying degrees depending upon the type of film and wrapping method used. In addition, disinfection prior to packaging sometimes alters conditions within the container so that produce previously unacceptable retains high quality.

The fundamental relationships between film type, wrapping technique (complete seals, puncture or partial seals) and produce were first postulated by H. Platenius (41). He points out the danger of using low gas transmission films for produce with high rates of respiration.

He proposed an investigation of the use of partially sealed containers for such produce. L. E. Scott (49) studied the use of acetate, cellophane and pliofilm on tomatoes, corn, peas, beans and asparagus in sealed packages for short storage periods; tomatoes were held in cold storage, others in warm storage. On the basis of gas analyses of the container atmosphere he concluded that all films permitted accumulation of carbon dioxide and depletion of oxygen. The type of produce, type of film, storage time and temperature were considered critical and the author pointed out the danger of generalizations regarding the use of prepackaging films and methods. Both of the above authorities in the field of prepackaging as well as a number of others indicate the necessity of investigating individual products under well defined conditions in order to arrive at even tentative conclusions regarding optimum film type and wrapping techniques (31) (46).

Such investigations have been reported for cherries by Gerhart (11) and for cranberries by Esselen (18). In addition to these a number of other studies have been reported which, while thoroughly technical, were limited to very short storage periods or very few film types (10) (14) (15) (16) (24) (26) (32) (52).

The use of disinfectants in combination with prepackaging has been reported by some commercial produce

packers (61) but systematic data regarding effectiveness are lacking.

Accumulation of carbon dioxide and depletion of oxygen in the container atmosphere have been reported as critical for the various film types and wrapping techniques (11) (31) (41) (49). Extensive studies of the effect of carbon dioxide and oxygen concentrations surrounding produce on flavor (25), odor (51) (56), color (56) (57), injury (6) (33), decay (5) (6) (58), respiration rates and quotients (39) (57) and nutritive value (40) have been reported for most products.

However, all these studies were made with produce held in chambers in which the concentration of carbon dioxide and oxygen were artifically kept constant throughout the experiments. In prepackaged produce the concentrations of O_2 and CO_2 are constantly changing depending on film type, wrapping method, produce type, temperature and degree of contamination as well as storage conditions. Thus correlation between instantaneous oxygen and carbon dioxide concentration and produce quality is complicated and, as Scott (49) points out, requires experimental data for each produce.

PLAN OF STUDY

The first phase of the experimental work was limited to an investigation of the relative effectiveness of a large number of chemicals in reducing decay of several vegetables and fruits. Surface application of germicides was accomplished by dipping the produce into aqueous solutions of the test chemicals.

In the second phase most of the commercial and some of the experimental films and wrapping techniques advocated for the post-harvest physical confinement of produce were evaluated using seven major vegetables and five fruits. The effect of these treatments on the storage and merchandizing quality of each produce was compared on the basis of a number of evaluations.

Finally, disinfection and wrapping were studied as combination treatments using the same methods of evaluation as in the first two phases.

Whenever possible objective methods were used to obtain data. When this was not feasible attempts were made to correlate subjective observations such as wilt, flavor and decay with objective analyses such as carbon dioxide and oxygen concentration of container atmosphere, weight losses or bacterial counts.

Statistical design and interpretation were used in the large scale field test in order to arrive at commercially significant recommendations.

The applied nature of this investigation required many small scale exploratory experiments in which visual and subjective methods had to be relied upon for evaluation. The shortcomings of such a procedure are obvious but often a necessary expedient in a strictly applied field such as food technology. In all such cases the information gained should be considered merely as a trend. As such, it served as a basis for larger pilot plant and field tests of this dissertation, or, where the work was not carried beyond the laboratory stage, as a starting point for future investigations.

In order to remain in the realm of food technology only chemical agents and films were investigated which can be obtained from manufacturers in commercial or experimental lots. No attempts were made toward synthesis or modification.

EXPERIMENTAL

Section I - Disinfection Studies

A. General

It has been stated that one of the principal factors responsible for deterioration of raw produce in storage is destruction by micro-organisms which either were present on the product and carried into storage or acquired during storage. Methods for reducing storage losses may be directed toward both sources of contamination by 1) germicidal treatments just before storing to reduce infection already acquired and by 2) physical protection in the form of overwrap films to eliminate storage contamination. In this section the first measure is discussed and illustrated.

While "in vitro" germicidal potency data are available for many compounds, comparative studies using actual produce are few. To determine the possibilities of several germicides a number of fruits and vegetables were treated with representative samples of various types of compounds.

First, preliminary tests were run in which a large number of chemicals were applied to small samples of fresh produce. Three levels of concentration for each chemical were arbitrarily chosen. These tests served to eliminate those compounds which caused the product to be damaged in

some way or which were not effective as disinfectants.

On the basis of the results from the preliminary tests the most promising chemicals were next evaluated on a "pilot plant" scale. Here, commercial storage units of produce were used to test the treatment. Results of these tests, in turn, were utilized to arrive at a decision regarding which treatments should be used in a field test.

In the preliminary studies only crude evaluations were used. But as the work progressed the evaluation was expanded until statistical analysis was employed for determining the results obtained in the field test. Only these last results are considered reliable enough to serve as a basis of recommendation for commercial application.

Six vegetables and two fruits were used for the preliminary studies. The most promising fruit and vegetable each was carried into the pilot plant stage. Finally the vegetable was field tested.

In addition, the results of the preliminary studies served as a basis of choice for the disinfectants used in the extended work on prepackaged fruits and vegetables where decontamination was coupled with physical confinement.

B. Preliminary Studies

1. Materials and Methods

a. Produce

Studies were made on several of the most commonly stored fresh products. The list included the following vegetables and fruits.

carrots
cauliflower
celery
chopped salad mix
lettuce
tomatoes
grapes
strawberries

The produce was obtained from a local wholesaler from single lots shortly after harvesting. However, the exact history of the products is unknown. They were held in cold storage until tested. Samples of each produce were sorted and trimmed for uniformity but were not washed.

b. Inoculation

All produce including control samples was uniformly inoculated before treatment. Mixed cultures of spoilage organisms (bacteria and mold) were obtained from samples of commercially stored and decayed produce. A typical culture was prepared for each fruit and vegetable and maintained by transfer to fresh produce. Before inoculation of a treatment series, a water suspension was prepared in a quantity sufficient for the entire test. The produce was then contaminated by application with a standard spray atomizer, keeping the method and times of exposure nearly constant. The organisms were applied to the test samples approximately 12 to 18 hours before the chemical treatment. During that time the samples were

maintained in cold storage.

c. Chemical Treatment

An attempt was made to select one or more compounds from each group of chemicals having "in vitro" germicidal power. Table 1 shows the various chemicals used in these experiments.

All compounds were applied by immersing the fruit or vegetable in an aqueous preparation of the chemic al. Most substances were water soluble and presented no problem but for the few which were not they were first dissolved in a solvent such as propylene glycol which in turn was miscible with water.

Generally, solutions of three concentrations were tested at levels based on information gained from "in vitro"potencies reported in the literature.

In order to improve contact of the solution with the surface of the produce a non-toxic wetting agent (64), "Aresket", was added. It was not used with quaternary compounds which possessgood wetting properties themselves.

Each sample was dipped into the germicidal solution for a specified time, drained and stored. Untreated samples of each lot served as controls.

d. Storage

After draining, each treatment of a particular product was placed on trays in a manner that separated it to prevent contact contamination. Storage cabinets were

TABLE 1

Germicides Used in Preliminary Disinfection Studies of Vegetables and Fruits

Type of Compound	Chemical Composition	Trade Name	Manufacturer	Produce Used
1.Quaternaries				
a. alkyl-chlorides	Alkyl(C_8-C_{18})dimethyl-benzyl ammonium chloride	Roccal	Winthrop-Stearns Inc.	all 12
	Alkyl(C_8-C_{18})dimethyl 3,4 dichloro-benzyl ammonium chloride	Tetrosan	Onyx Oil and Chem. Co.	celery
b. alkyl-bromides	Oleyl-dimethyl ethyl-ammonium bromide	Onyxide	"	all 12
	Cetyl-trimethyl ammonium bromide	Cetab	Rhodes Chem.Co.	celery
	Cetyl-dimethyl ethyl ammonium bromide	Ethyl Cetab	"	Celery
	85% octadecyl and 15% octadecenyl dimethyl ethyl ammonium bromide	Octimet	"	celery
c. pyridinium chloride	n-(lauroyl colomino formyl methyl) pyridinium chloride	Emulsept	Emulsol Corp.	grapes and celery
2.Chlorine liberators	Calcium hypochlorite	BK Powder	Penna.Salt Co.	all vegetables
	an azo-chloramid	Decco	Wallace and Tiernan Co.	all vegetables
3.Phenols	Hexylresorcinol	(experimental)	Sharp & Dohme	all 12
	Sodium Chloro-2-phenylphenol	Dowicide C	Dow Chem. Co.	all 12
4.Quinones	2,3 dichloro-1,4 naphthoquinone	Phygon	U.S. Rubber Co.	celery & grapes
	2,3 dichloro-1,4 hydroxynaphthoquinone	(experimental)	—	celery & grapes
5.Fatty acid salts	Sodium propionate	Mycoban	DuPont	grapes
	Calcium propionate	—	"	all but grapes and celery
6.SO_2 liberator	Potassium metabisulphite	—	Baker Chem. Co.	grapes
7.Benzoates	Sodium benzoate	—	"	grapes

especially cleaned to prevent infection. Samples were stored at room temperature and a high relative humidity (75-95% R.H.). This temperature level was selected because it was a method of accelerated storage which had been found effective in earlier exploratory work for rapid evaluation of treatments. The length of time a product was kept in storage varied according to the time required to produce mold or obvious spoilage.

e. Evaluation

At the time it became evident that spoilage had occurred the products were removed from the storage cabinets and evaluated. The effectiveness of the treatment was judged by comparison with correspondingly handled untreated controls for mold, rot or injury caused by the chemical. Observations were made only once for a series since handling the produce for inspection would have spoiled the effect of disinfection.

Of the treatments tested only those were considered effective which caused no apparent damage to the product and which reduced mold and or rot deterioration. In order to be considered effective a majority of the samples of the treatment were required to show improvement over the controls. (Two consecutive series were run for each product using three samples for each treatment). If the results were questionable or any damage was definitely present the treatment was considered not satisfactory.

2. Results

On the basis of the criteria for evaluation mentioned above, the following table was prepared to show a list of the effective chemicals together with the satisfactory concentrations for each product investigated. Effectiveness against mold and/or rot are indicated.

The results shown in Table 2 were used as a basis for selecting the proper treatment for the pilot plant studies on celery and grapes.

In addition the results of the preliminary experiments served as a guide in selecting the proper disinfection treatment for the major section of this thesis where produce disinfection was coupled with protection against storage contamination by means of plastic films.

C. Pilot Plant Studies

To confirm the results of the preliminary studies pilot plant experiments were planned. Through the use of larger samples of better known harvest history and uniformity it was possible to be assured of more reliable information. For this reason larger scale experiments were carried out using table grapes and celery.

1. Materials and Methods

a. Grapes

(1) Produce

Twenty-five lugs of Emperor and five

TABLE 2

Effective Mold and Rot Inhibitors for the Vegetables and Fruits Tested at Room Temperature and High Humidity Storage

Produce: (3 samples per treatment/series)	Chemicals Used: Name	PPM	Approx. days in storage	Effective against: Mold	Rot
Celery	Hexylresorcinol	1,000	8	x	
	Onyxide	500	8	x	
	Onyxide	1,000	8	x	x
	Dowicide C	500	8		x
	Dowicide C	1,000	8		x
	Cetab	500	8	x	
	Cetab	1,000	8	x	x
	Octimet	1,000	8	x	
	Decco	200	8		x
	Decco	400	8		x
	Decco	1,000	8		x
	Calcium hypochlorite	500	8		x
	Calcium hypochlorite	2,000	8		x
Carrots	Sodium propionate	5,000	10	x	
	Sodium propionate	10,000	10	x	
	Onyxide	500	10	x	
	Decco	500	10		x
	Hexylresorcinol	1,000	10	x	
Cauliflower	Sodium propionate	5,000	5	x	
	Sodium propionate	10,000	5	x	
	Onyxide	500	5	x	x
	Decco	500	5		x
	Decco	1,000	5		x
	Hexylresorcinol	500	5	x	
Chopped Salad Mix	Decco	500	3		x
	Decco	1,000	3		x
Tomatoes	Calcium propionate	20,000	4	x	
	Hexylresorcinol	500	4	x	
	Hexylresorcinol	1,000	4	x	
Lettuce	Decco	500	6		x
	Decco	1,000	6		x
Grapes	Roccal	10,000	5	x	
	Roccal	20,000	5	x	
	Sodium propionate	10,000	5	x	
	Dowicide C	800	5	x	
	Dowicide C	1,200	5	x	
	Phygon	100	5	x	
Strawberries	None effective	-	2		

lugs of Almeria grapes were obtained direct from the grower and trucked from California to Corvallis without delay. There they were placed in cold storage until the treatments were completed. The uniformity and excellent condition of both varieties made sorting unnecessary.

(2) Treatment

Since grapes were known to mold easily no inoculation was used although it is recognized that this represents a slight departure from the basic studies. The disinfection treatments applied were those chemicals listed previously in Table 2. Also the same concentrations which were reported in that table were used with the exception that 1000 p.p.m. Dowicide C was employed.

The experiment was carried out at a temperature of 33° F. to prevent a change in temperature of the fruit. The contents of one or two lugs received a single treatment in contrast to the portions of a bunch that were treated in the preliminary tests. The samples were dipped, drained on stainless steel screens and repacked into the washed, dried and relined lug boxes. Controls were untreated lugs.

(3) Storage of Almeria and Emperor Grapes

A special plywood cabinet was constructed for storing the grapes at 32.5° ± 1° F. and 80-90% R.H. This allowed the experimental pack to be isolated from other products in the storage room. Storage was maintained

for 14 weeks after which time the untreated commercially packed samples which served as controls appeared to be at least 50% unsalable.

(4) Evaluation

When it became evident that the control samples were considerably moldy the entire lot was examined for extent of mold, general appearance and flavor.

The extent of mold was determined by separating into three groups the bunches of grapes considered moldy, slightly moldy or not moldy. The weight of the bunches in each group was then recorded for each lug as it was inspected. While it was impossible to assign a clear-cut borderline between slight and heavy mold an attempt was made on the following basis. Light mold was that which could be eliminated by the removal of a few berries in the bunch or which did not spoil the fruit proper. More than that amount was rated as heavy mold. Actual examples of this division are shown in Plate I where sample H represents light mold and sample I represents heavy mold.

The appraisal of general appearance included the color and dryness of the stems, presence of natural bloom and color and firmness of the berries. It did not include the presence of mold since this was separately evaluated.

Flavor of the fruit was evaluated also. It was tasted by the investigators at the time the lugs were

Plate I

Typical Examples of Slightly Moldy and Heavily Moldy Emperor Grapes

Light Mold

Heavy Mold

opened and inspected. This tasting was performed with the object of detecting the presence of pronounced foreign flavors. The possibility is recognized, however, that slight flavor changes might have missed detection.

b. Celery

(1) Produce

About twenty-five crates of commercially harvested, precooled, Pascal celery was obtained direct from the packing house and trucked from Brooks, Oregon, to Corvallis. There it was stored at 33° F. until treated. Before disinfection could be applied the individual bunches were removed from the crates and trimmed to remove as many bruised and injured stalks as possible.

(2) Inoculation

To insure infection the stalks were immersed in forty gallons of water chilled to 33° F. with ice and containing a heavy inoculum of celery spoilage organisms. Following immersion the stalks were removed and allowed to drain overnight in cold storage. The following day the celery was treated.

(3) Treatment

After inoculation the chemical treatments reported promising in Table 2 were applied to one crate of celery per treatment. Several untreated crates were reserved as controls. Again chilled water was used to

prepare the germicidal dips. Each bunch was removed from the dip and shaken separately to remove excess water. The celery was then repacked into the Howard type crates which were lined with new parchment paper.

(4) Storage

The crates of celery were stored at 33-35° F. and 95% R.H. for ten weeks. At that time there was pronounced spoilage apparent so that the samples were ready for inspection.

(5) Evaluation

All crates were opened and examined at the same time so that comparisons were possible. The contents of each crate were checked for general appearance, mold development, visible decay and chemical damage.

The extent of mold was characterized in four categories as severe, some, slight or none and scored by plus and minus marks. Decay also was expressed in the same manner. It must be pointed out that no distinction was made between decay caused directly by attack of microorganisms, or that due to physiological changes, or both. Thus the synonymous terms rot and decay are used in a very general sense.

The term damage also demands explanation. It was observed that after prolonged storage bruised or cut areas on the stalks were subject to deterioration. This was apparent on the untreated as well as treated stalks but

appeared greater on the treated material. Thus there is no clear cut definition for damage. In this report it is interpreted to mean a quality decrease caused by either or both mechanical and chemical injury.

2. Results

a. Grapes

Each treatment was ranked on the basis of percent saleable produce. This figure was calculated from the weight of the no-mold/total weight fraction of each crate as described under materials and methods. Table 3 shows the treatment rank and percent saleable material for both the Almeria and Emperor varieties. General condition other than mold is also described.

An inspection of Table 3 indicates that protection was afforded by at least three of the chemical treatments. Among these, Dowicide C was outstanding for both Almeria and Emperor varieties.

On the basis of the organoleptic tests described under materials and methods no significant difference in flavor could be detected.

A crate each of untreated control and of Dowicide treatment was divided into the three classifications of mold; namely, heavy, light and no mold and is shown in Plate II for Almeria grapes and in Plate III for Emperor grapes. It may be observed that the heavy mold for the control samples was much more severe as

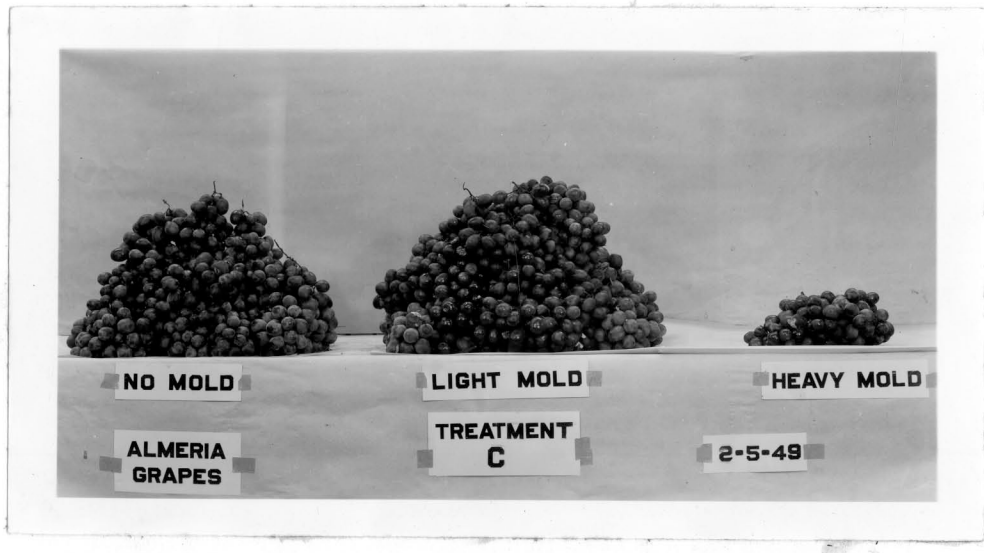
TABLE 3

Results of Pilot Plant Mold Inhibition Study with Table Grapes After 14 Weeks of Cold Storage

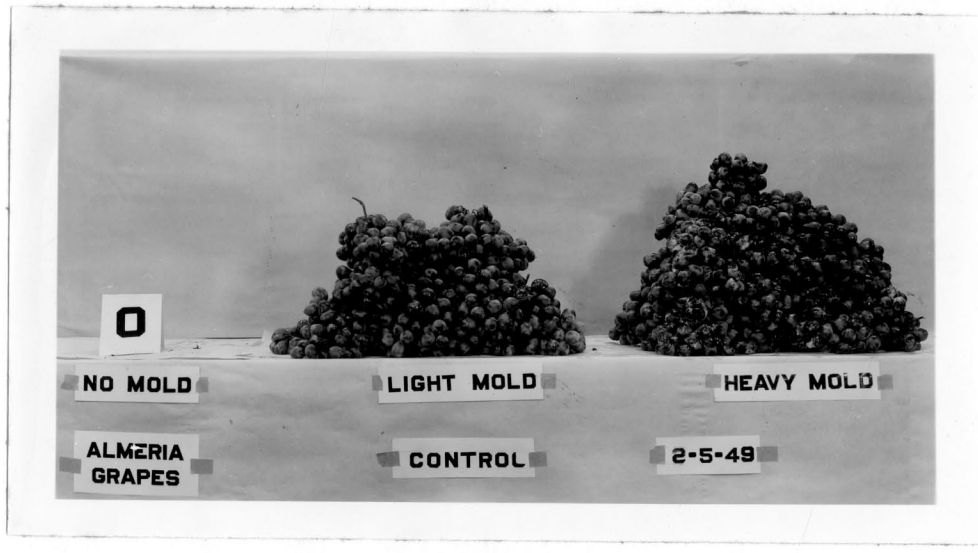
Treatment			Var. Emperor			Var. Almeria		
Chemical	Conc. in PPM	Code	Rank	% Saleable	Condition	Rank	% Saleable	Condition
Dowicide C pH = 8	1000	C	1	29.0	Fair, some stems brown and dry, no bloom	1	36.4	Fair to good, mostly dry and brown stems, some bloom, firm fruit
Roccal	20,000	A	2	17.4	Fair to poor, some brown and dry stems, sl. bloom	3	19.1	Very poor, brown spots on fruit due to treatment
Phygon	100	D	3	16.3	Fair to poor, some brown and dry stems, no bloom	2	33.0	Fair, very dry and brown stems, Good bloom
Roccal	10,000	E	4	7.8	Poor, mostly dry and brown stems, trace bloom	Not run		
Sodium-Propionate	10,000	B	5	1.3	V. poor, brown and dry stems, fruit soft	4-5	0.0	V. poor, dry and brown stems, some soft fruit
Controls		X	6	0.0	V. poor, brown and dry stems, fruit soft	4-5	0.0	V. poor, dry and brown stems, some soft fruit

Plate II

Distribution of Mold in Single Crate Lots
of Almeria Grapes Stored 14 Weeks at 33° F.



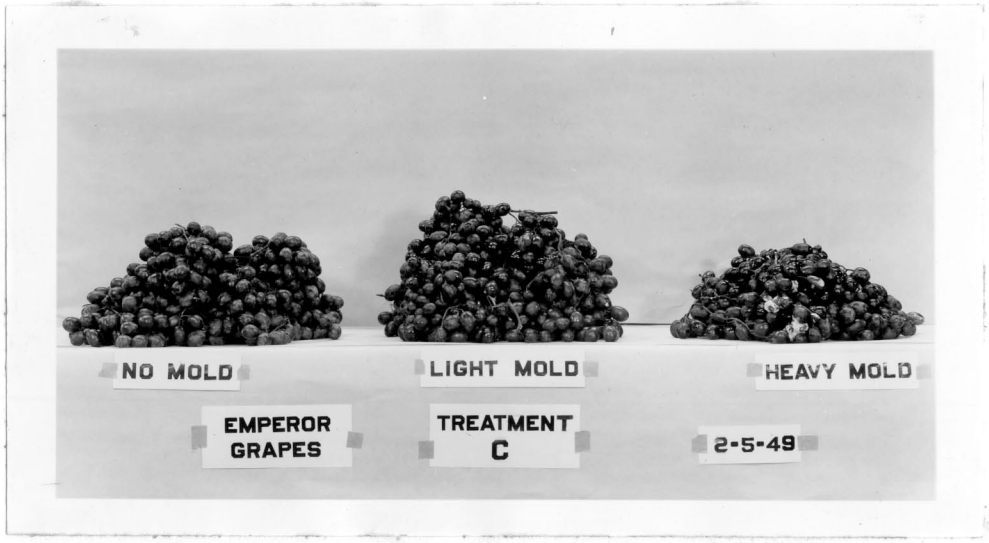
Best Treatment



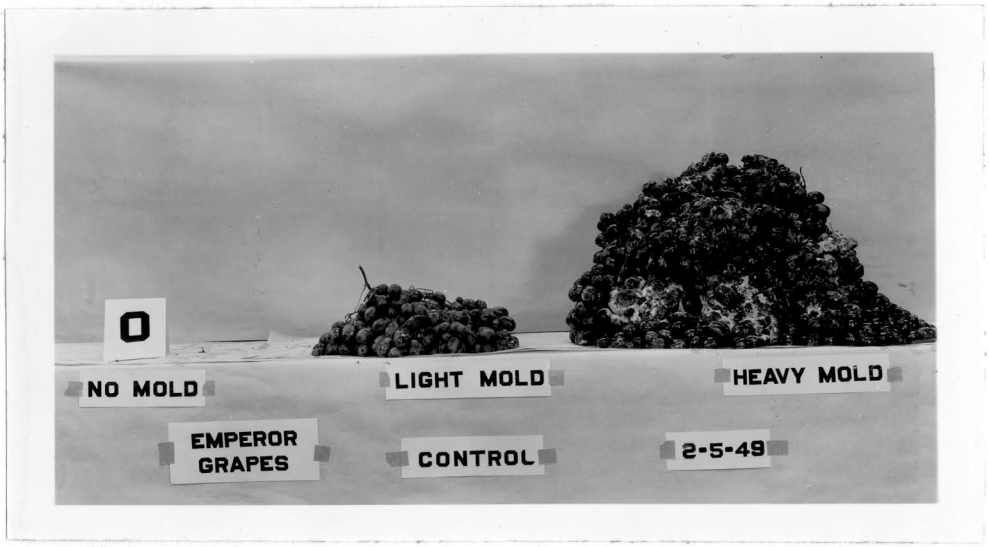
Untreated Lot

Plate III

Distribution of Mold in Single Crate Lots
of Emperor Grapes Stored 14 Weeks at 33° F.



Best Treatment



Untreated Lot

well as extensive than for the corresponding treated samples.

Plate IV illustrates a typical bunch of Dowicide treated Almeria grapes after 14 weeks of cold storage.

Since several of the treatments described in this section served as corresponding samples for a series of disinfected and pre-packaged grapes a discussion of the results of both series with respect to mold prevention will be given in Section II of this paper under pre-packaged grapes.

b. Celery

Results of the pilot plant test on Pascal celery are reported in Table 4. All samples showed some deterioration in quality. Observation indicated that three of the treatments were better than the rest and definitely better than the controls. The three preferred lots were Decco at 1000 p.p.m., Onyxide at 1000 p.p.m. and Cetab at 1000 p.p.m. Further studies were based on these results.

D. Field Study

In order to further reduce the limitations of laboratory testing a field test was planned for studying the effect of disinfecting celery prior to storage. By using a large sample consisting of several crates per treatment and carrying out the experiment in the plant instead

Plate IV

Almeria Grapes Treated with Dowicide C
and Stored 14 Weeks at 33° F.

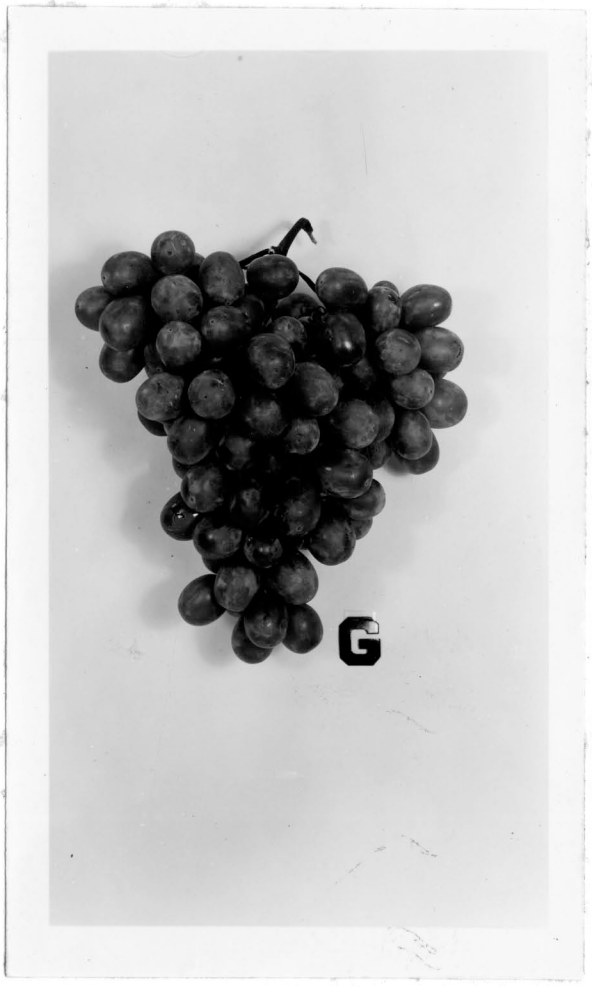


Table 4

Effect of Germicidal Dips on Celery
After 10 Weeks of Cold Storage -
Basis : 30 Bunches Per Treatment

Treatment		Condition of Each Crate		
Compound	Conc.	Mold	Rot	Damage
Decco	200	xx	x	-
Decco	400	x	-	-
Decco	1000	x	-	-
BK Powder	500	xx	xx	-
BK Powder	2000	xx	x	-
Hexylresorcinol	1000	x	xx	-
Dowicide C	1000	-	-	xx
Octimet	1000	-	x	x
Onyxide	1000	-	-	x
Cetab	1000	-	-	x
Control	-	xx	xxx	x
Washed Control	-	xxx	xxx	-
Repacked Control	-	xx	x	x

Legend: xxx severe
xx some
x slight
- none

of the laboratory the conditions of the experiment more nearly approached those of commercial operations. The disinfection treatments chosen for study were based on the results obtained in the pilot plant test.

1. Materials and Methods

a. Produce

145 Howard crates (approximately 4,000 bunches) of Pascal celery were harvested by the Labish Celery Growers in Brooks, Oregon, packed and hydrocooled to 40° F. by immersion. Within 24 hours after cutting, the celery was treated without any sorting or trimming except that which was done commercially.

b. Treatment

The lot was divided so that 40 crates were set aside for controls while the remainder was separated into three groups, one for each treatment.

Treatment was applied in the following way. Two 100 gallon capacity tanks were available. Each was filled with 80 gallons of solution, using cold tap water. The contents of approximately 1½ crates were submerged into the solution, accompanied by mild agitation, for ten minutes. The bunches were removed, shaken by hand to remove excess water and repacked in freshly lined crates. The entire lot was trucked to the Northwest Ice and Cold Storage Warehouse in Portland for storage.

The treatments used in this experiment are indicated in Table 5.

TABLE 5

Disinfection Treatments of Pascal Celery in Field Study

Code	Treatment			pH Adjusted to	No. Crates Treated
	Chemical	Concentration in PPM	Concentration of Wetting Agent Added		
C	Cetab	1,000	--	--	33
K	Decco	1,000	1,000	5.0	35
O	Onyxide	1,000	--	--	35
X	None	--	--	--	40

c. Storage

The lot of celery was stored separately in the warehouse in a room maintained at 32 $\pm$ 0.5° F and 97 $\pm$ 2% R.H. The air in the room was circulated by means of a large fan so that storage conditions would be more uniform. The product was stored for 14 weeks before the final evaluation was made.

d. Analysis

Periodically the storage conditions were checked and a crate of untreated celery sampled for inspection. These crates were not used in the final scoring.

After 8 weeks in storage half the crates in each of the four groups were examined and evaluated for quality. A final evaluation was made after 14 weeks in storage on the remaining half of each group.

The examination was made in the warehouse in an adjoining cold room. The crates were opened and each bunch critically examined and scored for eleven characteristics as follows:

1. Butt - for color, rot and mold
2. Stalks - for damage, rot, mold and crispness
3. Leaves - for color, mold and crispness
4. Heart - for general condition

Table 6 shows a typical record card used in the examination of each bunch.

Inspection of the record card will show that each observation was recorded in descriptive words. These were later assigned numerical values from one to five with five representing a perfect score. In general, the words used corresponded to the following:

good = 5

trace = 4

slight = 3

some = 2

poor = 1

Table 6: Sample Sheet Used for Recording Data of Celery Examination

Crate No.	Stalk No.	Butt			Stalk				Leaves			Heart
		Color	Rot	Mold	Damage	Rot	Mold	Crisp	Color	Crisp	Mold	
2	7	Br		Sl	Sl		Tr	limp	SlY	limp		
		Br		r	S	S			SlY		Tr	
		Br			Sl				Green			
		Br		S	Sl		Sl	Limp	SY	Limp	Tr	G
		light		S	Sl		Tr	Sl Limp	Good	Sll		
		Br	Tr	Sl	Sl		Tr		TrY			G
		Br		S	S	Sl	Sl	Sl L	Green	Sll	Sl	
		SBr	Bad	Bad	S	Sl	Tr		SY	Sll		G
		Br		S	Sl	Sl	S		Green		Tr	
		Br		Sl	S		Sl		SlY			G
		Br		Bad	Sl	Bad	S		SlY		Tr	G
	16	Br		S	Sl		Sl		TrY	Sl L		

As soon as the contents of a crate were examined the batch was immersed in twenty gallons of fresh tap water for ten minutes. A representative sample of this water was then obtained for each crate. This was transported to the laboratory and submitted to a bacteriological determination. Samples of tap water were collected at regular intervals to serve as controls for the bacterial counts. All crates were sampled in this manner, including the untreated controls.

Typical bunches from each treatment were selected and returned to the laboratory for organoleptic evaluation and photography.

2. Results

a. Microbiological

In Table 7 the results of the bacteriological examination are shown. The counts are reported as number per cubic centimeter as well as the number per crate of approximately thirty bunches of celery each.

TABLE 7

Result of Micro-organism Counts for Cold Storage Pascal Celery Using Standard Bacteriological Technique

Treatment Used			Ave. Total Count per cc	Ave. Total Count Per Crate	Number of Crates Tested
Compound	Conc.	Code			
8 Weeks Bacterial Count					
Decco	0.1%	K	430	3.3×10^{6}	18
Onyxide	0.1%	O	7.4×10^{6}	5.6×10^{11}	18
Cetab	0.1%	C	6.2×10^{6}	4.7×10^{11}	18
Control	--	X	3.5×10^{6}	2.6×10^{11}	18
14 Weeks Bacterial Count					
Decco	0.1%	K	0.5×10^{6}	4×10^{10}	17
Onyxide	0.1%	O	98.5×10^{6}	130×10^{10}	17
Cetab	0.1%	C	86.5×10^{6}	655×10^{10}	17
Control	--	X	17.0×10^{6}	363×10^{10}	17
14 Weeks Mold Count					
Decco	0.1%	K	152.0×10^{3}	$1,152.0 \times 10^{7}$	17
Onyxide	0.1%	O	2.5×10^{3}	19.3×10^{7}	17
Cetab	0.1%	C	1.3×10^{3}	9.6×10^{7}	17
Control	--	X	57.5×10^{3}	434.0×10^{7}	17

In order to be assured that differences observed were significant the test of analysis of variance was used. For this analysis the bacterial and mold counts were converted to logarithmic values in order to satisfy the condition of a normal population necessary for the analysis of variance.

In the following Table 8 are the results of the statistical analysis of the bacterial count.

TABLE 8

Results of Analysis of Variance for Log of Bacteria Count

Variation Due to	Sum of Squares	Degrees of Freedom	Mean Square	F	Remarks
Time	55.62	1	55.62	5.02	not significant
Chemical	350.34	3	116.78	10.53	significant
Interaction	33.26	3	11.09	23.90	significant
Error	59.39	128	0.46		
Total	498.60	135	--		

Since the main effect of chemical as well as interaction are significant the table of means reports the means of all 8 treatment combinations as well as the means of the 4 total means of treatments. The 5% Least Significant Difference between any two of the 8 treatment combinations is 0.46 while the 5% L.S.D. between any two of the 4 total means of treatments is 2.57 (Table 9).

Table 9

Table of Means for Log of Bacteria Count

	Chemical			
Time	O	C	K	X
8 wks.	7.128	7.014	2.150	6.714
14 wks.	7.909	7.881	5.124	7.207
Total	7.519	7.448	3.637	6.961

Thus, inspection of the table shows that the Decco treatment was definitely better than the rest for reducing the bacterial count at both storage periods and that the onyxide and cetab treatments were no better than the control. Also, as might be expected all treatments were lower in count at the eight weeks period than after 14 weeks in storage.

On the other hand, the results of analysis of variance indicate quite a different effect of the chemicals on mold growth (For experimental data refer to Table 8.). The 5% L.S.D. between any two treatment means is 0.19. See Table 10.

TABLE 10

Results of Analysis of Variance
for Log of Mold Count After 14 Weeks Storage

Variation Due to	Sum of Squares	Degrees of Freedom	Mean Square	F	Remarks
Treatment	53.57	3	17.86	220.73	significant
Error	5.18	64	0.081		
Total	58.75	67			

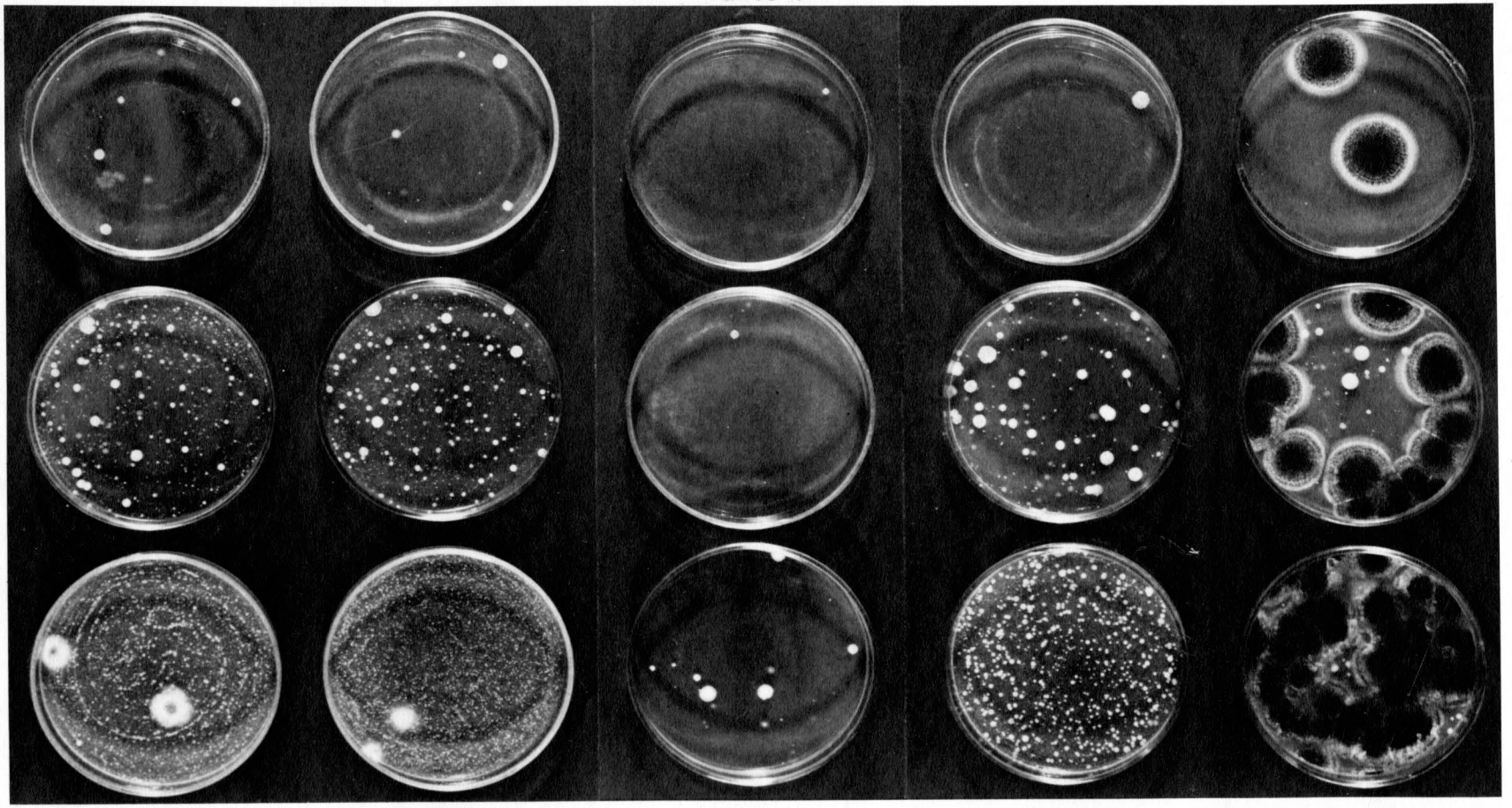
Since the treatment means were Onyxide = 3.58, Cetab = 3.34, Decco = 5.41 and control = 5.00 it is evident that for inhibition of mold development Decco is the poorest treatment followed by the untreated control, Onyxide and Cetab in the order named. At the eight weeks observation period no significant mold growth was obtained by the plate count method. It is believed that this probably was caused by the absence of sporulation during the early part of storage.

Plate V illustrates typical plates from the first bacteriological examination (8 weeks). Examples from each treatment are shown for bacteria and one set of plates with mold growth was also included.

b. Quality Evaluation

The method of recording and scoring experimental data obtained during the quality evaluation of celery was described under materials and methods. By

Plate V



Cetab (Bact. Count) | Onyxide (Bact. Count) | Decco (Bact. Count) | Controls (Bact. Count) | Controls (Mold Count)

Typical Plates Obtained From Cold Storage Celery

Top row: Dilution 1:1,000,000 Center row: Dilution 1:10,000 Bottom row: Dilution 1:100

Table 11

Experimental Results for the Field Study Quality Examination of Pascal Celery Stored at 32° F. and 98% R.H.
Each value represents mean score of approximately 500 bunches
Perfect score for each quality factor = 5.00

Treatment			Butt			Stalk				Leaves			Heart
Chemical	Conc.	Code	Color	Rot	Mold	Damage	Rot	Mold	Crisp-ness	Color	Crisp-ness	Mold	Condition
8 Weeks													
Decco	1000PPM	K	4.90	4.75	4.39	3.29	4.82	4.92	4.84	3.97	4.71	4.46	4.99
Onyxide	1000PPM	O	3.26	4.80	4.96	2.07	4.50	5.00	4.98	3.23	4.85	5.00	4.67
Cetab	1000PPM	C	4.40	4.87	4.93	1.96	4.19	4.99	4.99	2.78	4.93	5.00	4.61
Controls	-	X	4.99	4.79	4.35	2.68	4.85	4.98	4.99	2.97	4.90	4.75	4.95
14 Weeks													
Decco	1000PPM	K	4.56	4.17	2.36	2.33	3.49	3.09	4.25	3.02	4.76	3.64	4.67
Onyxide	1000PPM	O	4.75	4.20	4.58	1.98	1.99	4.93	5.00	2.10	4.99	4.98	3.22
Cetab	1000PPM	C	4.95	4.03	4.70	1.96	1.84	4.95	5.00	2.00	4.99	4.99	3.53
Controls	-	X	4.54	4.18	2.64	2.09	2.73	3.23	4.85	2.83	5.00	4.01	4.48

assigning a numerical score to each descriptive word accompanying the eleven characteristics judged it was possible to evaluate the quality of the celery quantitatively (See Table 11.). Furthermore, it was possible to determine whether the differences found were significant by statistical analysis. Since a total of more than 4,000 bunches of celery were observed it is possible to attach significance to smaller differences in the results than if fewer bunches had been used.

The results for each characteristic will be discussed separately.

(1) Mold

(a) On Butts

Results for analysis of variance for the mold found on the celery butts are given in Table 12a.

TABLE 12a

Results of Analysis of Variance for Mold on Celery Butts

Variation Due to	Sum of Squares	Degrees of Freedom	Mean Square	F	Remarks
Time	40.20	1	40.20	5.65	not significant
Chemical	62.81	3	20.94	2.94	not significant
Interaction	21.35	3	7.12	76.66	significant
Error	11.89	128	0.093		
Total	136.25	135			

Since the interaction is significantly different the treatment combination means are given in Table 12b.

TABLE 12b

Table of Means for Mold on Celery Butts

Time	Chemical			
	O	C	K	X
8 wks.	4.96	4.93	4.39	4.35
14 wks.	4.58	4.70	2.36	2.64

The 5% L.S.D. between any two of the eight treatment combinations is 0.21.

On the basis of the above results it was determined that the Onyxide and Cetab treatments were better than the Decco and control at all times while the control was better than the Decco treatment after 14 weeks in cold storage. Also, at 8 weeks all treatments were better than the corresponding treatment at 14 weeks.

(b) On Stalks

In Table 13a the results for analysis of variance for mold on celery stalks are given.

TABLE 13a

Results of Analysis of Variance for Mold on Celery Stalks

Variation Due to	Sum of Squares	Degrees of Freedom	Mean Square	F	Remarks
Time	28.97	1	28.97	3.39	not significant
Chemical	28.38	3	9.46	1.11	not significant
Interaction	25.67	3	8.56	158.47	significant
Error	6.91	128	0.054		
Total	89.93	135	--		

Table 13b. reports the treatment combination means.

TABLE 13b

Table of Means for Mold on Celery Stalks.

	Chemical			
Time	O	C	K	X
8 wks.	5.00	4.99	4.92	4.98
14 wks.	4.93	4.95	3.09	3.23

The 5% L.S.D. between any two of the eight combination treatments is 0.16.

The results for moldy stalks indicated that after 8 weeks in storage there was no difference observed between any of the four treatments. However, the Onyxide and Cetab treatments at 14 weeks showed less mold than the control and Decco treated celery.

(c) On Leaves

Results obtained from the observations of moldy leaves are shown in Table 14a.

TABLE 14a

Results of Analysis of Variance for Mold on Celery Leaves

Variation Due to	Sum of Squares	Degrees of Freedom	Mean Square	F	Remarks
Time	5.39	1	5.39	3.15	not significant
Chemical	22.28	3	7.43	4.35	not significant
Interaction	5.13	3	1.71	20.66	significant
Error	10.59	128	0.0827		
Total	43.38	135	--		

In Table 14b. are given the treatment combination means.

TABLE 14b

Table of Means for Mold on Celery Leaves

	Chemical			
Time	O	C	K	X
8 wks.	5.00	5.00	4.46	4.75
14 wks.	4.98	4.99	3.64	4.01

The 5% L.S.D. between any two of the eight treatment combinations is 0.20.

It was learned that there was more mold visible on the celery leaves for the Decco treated product than for any other treatment while the untreated celery exhibited more mold than the two quaternary treated groups. This was true for each of the two times the celery was examined. It was also true that chemicals O and C allowed less mold growth during 14 weeks of storage than developed on treatments K and X within 8 weeks.

(2) Evidence of Rot

(a) Rot on Butts

Inspection of Table 15 shows that the occurrence of rot on celery butts was directly related to the length of time in storage and was independent of the chemical treatment. Therefore, the chemicals neither produced or protected against this rot.

TABLE 15

Results of Analysis of Variance for Rot on Celery Butts

Variation Due to	Sum of Squares	Degrees of Freedom	Mean Square	F	Remarks
Time	14.69	1	14.69	94.62	significant
Chemical	0.054	3	0.018	0.12	not significant
Interaction	0.381	3	0.127	0.82	not significant
Error	19.86	128	0.155		
Total	34.99	135			

(b) Rot on Stalks

But the development of rot on the stalks was evidently affected by more than the time in storage. See Table 16a. for the results of analysis of variance.

TABLE 16a

Results of Analysis of Variance for Rot on Celery Stalks

Variation Due to	Sum of Squares	Degrees of Freedom	Mean Square	F	Remarks
Time	147.06	1	147.04	63.18	significant
Chemical	27.40	3	9.13	3.92	not significant
Interaction	6.98	3	2.33	13.19	significant
Error	22.58	128	0.18		
Total	203.99	135	--		

In Table 16b. the means of the treatment combinations as well as the total means for time regardless of treatment are given.

TABLE 16b

Table of Means for Rot on Celery Stalks

Time	Chemical				Total
	O	C	K	X	
8 wks.	4.50	4.19	4.82	4.85	4.59
14 wks.	1.99	1.84	3.49	2.73	2.51

The 5% L.S.D. between any two of the eight treatment combinations is 0.29.

Inspection of the table of means indicates that all treatments had less rotting of stalks after 8 weeks storage than at 14 weeks. But in addition to that, at 8 weeks the Decco and control treatments were better quality than the celery treated with quaternary ammonium compounds. By the time of the 14 weeks inspection period treatment K was better than the other three variables.

(3) Evidence of Damage

The extent of damage, by either chemical or mechanical causes, was affected by time in conjunction with the treatment. Table 17a. reports the results of analysis of variance for that quality factor.

TABLE 17a

Results of Analysis of Variance for Damage of Celery Stalks

Variation Due to	Sum of Squares	Degrees of Freedom	Mean Square	F	Remarks
Time	5.74	1	5.74	3.40	not significant
Chemical	15.63	3	5.21	3.09	not significant
Interaction	5.07	3	1.69	22.11	significant
Error	9.78	128	0.076		
Total	36.23	135	--		

The results of the 8 combination means are given in Table 17b.

TABLE 17b

Table of Means for Damage of Celery Stalks

	Chemical			
Time	O	C	K	X
8 wks.	2.07	1.96	3.29	2.68
14 wks.	1.98	1.96	2.33	2.09

The 5% L.S.D. between any two of the eight treatment combinations is 0.19.

For this quality factor the results indicated that the chemicals Onyxide and Cetab caused more extensive damage than was found on the controls, while the Decco

chemical proved better than no treatment with respect to stalk damage.

(4) Condition of Hearts

Table 18a. reports the results of the analysis of variance for the celery hearts.

TABLE 18a

Results of Analysis of Variance for Condition of Celery Hearts

Variation Due to	Sum of Squares	Degrees of Freedom	Mean Square	F	Remarks
Time	23.49	1	23.49	9.75	not significant
Chemical	20.55	3	6.85	2.84	not significant
Interaction	7.23	3	2.41	18.95	significant
Error	16.27	128	0.13		
Total	67.54	135	--		

The means of the eight treatment combinations are given in Table 18b.

TABLE 18b

Table of Means for Condition of Celery Hearts

Time	Chemical			
	0	C	K	X
8 wks.	4.67	4.61	4.99	4.95
14 wks.	3.22	3.53	4.67	4.48

The 5% L.S.D. between any two of the eight treatment combinations is 0.24.

The hearts of the celery from treatments 0 and C were always poorer than the treatments K and X and after the second half of the storage time treatment 0 was not as good as treatment C. In addition each treatment showed greater deterioration after 14 weeks than the corresponding treatment at 8 weeks storage.

(5) Crispness

(a) Stalks

The results of analysis of variance for the crispness of celery stalks are given in Table 19a.

TABLE 19a

Results of Analysis of Variance for Crispness of Celery Stalks

Variation Due to	Sum of Squares	Degrees of Freedom	Mean Square	F	Remarks
Time	1.10	1	1.10	1.59	not significant
Chemical	4.63	3	1.54	2.23	not significant
Interaction	2.08	3	0.692	6.99	significant
Error	12.67	128	0.099		
Total	20.48	135	--		

The 5% L.S.D. between any of the two of the eight treatment combinations is 0.21.

TABLE 19b

Table of Means for Crispness of Celery Stalks

	Chemical			
Time	O	C	K	X
8 wks.	4.98	4.99	4.84	4.99
14 wks.	5.00	5.00	4.25	4.85

After 8 weeks in cold storage there was no difference in the crisp quality of the stalks. The situation was the same after 14 weeks in storage except that the Decco treated lot was somewhat less crisp than

the other three lots. It was believed that this difference may have been due to the air current from the fan causing evaporation from some of the treatment K crates which were located nearest it.

(b) Leaves

In Table 20a. the results of the analysis of variance for crispness of leaves are shown.

TABLE 20a

Results of Analysis of Variance for Crispness of Celery Leaves

Variation Due to	Sum of Squares	Degrees of Freedom	Mean Square	F	Remarks
Time	0.233	1	0.233	4.51	significant
Chemical	1.145	3	0.382	7.38	significant
Interaction	0.043	3	0.014	0.27	not significant
Error	6.620	128	0.052		
Total	8.041	135	--		

The treatment combination means as well as the total means for both time and treatments are given in Table 20b.

TABLE 20b

Table of Means for Crispness of Celery Leaves

	Chemical				
Time	O	C	K	X	Total
8 wks.	4.85	4.93	4.71	4.90	4.85
14 wks.	4.99	4.99	4.76	5.00	4.93
Total	4.92	4.96	4.73	4.95	

The 5% L.S.D. for any two of the four treatment means is 0.11.

Although only one important difference was observed in the results on crispness of stalks, two major causes were noted for the leaves. It was found that at 14 weeks all treatments had more limpness of leaves than all treatments after 8 weeks storage. And, at both examination periods the leaves of the Decco treatment were less crisp than any of the others. It is believed that evaporation due to the fan position was the cause of differences in limpness in the leaves rather than the chemical.

(6) Change in Color

(a) Butts

The results of analysis of variance for the color of the celery butts are reported

in Table 21a.

TABLE 21a

Results of Analysis of Variance for Color of Celery Butts

Variation Due to	Sum of Squares	Degrees of Freedom	Mean Square	F	Remarks
Time	3.36	1	3.36	0.48	not significant
Chemical	13.29	3	4.43	0.63	not significant
Interaction	21.00	3	7.00	5.84	significant
Error	153.42	128	1.20		
Total	191.06	135	--		

The means of the treatment combinations are given in Table 21b.

TABLE 21b

Table of Means for Color of Celery Butts

Time	Chemical			
	0	C	K	X
8 wks.	3.26	4.40	4.90	4.99
14 wks.	4.75	4.95	4.56	4.54

The 5% L.S.D. between any two of the eight treatment combinations is 0.74.

It was observed that the butts of the Onyxide treated celery were poorer in color than the other treatments at the 8 week examination period. But by the time of the second examination no difference was found among the four treatments. The fact that treatment O appeared worse in butt color at the 8 week period than any treatment after 14 weeks in cold storage indicates the possibility of poor attention to the color of butts during the second inspection.

(b) Leaves

Table 22a. shows the results of the analysis of variance for the color observed for celery leaves.

TABLE 22a

Results of Analysis of Variance for Color of Celery Leaves

Variation Due to	Sum of Squares	Degrees of Freedom	Mean Square	F	Remarks
Time	18.83	1	18.83	11.91	significant
Chemical	24.45	3	7.48	4.73	not significant
Interaction	4.74	3	1.58	4.82	significant
Error	41.97	128	0.33		
Total	87.99	135	--		

The means of the treatment combinations as well as the total means for time are given in Table 22b.

TABLE 22b

Table of Means for Color of Celery Leaves

Time	Chemical				Total
	O	C	K	X	
8 wks.	3.23	2.78	3.97	2.97	3.24
14 wks.	2.10	2.00	3.02	2.83	2.49

The 5% L.S.D. between any two of the eight treatment combinations is 0.39.

The results of the tables indicate that as the storage time increased the color of the celery leaves decreased regardless of chemical treatment. But at the same time, there was some effect of both the chemical and time of storage on the leaf color. The Decco treated celery maintained the best green color for all times and treatments and the Cetab treatment was poorest under the same conditions.

c. Flavor

It was mentioned that representative bunches of celery for each treatment were returned to the laboratory for flavor evaluation. Stalks were selected, washed and tasted by the experimenters. While no attempt

was made to determine the consumer acceptability of the product it was carefully judged for the presence of foreign flavors. In the opinion of the workers, there was no difference in flavor among the four treatments.

d. Photography

Before tasting the celery photographs of the typical bunches were taken. An attempt was made to exhibit together bunches which would illustrate the variation within each treatment lot. Thus it becomes apparent why a large sample size is necessary before valid conclusions may be drawn. On the following pages plates VI to X represent celery from each treatment including the controls after 14 weeks in cold storage at $32^{\circ} \pm 0.5^{\circ}$ F. and 97% $\pm$ 2% R.H.

Plate VI

Bunches Typical of the Poorest and Best Samples of Untreated Pascal Celery After 14 Weeks of Storage

Plate VII

Untreated Bunch of Pascal Celery Showing Typical Mold Development After 14 Weeks of Cold Storage

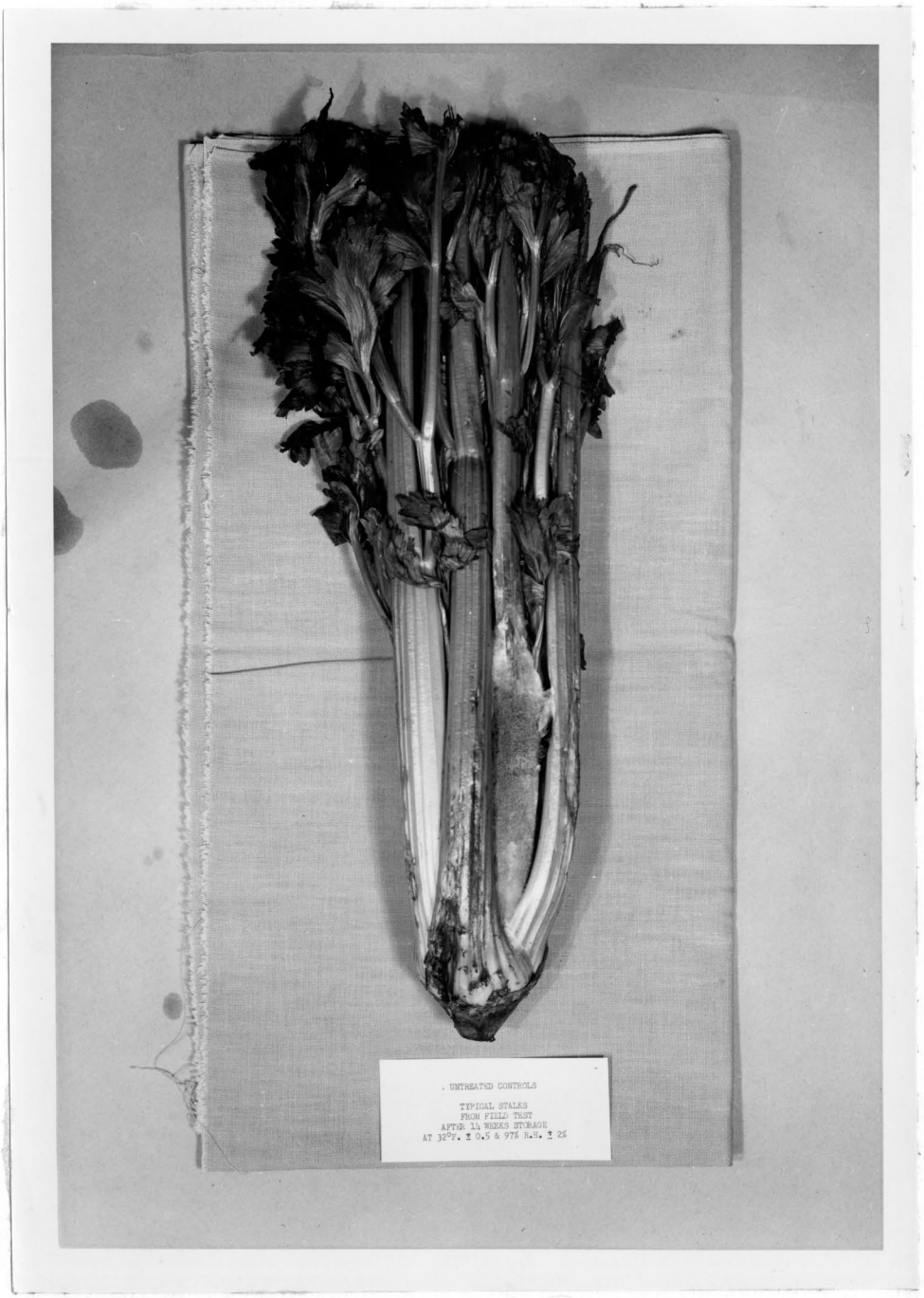


Plate VIII

Bunches Typical of the Poorest and Best Samples of Pascal Celery, Treated with 1000 p.p.m. Decco After Harvest and Stored 14 Weeks

Plate IX

Bunches Typical of the Poorest and Best Samples of Pascal Celery, Treated with Onyxide After Harvest and Stored 14 Weeks

Plate X

Bunches Typical of the Poorest and Best Samples of Pascal Celery Treated with Cetab After Harvest and Stored 14 Weeks

3. Discussion

On the basis of the statistical analysis of the field test data it appears that the treatments differed from the untreated lot in mold and bacterial count as well as in several subjective quality characteristics. Both in total mold counts and subjective evaluation of extent of mold growth treatments O and C showed less mold than the control or K lots. Formation of rot as well as corresponding bacterial counts were less for treatment K than for O, C and controls. The above differences were more apparent after 14 than after 8 weeks of storage. While in the case of mold the results were the same for butts, stalks and leaves, in the case of rot development stalks showed greater differences between treatments than butts or hearts.

Assuming an equal degree of damage due to handling for all four lots prior to storage it was found that after 14 weeks of cold storage treatments O and C showed significantly higher damage scores than K or controls. Thus damage due to the chemical treatment was indicated. This quality loss was not evident in the preliminary and pilot plant celery tests for either O or C probably because of the smaller number of samples studied.

Because of the above mentioned chemical changes treatments onyxide and cetab cannot be recommended for

commercial operation despite their outstanding mold inhibiting power. Only where mold contamination is very severe could treatments O or C be employed to increase celery saleability.

Decco, on the other hand, reduced rot significantly compared to untreated celery without any accompanying chemical damage. The commercial application of Decco is warranted especially when long storage periods are required and where mold contamination is not the principal cause of spoilage.

E. Discussion of Section I

The interpretation of the results on surface disinfection of raw vegetables and fruits is subject to a number of limitations.

1. Sample Size

Large variations exist between individual samples of the same lot of produce with respect to appearance, extent of field contamination and susceptibility to inoculation. Thus a large number of samples are required to obtain quantitative information about the effectiveness of any germicidal treatment in reducing the microbiological activity of the natural flora or of an inoculum applied to the produce prior to treatment. Possible damage to the appearance or flavor of the produce due to the chemical treatment must be determined

simultaneously. Here again only large sample sizes can yield quantitative information.

It was considered impractical to test the great number of potential surface disinfectants on a scale necessary to obtain quantitative information. Sufficient qualitative information could be obtained from small size samples to narrow down the list and concentrations of germicides effective for various vegetables and fruits. Naturally such tests are subject to chance variations in original sample quality so that unquestionably some treatments were eliminated from larger tests without justification. On the other hand, some treatments were considered as qualitatively better than controls when actually only raw material variations were responsible for the difference. The purpose of the larger scale so-called "pilot plant" test was primarily to eliminate the latter treatments from those showing consistent improvement over controls. These larger scale tests, still essentially qualitative in nature, can be used merely as a basis for field tests such as the one carried out for celery where sufficient quantitative information was gained to make recommendations for commercial use.

2. Method of Evaluation

Since even the large scale tests are primarily based upon subjective determinations, accuracy cannot be

compared to objective measurements. Mold and bacterial counts, weight losses and color examination all yield more reproducible information but they must be used as supporting evidence to subjective quality determinations.

Perhaps the most difficult evaluation is the diagnosis and extent of bacterial decay. Physiological injury and natural storage death often produce an effect similar to bacterial spoilage. In addition, the above factors are inter-related since physiological damage often makes the plant tissue more susceptible to bacterial invasion and dying. Evaluation could perhaps be simplified by using specific isolated organisms causing easily recognizable decay. On the other hand such a procedure would yield information regarding the value of the chemical which might be far removed from commercial significance where under normal conditions of harvest, handling and storage a mixed flora is usually encountered.

3. Infection

Since in this study mixed flora inoculations were used throughout, information regarding the effectiveness of chemical treatments is limited to the control of decay producing organisms either naturally present on normal produce or obtained from a commercially stored and spoiled sample.

Control of any specific organism not normally present but which would produce decay of the produce in question represents a different problem and would require an approach different from the one used in this study.

4. Treatments

In the light of the above limitations it appears that, in general, chlorine liberating compounds are more effective against bacteria than quaternary ammonium compounds which, in turn, are better mold inhibitors than the Decco and calcium hypochlorite, at least in the concentrations found effective. The chlorine liberators, especially Decco, show less tendency toward physiological damage than the quaternaries. Among the latter the alkyl bromides appeared generally preferable to alkyl chlorides from the standpoint of damage to produce. Dowicide, while effective against both mold and bacteria, caused injury in most but not all products. However, the above generalizations have to be modified for each produce since a treatment found effective for grapes was not necessarily good for celery. In addition the susceptibility to damage varied from produce to produce. Thus only a study of the results on each product tested can be used as an ultimate criterion for future work or commercial practice. Any industrial application

must await clearance by the food and drug authorities with regard to toxicity of the residue. Also quantitative data regarding the amount of chemical present in the stored produce will have to be obtained before their use can be considered.

While chemical treatments effective in reducing the surface contamination were found for most of the products tested it should be observed that permanent protection against re-infection after treatment is not implied. A number of experiments in which disinfected produce was re-infected at regular storage intervals indicate that permanent protection against storage infection was limited. In order to improve storage protection, the studies described in Section II of this paper were undertaken, in which the produce was wrapped in transparent plastic films prior to storage.

Section II

Prepackaging

A. General:

A systematic study was initiated to evaluate the relative merits of transparent films for the prepackaging of seven major vegetables and four berry fruits. Nine types of films used at the present time, either experimentally or commercially, were investigated. In addition, varying degrees of gas and moisture-vapor transmission were obtained by the use of different methods of packaging with the films. Also, on the basis of the disinfection studies described earlier an effective chemical treatment was singled out for each product (see page 101) and applied just prior to packaging. The packaged produce was then stored under controlled conditions of 1) simulated commercial cold storage, followed by 2) warm retail merchandizing. Duplicate samples were withdrawn from cold storage at specified intervals for evaluation. At this time additional samples were withdrawn from cold storage and placed in warm storage. These, in turn, were evaluated after definite periods of time. For each sample the gas analyses of the container atmosphere (% CO_2 and O_2) and per cent weight loss were correlated with the extent of decay as well as a number of subjective characteristics.

B. Materials and Methods:

1. Films Investigated.

The films used in this study are tabulated in Table 23.

TABLE 23

Packaging Materials Employed

Film	Type	Thickness In inches	Source	Experimental Code
Pliofilm	75 FF	0.00110	U.S.Rubber Co.	A
Pliofilm	75 N2	0.00100	U.S.Rubber Co.	B
Pliofilm	75 P6A	0.00080	U.S.Rubber Co.	C
Cellulose Acetate	Lumarith D-912	0.00090	Celanese Corp.	U
Cellulose Acetate	100 CA-48	0.00100	I.E. DuPont	H
Regenerated Cellulose	300 LSAT	0.00110	I.E. DuPont	M
Regenerated Cellulose	300 MSAT-86	0.00100	I.E. DuPont	L
Cellulose Butyrate	Kodapak II 130	0.00130	Eastman Kodak Co.	K
Polyethylene	Polythene	0.00150	I.E. DuPont	P

Moisture-vapor transmission rates for each film were determined at the temperature and humidity levels used in these experiments. Fifteen milliliters of distilled water were placed into the bottom half of petri dishes. The test films were stretched across the open dishes and sealed with

locker tape to assure an air-tight closure. Duplicate dishes of each film were placed in cold storage at 33° F ± 1° F and 86% R.H. ± 5% for eight days and at 80° F ± 1° F and 82% R.H. ± 5% for five days. At the end of each storage period the weight of the dishes was recorded and losses calculated.

2. Vegetables.

The following vegetables were used in this study:

1) carrots
2) celery
3) lettuce
4) tomatoes
5) cauliflower
6) salad mix
7) spinach

a. Processing.

The vegetables were obtained in single lots through a local wholesaler. The products were California grown with the exception of the tomatoes which came from Mexico and the spinach which came from Washington. Although it was not possible to learn the harvest history of each vegetable it was procured from the most recent refrigerated truck shipments at the time needed.

Immediately upon receipt each product was placed into cold storage and processed within the next forty-eight hours. Each product was sorted to obtain units of approximately equal size and to remove any of obviously poor quality. Next, each was washed with agitation in 37-40°F running water. Lettuce was not washed but merely trimmed of

its outer leaves. Spinach, cauliflower and chopped salad were dried in previously sterilized cloth bags in the 32° F room while tomatoes and carrots were surface dried with a blast of warm air and celery was shaken by hand to remove the excess water. Packaging followed immediately to prevent a rise in internal temperature.

The chopped salad mix was prepared in the laboratory since previous experience had indicated that rather sanitary handling was necessary to obtain a product with good keeping qualities.

The ingredients were purchased from the wholesaler, trimmed and cleaned, then shredded by a laboratory Hobart shredder. The components were then weighed and blended in the following proportion which represented a typical commercial product:

white cabbage	= 64.4%
red cabbage	= 3.4
endive	= 3.4
carrots	= 11.3
celery	= 17.3

Following preparation, samples of approximately equal weight were placed into bags of equal size for a particular vegetable. The size of the bags varied for different products to accommodate for differences in shape. All were double seamed on three sides prior to filling.

Seven of the nine films listed in Table 23, Kodapak and pliofilm C excepted, were used for packaging the

above vegetables. Six variations in the method of packaging were used.

1. In the first, so-called basic series, a gas tight closure was made with a double seam for each of the eight films.

2. The second group consisted of bags which were not sealed but closed by means of a stapled tent flap using three uniformly spaced staples across the top. Film numbers L and U, representing relatively high and low permeability were used in the second group.

3. In the third series the bags were tightly sealed. A single one millimeter diameter puncture was then made in each bag. Film number L was used.

4. The fourth series was identical with the third group except that four punctures were made instead of one.

5. The fifth series was produce which had been held at 75° F and 80% R.H. for twenty-four hours prior to packaging. Film L was used with a gas tight seal.

6. The last group included produce which had been chemically treated before packaging. This treatment was applied immediately following the washing operation described above. The treated product was then dried and packed as follows:

(a) Tightly sealed in a relatively high permeability film H.

(b) Tightly sealed in a relatively low permeability

film A.

(c) Tightly sealed in film L with a single puncture as in variation 3.

(d) Tightly sealed in relatively low permeability film L. However, a single hole of one centimeter diameter was made and covered by a small piece of film number H, (high transmission type).

Untreated as well as chemically treated product was stored without packaging. These served as controls.

The above packaging variations, together with their experimental codes are listed in Table 24.

Plate No. 11 illustrates typical examples of the wrapped vegetables which were used in this experiment.

Upon packaging the final weight of each sample was recorded. Efforts were made at the time of packing to keep the amount of product in each sample within a given range for each vegetable. The weight ranges are reported in Table 26 for each vegetable packed.

TABLE 24

Packaging Variations

Treatment Number	Group Number*	Code of Film Used	Packaging Method	Vegetable Packed**
X		none	control	all seven
DX		none	disinfected control	all seven
1	(1)	L	tightly sealed	all seven
2	(4)	L	four punctures	all seven
3	(3)	L	one puncture	1,2,3,4
4	(5)	L	product packed while warm and tightly sealed	1,2,3,4
5	(2)	L	tent flap closure	all seven
6	(6)	L	tightly sealed bag with acetate window, produce disinfected***	1,2,3,4, 5,6
7	(6)	L	sealed with one puncture, produce disinfected	1,2,3,4, 5,6
8	(1)	M	tightly sealed	1,2,3,4
9	(1)	P	tightly sealed	all seven
10	(6)	A	tightly sealed produce disinfected	1,2,3,4
13	(1)	B	tightly sealed	1,2,3,4
14	(1)	A	tightly sealed	1,2,3,4, 5,6
15	(1)	H	tightly sealed	all seven
16	(2)	U	tent flap closure	1,2,3,4
18	(6)	H	tightly sealed; product disinfected	1,2,3,4
19	(1)	U	tightly sealed	1,2,3,4

* Group number corresponds to the various wrapping techniques described on page 97.

** Vegetables corresponded to numbers listed on page 95.

*** Disinfectant treatments given in Table 25.

Plate XI

Typical Samples of Prepackaged Produce Prior to Analysis

TABLE 25

Disinfection Treatment of Vegetables

Vegetable	Chemical	Concentration	pH[x]	Time Dipped
carrots	"Decco"*	500 ppm	4	10 min.
celery	"Decco"	1000 ppm	5	10 min.
lettuce	"Decco"	1000 ppm	6	5 min.
tomatoes	Calcium propionate "A resket"***	2% 0.17%	?	10 min.
cauliflower	"Onyxide"**	500 ppm	?	5 min.
chopped salad	"Decco"	500 ppm	4.5	10 min.

* Organic chlorine compound of Wallance & Tiernan Co.

** Oleyldimethylethylammonium bromide

*** Wetting agent of Monsanto-Chemical Co.

x Adjusted with HCl

TABLE 26

Packaging Standards

Vegetable	Approximate Number of Samples Packed	Range of Unit Weights (grams)
carrots	330	265 - 315
celery	330	370 - 420
lettuce	330	320 - 360
tomato	330	200 - 240
cauliflower	60	58 - 64
chopped salad	60	72 - 76
spinach	50	56 - 60

b. Storage

All samples were stored in a room maintained at 33° F. ± 1° F and 86% R.H. ± 5%. It was planned to test the products after five storage intervals, namely: 10, 20, 40, 80, and 120 days. Due to deterioration, tomatoes, salad mix, cauliflower and spinach were not evaluated after the 80 day periods. Carrots, celery and lettuce were stored for the full 120 day interval. Storage periods did not adhere strictly to the intervals specified but varied slightly in some cases. At each storage period duplicate samples were removed and evaluated immediately to avoid any changes caused by a rise of internal temperature. In addition after 20, 40 and 80 days cold storage, duplicate samples of carrots, celery, lettuce and tomatoes were removed and placed in a cabinet maintained at 80° F ± 1° F and 82% R.H. ± 5% to simulate merchandizing conditions. Single samples of spinach, cauliflower and chopped salad mix were tested in warm storage only after the 40 day cold storage period. Enough samples were placed in the warm cabinet so that evaluations could be made at two intervals of warm storage. These intervals varied from one to fourteen days depending upon the keeping quality of the vegetable in warm storage. However, these times were kept identical for each product after each cold storage interval. After removal from cold storage and before placing them into warm storage each sample was weighed. Code numbers 6,7,10 and 18 which had received the

disinfection treatment before packaging were not taken directly from cold storage and analyzed but were held in warm storage before they were evaluated.

c. Analysis

The evaluation of each sample consisted of determining; (1) weight losses, (2) per cent carbon dioxide and sometimes per cent oxygen of the container atmosphere, (3) subjective characterics as aroma, color, wilting, flavor and extent of mold and/or rot.

(1) Weight losses - Changes in weight were expressed as per cent lost during storage. Cold storage losses were calculated on the basis of the original weight while warm storage losses were expressed on the basis of the weight at the time of removal from cold storage.

(2) Gas Analysis - Since limited volumes of gas were available for each analysis and since the vegetable within the package had to remain intact for other evaluations it became necessary to develop a special apparatus for analysis.

Development of Analytical Procedure:

Since a great number of analyses had to be run, only a simple procedure would be satisfactory. After a number of unsuccessful attempts a satisfactory crude method was developed which was gradually modified to the procedure described below.

A small rubber ring (a) prepared by cutting a piece of standard rubber tubing 3 to 4 mm. I.D. into strips 3 to 5 mm. long, is glued onto the top of the prepackaged product before analysis (see Diagram I). The box (b) is then placed on a movable ring clamp (c) in such a position that the needle (d) of the sampling apparatus centers the rubber ring (a) on the berry box to be analyzed. The above mentioned needle is of the hypodermic type (about 500 microns I.D. and 1 mm. O.D.) and attached to the absorption system (f) through rubber tubing and a three-way stopcock (g). The absorption system is essentially a semi-micro Fisher-Orsat unit consisting of two 25 cc. absorption bulbs (h) for oxygen and carbon dioxide and a 25 cc. burette (k) connected to a leveling bulb (l).

This bulb consisted of an Erlenmeyer flask with a bottom outlet. To the mouth of the flask was connected an inflated rubber bulb. The confining liquid was raised and lowered in the burette by manually applying pressure to the bulb. Thus the usual tiring method of raising and lowering the leveling bulb was eliminated. (For details see Diagram I.) At the beginning of the analysis the rubber ring is filled with a few drops of H_2O (glycerol is recommended for boxes wrapped with acetate films). The package is then raised until the now water-submerged hypodermic needle has punctured the wrapping film and penetrated below the surface to about one inch. The standard containing

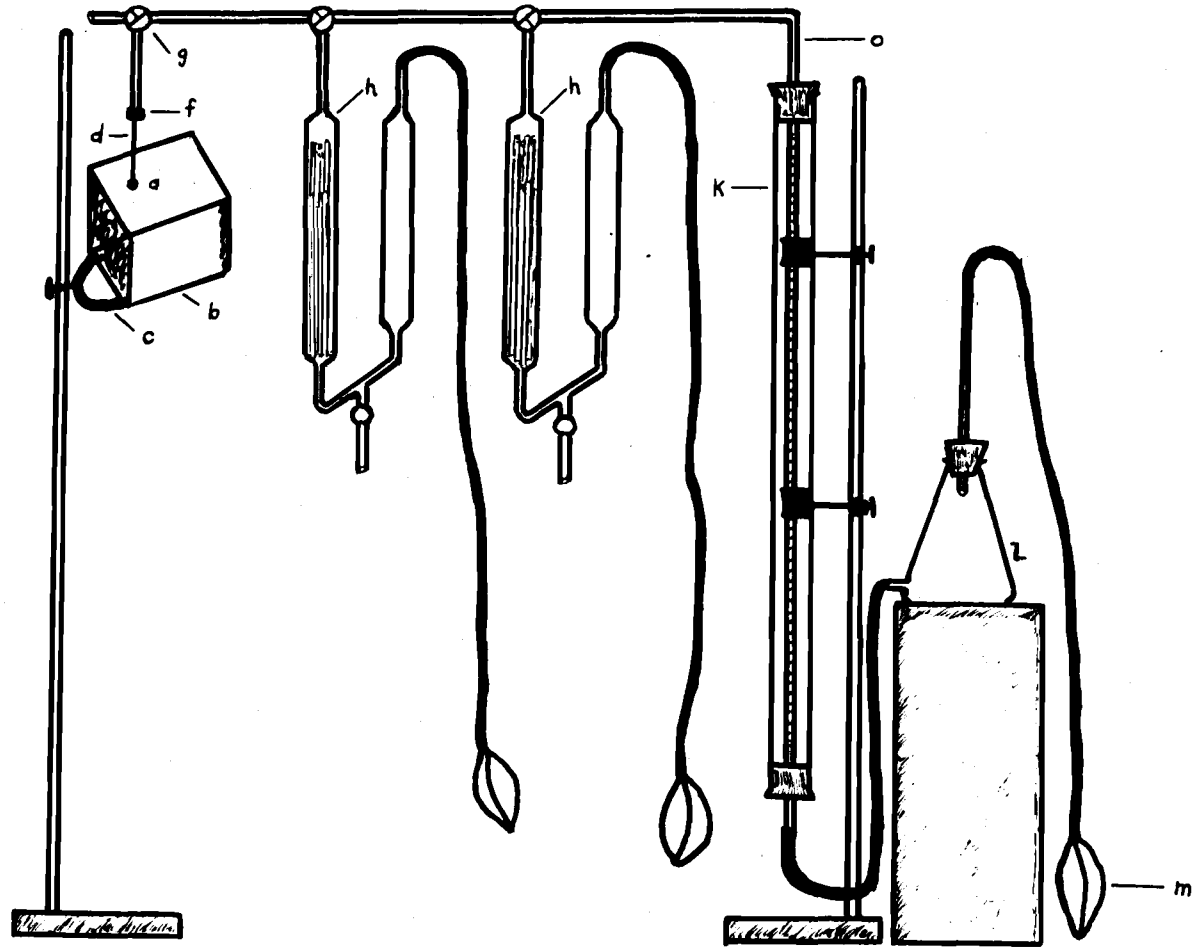


Diagram I: Gas Analysis apparatus

fluid of the absorption system which had previously been raised to the maximum level is now lowered to the 25 cc. mark, thus drawing a 25 cc. sample of gas into the analyzer. This volume of gas is then pumped back into the bag by again raising the containing fluid to a maximum level. A new sample is then drawn into the analyzer. This flushing operation is repeated three times in order to obtain a more representative sample of the container atmosphere. The seal surrounding the needle prevents any contamination with outside atmosphere during sampling. After the fifth pumping operation the stop-cock on the sampler is closed and the package removed. The leveling bulb is now raised to the 15 cc. mark on the burette and the stop-cock on the sampler again opened to allow the escape of 10 cc's of the gas volume of the burette. This operation will clear the needle for the next analysis. The remaining 15 cc's are then analyzed according to the Orsat gas analysis procedure.

The bags which were not tightly sealed, that is those with punctures and tent flaps, were sealed with scotch tape before gas analysis.

Precision of Method:

1. Apparatus: Two consecutive samples of air were analyzed in a standard Orsat apparatus (100 cc. sample) as well as in the semi-micro unit (15 cc. sample).

An average of 20.55% O_2 was obtained with the micro unit and 20.67% O_2 with the semi-micro unit.

2. Sampling Method: Triplicate samples were obtained from the same package by storing it only half full of produce to allow the removal of three consecutive samples of gas, each having a volume of15 cc. Three rubber rings were glued onto the bag and samples withdrawn and analyzed as rapidly in succession as possible. Each ring was sealed with scotch tape immediately after sampling to prevent contamination with outside atmosphere until completion of all three analyses. This test was run on two different samples.

The results shown below indicate a sampling precision well within the range of the apparatus at hand.

Sample No.	%CO_2	%CO_2	%CO_2	%O_2	%O_2	%O_2
1	19.95	19.95	19.93	2.11	2.13	2.12
2	1.10	1.12	1.12	18.80	18.80	18.79

Despite the precautions which were taken so that uniformity of samples would be obtained it was found that the percent of carbon dioxide and oxygen varied considerably between duplicate samples. Oxygen determinations varied as much as fifty percent and were not used for the interpretation of data. Carbon dioxide values of the duplicates were averaged providing the variation between them was less than 20%. In the infrequent case where the

variation was greater than 20% the value nearest the general trend for that treatment was used. Results were calculated to two significant figures. After completion of the gas analysis each sample was returned to cold storage until all samples of a particular series were analyzed.

(3) Immediately following the gas analysis of a series all samples were subjectively evaluated. Each duplicate set was examined by the experimenters and compared with the other samples in the series. First the aroma of the product was noted immediately upon opening the package. Observation of the odor of the package atmosphere proved to be a rather sensitive test. It often happened that after the product was removed from the bag its aroma was not unnatural although the odor within the package had been slightly off in character. Next, the general appearance including mold, rot, wilting, color or any other significant variation was observed. Finally, small representative portionswere tasted raw and scored for flavor. Scoring for all observations was based on a four point scale with half point subdivisions corresponding to the descriptive words of; none, trace, slight, slight-some, some, poor and severe.

The terms rot and decay were used in the most general sense - meaning deterioration of the product. It was not possible to ascertain whether decay was caused by microorganism infections or to gradual physiological breakdown

or both. The nature of this investigation was such that no sample could be evaluated more than once without seriously affecting conditions within the package and thus impairing the results. Therefore, it must be recognized that each evaluation represents data acquired from different samples of the same treatment. Thus, for example, it was assumed that the carbon dioxide content of a sample of spinach which was analyzed after being in warm storage for two days would have been the same after one day as another sample of the same treatment which was analyzed after one day in warm storage. For this reason efforts were made to have all samples as uniform as possible.

2. Berries

Four berry fruits were used in the prepackaging studies. These were Marshall strawberries, Newburg raspberries, Boysenberries and Evergreen blackberries.

a. Processing:

The highly perishable nature of berries required exacting control of the raw materials. In each case the berries were picked especially for these experiments and brought into the laboratory immediately. Here they were handled in the following manner.

(1) Red raspberries - variety Newburg, and Strawberries - variety Marshall: The berries were divided into four lots each. The first lot was sorted for damaged and underripe fruit. A standard amount was placed in new one

pound hallocks and packaged at once. A typical package is illustrated in Plate II. Each package was weighed and placed into cold storage.

The second lot was sorted in a cold storage room and hydro-cooled in 32° F ice water. When the internal temperature of the strawberries reached 34° F, and raspberries reached 40° F, they were removed and placed upon stainless steel screens to drain at 33° F. After draining approximately 20-30 minutes the berries were packed into carboard hallocks and overwrapped. They were then weighed and stored at 33° F.

In lot three the berries were sorted and dipped into a solution of ice water plus one tenth of one percent "Aresket", a non-toxic wetting agent. The Aresket was added to improve wetting of the berry surface and hence better removal of dirt and foreign materials. After a ten minute dip the berries were drained and equal amounts were packed at 33° F. The packages were weighed and stored.

The berries in lot four were held after receipt for eighteen hours at 33° F. They were then sorted, packed, weighed and stored.

(2) Boysenberries and Blackberries - variety Evergreen: Since poor results had been obtained with hydro-cooled strawberries and raspberries, these treatments were not included for boysenberries and blackberries.

The boysenberries were divided into two lots, the first lot was sorted and packaged without cooling; then weighed and placed in cold storage. The second lot was held at 33° F for eighteen hours prior to sorting and packaging.

All blackberries were cooled for eighteen hours before packaging. The pretreatment of berries just described refers to the cooling and washing process before packaging. Pretreatments were designated by code letters which were prefixed to the film code letters.

TABLE 27

Pretreatment Variations

Pretreatment Code	Method	Berries Pretreated
W	Packed directly from field without cooling or washing.	Strawberries Raspberries
C	Held at 33° F overnight before packing.	Strawberries Raspberries Boysenberries Blackberries
I	Cooled in 32° F ice water, drained and packed	Strawberries Raspberries
N	Cooled and washed in 32° ice water plus wetting agent, drained and packed	Strawberries Raspberries

All the nine films shown in Table 23 were used as wraps for berries. Although not all these films were used for each type of fruit as is evident in Table 28 in which

the packaging variations for berries are listed. As in the case of vegetables, a basic series was set up in which the berries were packaged within completely sealed films. Variations other than packaging of cold, warm or washed produce included only a series of punctured films. One, two or eight one millimeter diameter holes were tested in the blackberry series only.

TABLE 28

Packaging Variations

Treatment Code	Code of Film* Used	Packaging Method	Berry Packed
A	A	tightly sealed	all four
B	B	tightly sealed	strawberry, raspberry
C	C	tightly sealed	strawberry, raspberry, boysenberry
H	H	tightly sealed	all four
L	L	tightly sealed	strawberry, raspberry, boysenberry
M	M	tightly sealed	all four
P	P	tightly sealed	raspberry, boysenberry
U	U	tightly sealed	raspberry, boysenberry, blackberry
A_1	A	sealed with one puncture	blackberry
A_2	A	sealed with two punctures	blackberry
A_8	A	sealed with eight punctures	blackberries
K	K	tightly sealed	blackberry

* For film type see Table 23.

Again, as in the vegetable experiments, the berry sample weights were kept within fairly narrow limits. They varied between 370 - 390 grams per sample.

All samples were stored at 33° F ± 1° F and 85% R.H. ± 5%. Single samples were removed at four storage intervals. These periods were, with a few exceptions, 6, 10, 15 and 20 days. The samples were evaluated immediately to avoid a rise of internal temperature. After 10, 15 and 20 days of cold storage additional samples were placed at 80° F ± 1° F and 88% R.H. ± 5% for one and two days, after which times complete evaluations were made.

c. Analysis.

In general, the evaluation of pre-packaged berries followed the same procedure as that described for vegetables with the following exceptions.

(1) Weight losses in warm storage were reported on the basis of the original weight rather than the weight at the time of removal from cold storage.

(2) Percent oxygen as well as percent carbon dioxide was used for interpretation of results while for vegetables only the carbon dioxide values were considered.

(3) A three point scale with one point intervals was used for the judging of subjective characteristics, thus replacing the four point scale used for vegetables. The berries were scored for mold, leakage, flavor, color and shriveling which made possible a perfect score of ten

points. An overall quality rating of 0,1,2,3 = poor; 4,5, 6,7 = commercial and 8,9,10 = dessert was assigned to each product. However, any sample in which the flavor was scored zero automatically scored "poor quality" regardless of other characteristics.

4. Other Fruits.

The pre-packaging study on grapes was set up in conjunction with the pilot plant disinfection study on grapes outlined in the first section of this paper. Since principal emphasis in this pilot plant investigation was the comparison of mycostats with and without packaging, only a single type of wrap was used. Thus no information was gained relative to the behavior of grapes packaged with various film types or wrapping techniques.

a. Processing:

On the basis of the previously completed berry prepackaging study it was considered best to use a low moisture vapor transmission film as a wrap to prevent drying of stems and shriveling of fruit; pliofilm 75FF was used.

It was modified in each case by a small window of high gas transmission acetate to prevent accumulation of carbon dioxide within the crate while retaining the benefits of high internal humidity and protection against re-infection from the surrounding atmosphere.

Part of the twenty crate lot of Emperor grapes,

which was obtained directly from the grower and used in the pilot plant disinfection study outlined in Section I, was employed for the above combination treatments.

Up to the point of wrapping, the treatments were identical to the method of disinfection alone without further treatment. Single crate lots were dipped, drained, repacked and then sealed.

In addition to the aqueous chemical dips, a gaseous treatment was added to the series. Potassium metabisulphite, a slow SO_2 liberator, was added to the grapes prior to packaging either as pellets wrapped in filter paper or in the form of commercial grape box excelsior cushions impregnated with potassium metabisulphite. Thus the SO_2 liberated from the salt probably would maintain a very low but definite partial pressure of the gas within the overwrapped crates.

Finally, unwrapped crates with and without potassium metabisulphite cushions as well as wrapped but untreated crates were stored as controls for comparison.

The following table 29 summarizes the various treatments used in the combination disinfection plus protection methods.

TABLE 29

Chemical Treatments Used in Crates of Prepackaged Emperor Grapes

Compound Name	Compound Conc'n	Method of Prepackaging	Lab Code
Roccal	2%	Sealed liner* of 75FF plio in crate of treated grapes	F
Sodium propionate	1%	Sealed liner of 75FF plio in crate of treated grapes	G
$K_2S_2O_5$ pellets	5 g./ crate	Envelope containing pellets placed inside sealed pliofilm liner of crate	K
$K_2S_2O_5$ cushion	ca 5 g./ crate	Commercial cushion placed inside of sealed pliofilm liner of crate	J
$K_2S_2O_5$	-	Commercial cushion placed in buttom of unwrapped crate	U
Control	-	Sealed pliofilm liner in crate of untreated grapes	M
Control	-	Unwrapped, untreated crate of grapes.	X

* A 2" diameter hole cut in top center of each wrap and sealed with a Lumarith acetate window.

b. Storage.

Storage conditions, time and temperature were kept identical with the plain disinfection treatments described in section I to allow direct comparison of results.

c. Analysis:

Methods of evaluation were also the same as for the unwrapped treatments. The percent saleable (mold free and undamaged) fruit per crate was considered as the

primary criterion for rank of the treatment.

C. Results:

1. Films

a. Moisture Vapor Transmission:

The films were evaluated from the results of the petridish experiments in terms of percent protection against moisture loss as compared with uncovered petri dishes. The relative rank of each film in Table 29 was based on the data obtained in warm storage. The corresponding cold storage protection figures are also shown.

$$\% \text{ Protection} = \frac{(\text{wt. } H_2O \text{ lost in open dish}) - (\text{wt. } H_2O \text{ lost by sample}) \times 100}{(\text{weight } H_2O \text{ lost in open dish})}$$

Inspection of Table 30 shows that greater protection was afforded by all films in cold storage even though the percent relative humidity of both storage atmospheres was about the same. While, in general, the films maintained the same relative rank under both storage conditions it should be noted that the Celanese Lumarith (code U) and the Kodak Kodapak (code K) showed a greater decrease in protection than other films upon removal to an 80° F room. This was not true of the Du Pont cellulose acetate (code H). The presence of one or four punctures in a low transmission film such as MSAT - 86 (code L) did not materially reduce the protection afforded by the film.

Not all the films used in this study were of the same gauge which limited the investigation to a comparison of the particular sheets tested. Ideally, only sheets of

TABLE 30

Moisture-Vapor Transmission of Films Used in this Investigation

Film			Protection			
			8 days at 33 ±1°F and 86% ± 5% R.H.		5 days at 80 ±1° F and 82 ± 5% R.H.	
Code	Type	Gauge	Percent	Rank	Percent	Rank
A	75FF pliofilm	110	100	3.5	97.0	7
B	75N2 pliofilm	100	100	3.5	98.0	5
C	75P6A pliofilm	80	100	3.5	98.2	4
U	P-912 Lumarith	90	73.1	9.5	51.6	10
H	100 CA-48 Acetate	100	55.2	11	50.2	11
L	300MSAT-86 cellophane	100	100	3.5	97.5	6
M	300LSAT cellophane	110	90.5	8	81.5	8
K	Kodapak 11-130 Butyrate	130	73.1	9.5	59.2	9
P	Polythene polyethylene	150	100	3.5	99.5	1
4L	4 holes in L	100	97.0	7	98.4	3
1L	1 hole in L	100	100	3.5	98.7	2
X	open control	-	0	12	0	12

equal gauge should be used.

b. Gas Transmission:

Carbon dioxide and oxygen transmission rates were not determined experimentally for the various films. Gas transmission rates for each film are principally a function of the partial pressure gradient across the test barrier. Since the concentrations of oxygen and carbon dioxide of the produce container atmosphere are continually changing during storage, any given transmission rate would be of limited value for predicting the gas accumulation throughout storage. High transmission rates are to be expected under extreme conditions such as a partial pressure differential of 760 mm. of mercury. Such conditions rarely exist in prepackaged products but may serve as a guide for the discussion of results of the vegetables and fruits tested. Table 31 reports oxygen and carbon dioxide transmission rates at 760 mm differential for most of the films used in this study.

It will be observed that films which showed high gas transmission rates generally also showed poor protection against moisture loss. A notable exception was found in the polyethylene film which exhibited high gas transmission rates even though protection against moisture loss was also high.

TABLE 31

Oxygen and Carbon Dioxide Transmission Rates*

Film Code	Gauge used in this Study	Gauge Reported in Literature	cc/100 sq. in/100 hrs. at 77°F and 760 mm Hg. differential in partial pressure	
			Carbon Dioxide	Oxygen
A	110	75	5,289	1,101
B	100	75	561	93
C	80	75	2,485	484
U	90	120	2×10^{14}	-
H	100	90	17,000	2,300
L	100	90	35	1.0**
M	110	-	-	-
K	130	-	-	-
P	150	100	14,000	3,500

* Gerhart, F., and Wright, T.R.; ref. 11.

** Davis, D. W., ref. 8. Modern Pack. My. '46 (Permeability rate in cc/sq. M/24 hours at 21° C and 760 mm Hg.)

2. Vegetables:

a. Method of Presentation of Data.

Graphic presentation of the data was used in preference to tabulation for vegetables. Since each point represents only one set of duplicate samples and since relatively few points are located for a given treatment, curves were not drawn. Instead the various points were connected by lines merely to show their relative positions. Usually all treatments were shown on a single graph for a particular product with the abscissa representing the time in cold or warm storage and the ordinate showing a quantitative characteristic such as per cent weight loss, carbon dioxide, or numerical quality score.

Some bar charts were prepared in order to show the changes which occured during warm storage. Each treatment is represented by a group of three bars. The first bar always shows the value determined as the product was removed from cold storage. The second and third bars represent the values determined during the two intervals the product was held at 80° F.

Each combination of film type, wrapping technique or disinfection method is identified by the code numbers described under "materials and methods".

b. Head Lettuce

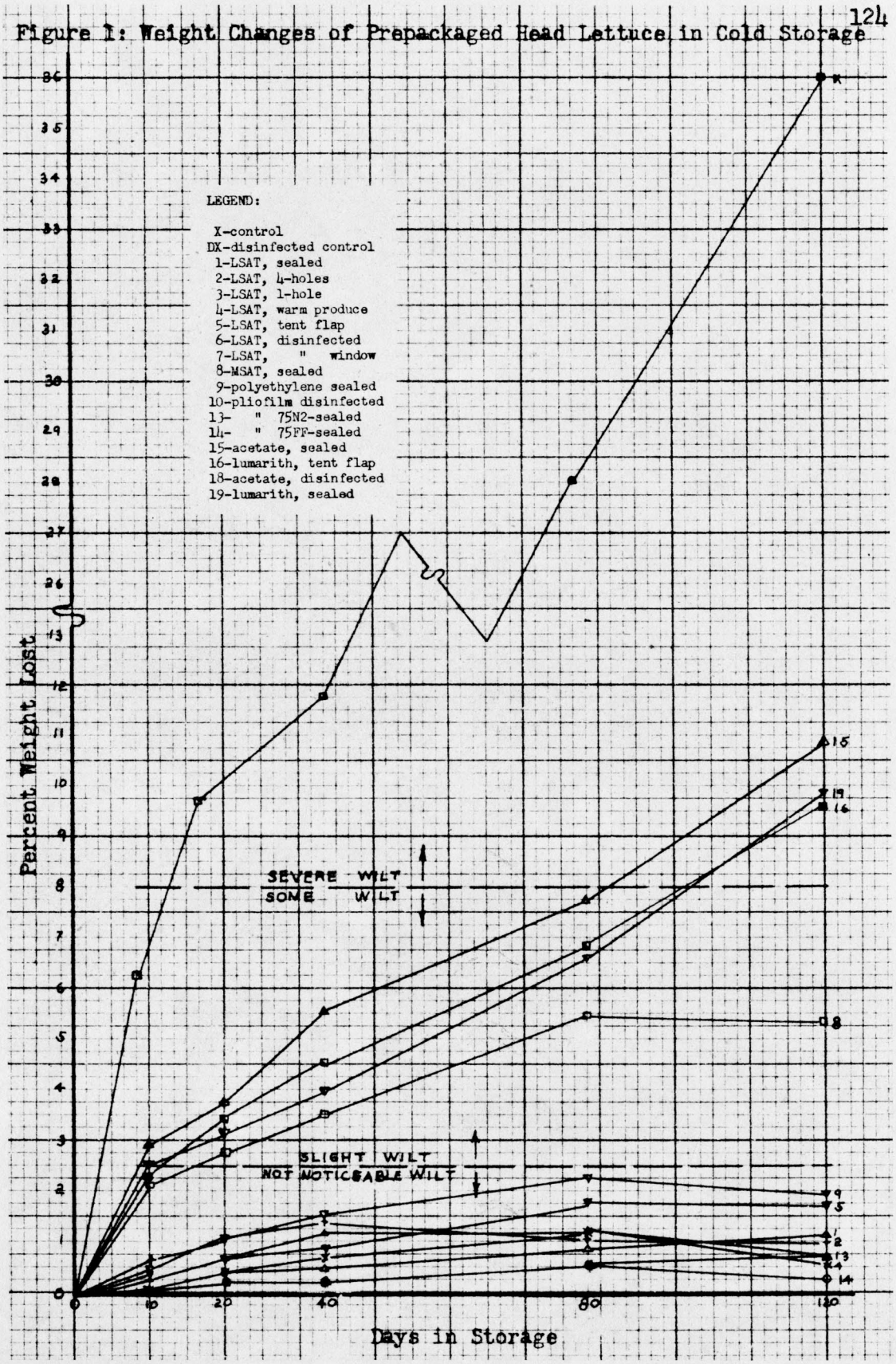
(1) Transpiration

(a) Cold Storage

Figure 1 shows the percent weight loss of pre-packaged lettuce in cold storage. Considerable differences between treatmentswere noted beginning with the first storage interval. At that time, ten days storage, all films showed reduction of shrinkage when compared with controls. The unwrapped samples lost approximately twice as much weight as the treatments with the poorest protection and more than ten times the amount lost by those having a high protection.

With increased storage time the spread of the differences between treatments usually widened until after 120 days of storage the controls had lost 36% of their original weight while in comparison treatment number 15 lost about 11%. The two Lumarith treatments (sealed bags and tent flaps) showed consistently lower weight losses than treatment No. 15, but no significant difference between the sealed and stapled bags was found. Treatment No. 8, (MSAT), with about 5% weight loss might be considered an intermediate moisture-vapor transmission film for cold storage lettuce since it fell consistently between the above mentioned high M.V.T. films and the low transmission treatments. The latter treatments had less than 2.5% weight loss even after 120 days of storage. Punctures and tent flaps did not increase the weight losses of lettuce in low transmission films significantly.

Figure 1: Weight Changes of Prepackaged Head Lettuce in Cold Storage



(b) Warm Storage:

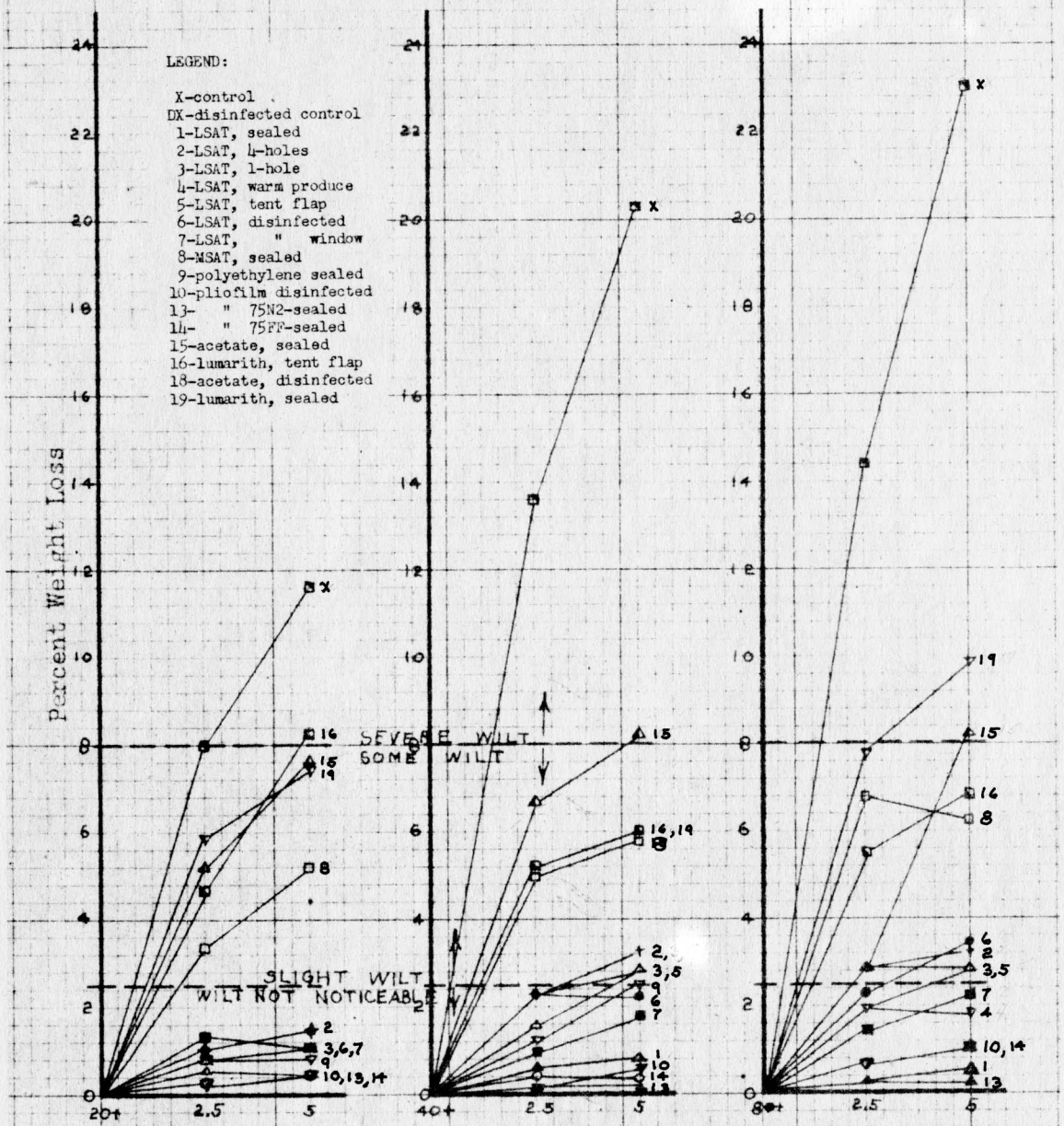
Figure 2 shows the per cent weight loss of lettuce after 2.5 and 5.0 days of warm storage. These losses are reported after 20,40 and 80 days of previous cold storage. Shrinkage was greater in warm than in cold storage. The unwrapped controls lost as much weight in 2.5 days as the corresponding cold storage controls lost in about 40 days. Again all films reduced weight changes as compared with unwrapped samples. The acetate treatment lost about $\frac{1}{2}$ as much weight as the control. Again, treatment 8 (MSAT) behaved as an intermediate transmission film. All other treatments showed small weight losses. In general, shrinkage in warm storage was less after the 20 day cold storage interval as compared with the corresponding 40 and 80 day figures. At the latter periods the low transmission films which had been punctured or staple sealed had weight losses up to 3%. Since these treatments had lost 1% while in cold storage the total shrinkage amounted to about 4% which was close to the borderline of noticeable wilt.

(2) Respiration

(a) Cold Storage

Figure 3 indicates the relative accumulation of carbon dioxide in prepackaged head lettuce up to 120 days of cold storage. Accumulations ranging from

Figure 2: Weight Changes of Prepackaged Head Lettuce in Warm Storage



20 days at 33°F, plus $2\frac{1}{2}$ and 5 days at 80°F

40 days at 33°F, plus $2\frac{1}{2}$ and 5 days at 80°F

80 days at 33°F, plus $2\frac{1}{2}$ and 5 days at 80°F

1 to 12% are found after ten days. Five distinct groupings are noticeable at that time. These same groupings can be traced through all the storage periods up to 120 days. Except for treatments 13 and 14, the accumulated carbon dioxide was not altered from 10 to 120 days indicating an equilibrium between carbon dioxide production and diffusion. Treatments 13 and 14 (pliofilm wrapped) also leveled off after 20 days of cold storage.

The first group included all the acetate base treatments as well as the four puncture MSAT film. Carbon dioxide accumulation was less than 1% at any time. No difference existed between stapled and sealed acetate films.

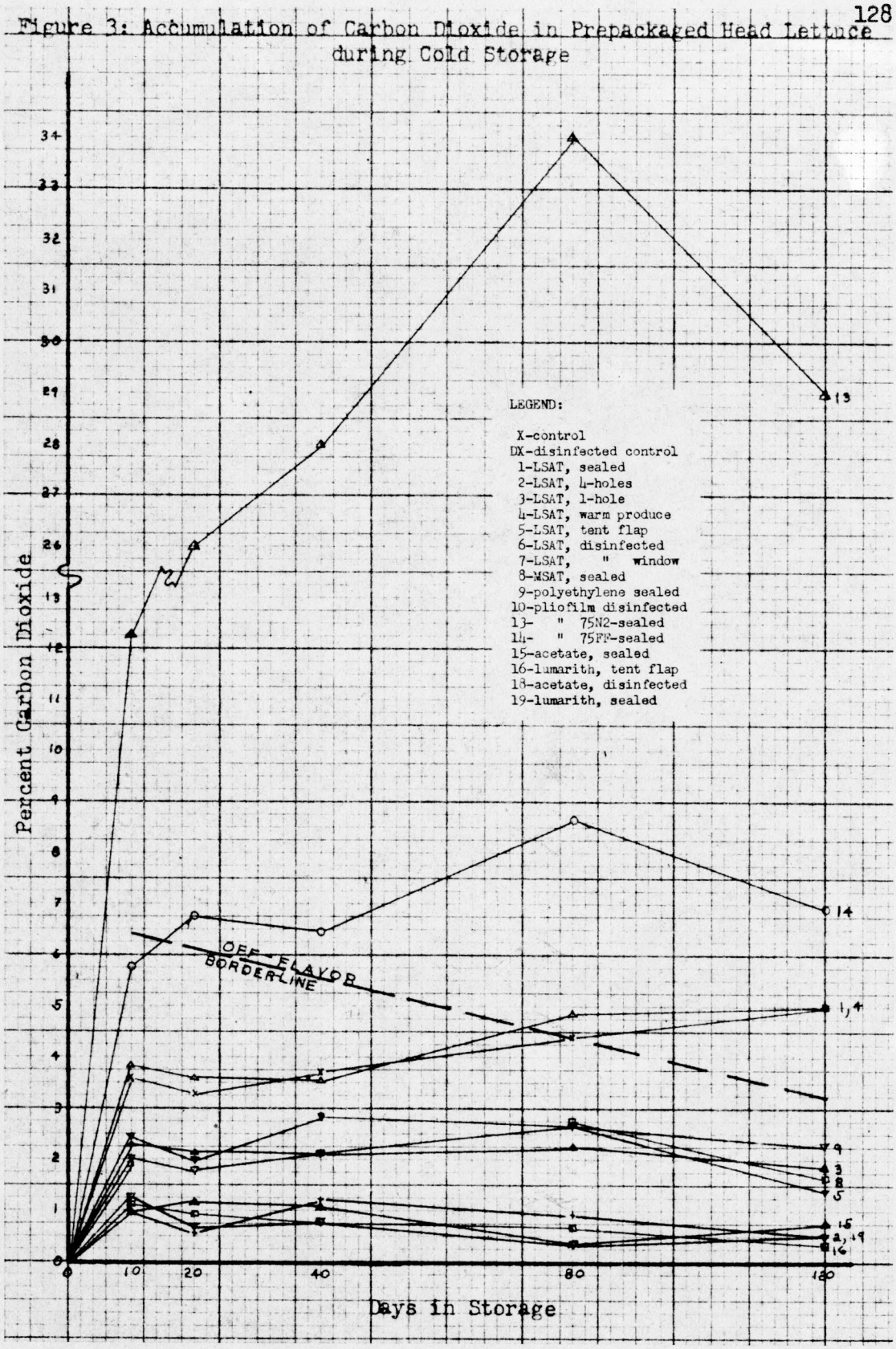
The second group fell at about the 2% CO_2 level and included the sealed LSAT and polyethylene treatments as well as single puncture and tent flap MSAT bags.

The next group was located in the interval of 4 to 5% CO_2 concentration between 10 and 120 days of storage. It included the cold and warm packed samples of lettuce in sealed MSAT film. This indicated that the temperature of the produce at the time of packaging did not affect the carbon dioxide concentration.

The fourth and fifth groups consisted of the rubber hydrochloride pliofilms having carbon dioxide concentrations of about 7 and 30%, respectively.

It is interesting to note that the carbon dioxide level in MSAT sealed bags can be reduced from 4 to 2% by a

Figure 3: Accumulation of Carbon Dioxide in Prepackaged Head Lettuce during Cold Storage



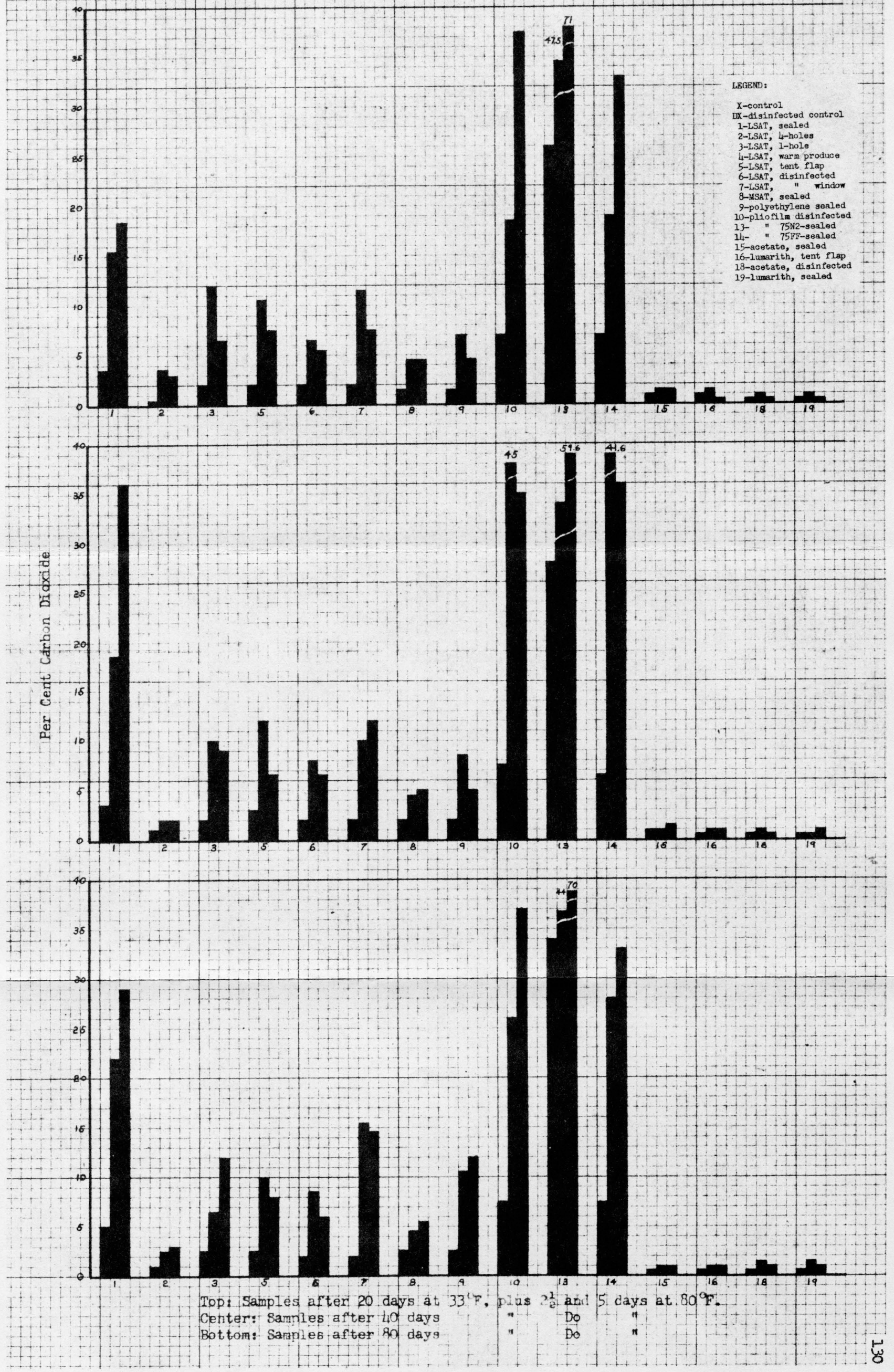
single puncture while four punctures further reduce the accumulation to that found in the high transmission acetate films. This is in contradistinction to the M.V.T. (moisture-vapor transmission) data indicated by figure 1. Tent flaps closely resembled single punctures.

In general, all films of the basic group showing low M.V.T. values also exhibited low carbon dioxide transmission rates and hence a greater accumulation of this gas. Exception to this was found in treatment 9, polyethylene film. However, it should be noted that films having about an equally high protective index against moisture loss showed considerable variations in the amount of carbon dioxide accumulated during cold storage.

(b) Warm Storage:

Figure 4 shows the carbon dioxide concentration of prepackaged head lettuce in warm storage. Analyses were made after 2.5 and 5.0 days of warm storage for each of 20, 40, and 80 day cold storage intervals. Inspection of the chart indicates a sharp rise in carbon dioxide accumulation after 2.5 days for all samples except the "acetates". Somewhat the same grouping of samples as shown in Figure 3 for low temperature storage could be recognized. A consistent exception to this trend was exhibited by the four puncture treatment, which unlike its behavior in cold storage, accumulated more carbon dioxide in

Figure 4: Accumulation of Carbon Dioxide in Prepackaged Head Lettuce in Warm Storage



Top: Samples after 20 days at 33°F. plus 2½ and 5 days at 80°F.
Center: Samples after 40 days " Do "
Bottom: Samples after 80 days " Do "

warm storage than the acetate samples.

The fifth day carbon dioxide concentrations were often lower than the corresponding 2.5 day values thus creating a "hump" on the chart for the 2.5 day period. This phenomenon could be attributed probably to a reduction in the rate of respiration due to the high carbon dioxide accumulation prevalent at the 2.5 day interval. This reduction in carbon dioxide evolution caused a shift in the equilibrium between gas production and diffusion. Hence the lower carbon dioxide levels at the five day storage period.

The disinfection treatments represented by codes 6, 7, 10 and 18 resembled the corresponding treatments without disinfection, namely 2, 3, 14 and 15 from the standpoint of CO_2 accumulation. The effect produced by the presence of an acetate film window in an MSAT bag was to rank it somewhere between the one and four hole treatments.

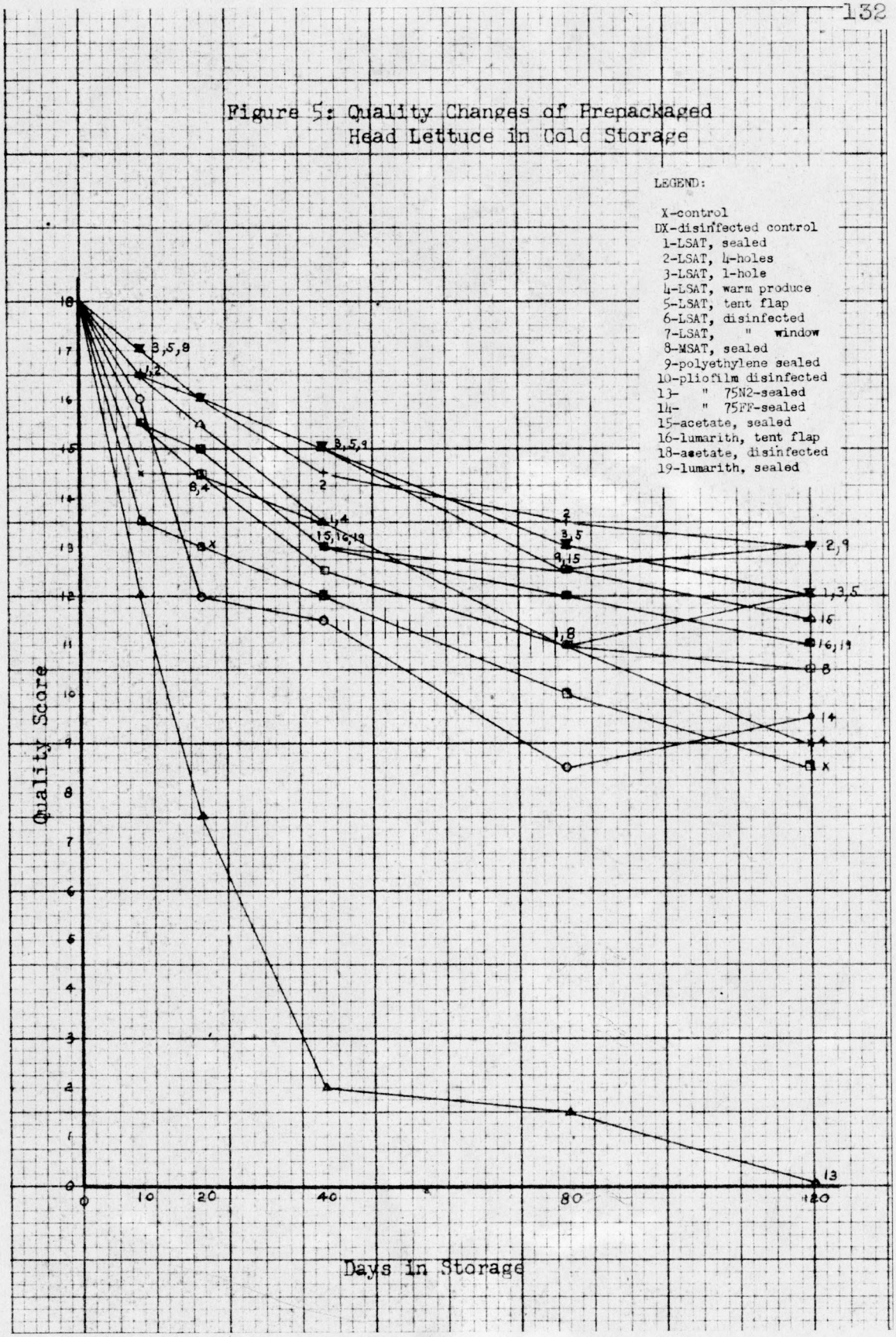
Differences in warm storage behavior following the three cold storage intervals were inconsistent with regard to carbon dioxide accumulation. At best it might be pointed out that the films having low gas transmission rates showed increasing carbon dioxide concentrations in warm storage after longer previous cold storage intervals.

(3) Overall Quality:

(a) Cold Storage:

Cold storage time (10 to 120 days)

Figure 5: Quality Changes of Prepackaged Head Lettuce in Cold Storage



against overall quality of head lettuce is plotted in Figure 5. Quality was expressed in a range of scores from 0 to 18. Using a four point scoring system outlined under materials and methods, values of 0 to 3 were assigned to each quality. These qualities were a) rot, b) mold, c) aroma, d) flavor, e) appearance of outer leaves and butt, f) condition of longitudinal cross section. Since each factor was equally weighted an overall expression of sample quality was obtained by addition of the numerical values assigned.

Differences in quality were observed beginning with the first storage period. All samples with the exception of treatment 13 which had an off flavor, rated higher than the controls after 10 days at 32° F. Mold (in controls), wilting (treatments 8, 15, 16 and 19), and off odor (treatment 4) were responsible for quality losses. The spread in quality between codes increased with each storage period up to 80 days showing that the differences were enhanced with the longer holding times. It should also be noted that the quality of all samples decreased during storage and was lowered four points for the best sample (17 to 13) and twelve points for the poorest sample (12 to 0). At the twenty day period treatment 14 dropped sharply due to some off flavor and odor formation.

At the forty day interval the punctured, stapled and polyethylene bags rated highest. Treatment #1 dropped to its warm pack equivalent, treatment 4, because of off odor

and slight off flavor formation which probably were caused by carbon dioxide accumulation. The wilting and poor appearance of outer leaves of the acetates and LSAT cellophane wrapped samples caused them to be rated below treatments 1 and 4. Controls were rated even lower since they showed some mold in addition to poor outer leaves. Treatments 13 and 14 exhibited injury and were unacceptable.

At the eighty day period lettuce packed in all the sealed films except polyethylene and the acetates showed off flavor and was rated low. At the final storage period acceptable quality was exhibited by treatments 2 and 9 representing multiple puncture MSAT and sealed polyethylene respectively. The single hole and tent flaps were of borderline acceptability with treatments 15, 16, and 19 showing too much wilting to be saleable without considerable trimming.

It should be recognized that the position of a number of points are justified with difficulty. It is not likely that samples of treatments 1, 9 and 14 would have a higher quality rating at 120 days than at 80 days. Despite all efforts for uniformity it was impossible to assign more than qualitative significance to the charted values. A larger number of samples than used in this study would be required to place confidence in each set of values. Instead only trends and the relation of the treatments to the control samples and to each other can be derived from this study.

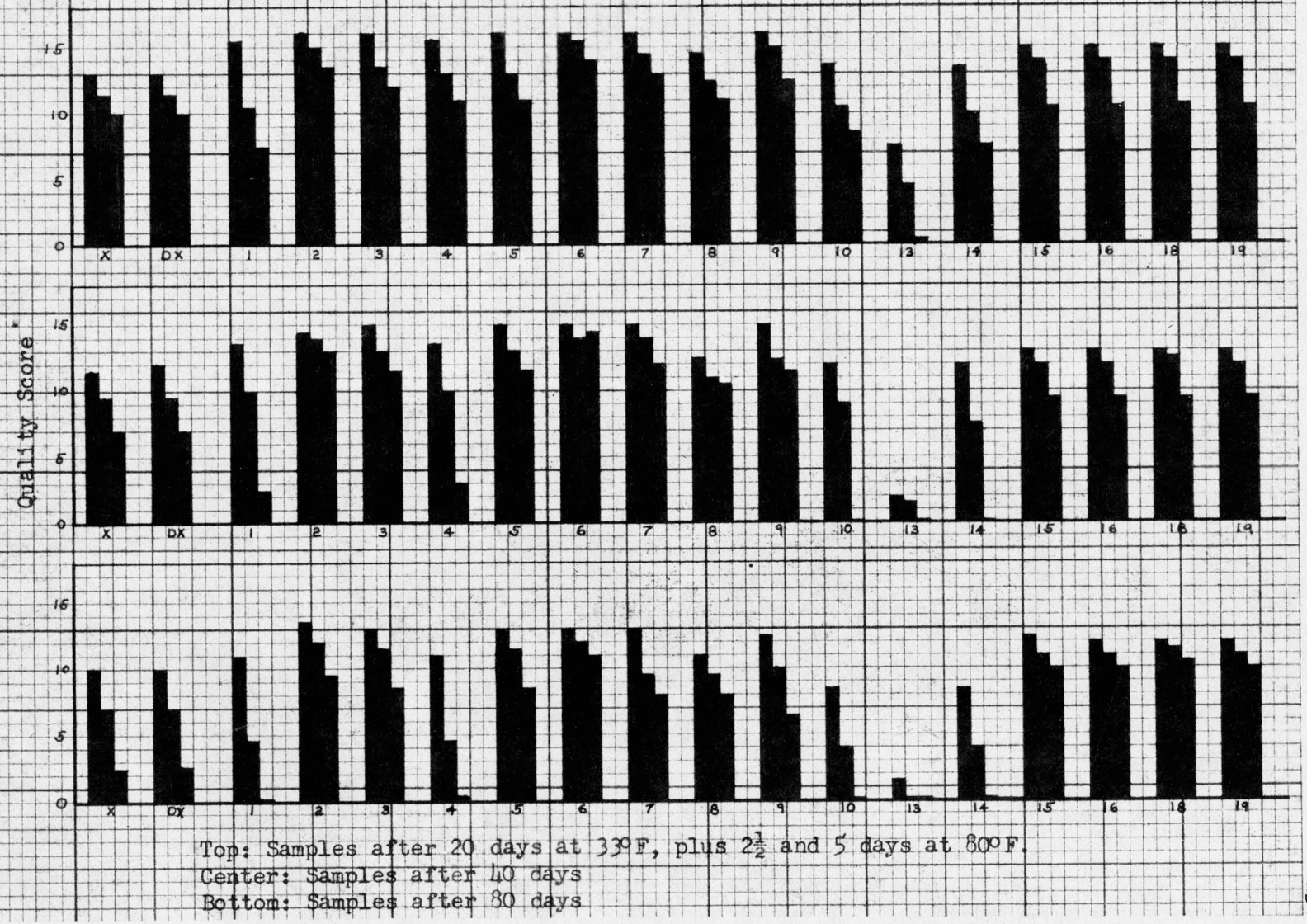
(b) Warm Storage

Illustrated in figure 6 are quality scores after 2.5 and 5.0 days of warm storage following the 20, 40, and 80 days of cold storage. Quality was evaluated on the same basis as described for low temperature storage. As expected, the rate of quality deterioration was more rapid in warm storage.

All lettuce packed in pliofilms including the disinfection treatment 10 deteriorated rapidly showing complete spoilage of the sample after five days. Treatment 1 also dropped rapidly in quality similar to the above. The controls, although better, were wilted and moldy after 2.5 days. These defects were more severe after 5.0 days. The high transmission acetate, both sealed or stapled, retained fair quality for 2.5 days but after 5.0 days wilting was pronounced. There was no noticeable difference between the disinfected and corresponding acetate treatment having no disinfection. The punctured, stapled and window, low transmission film and polyethylene samples maintained good quality while their corresponding disinfected samples (6, 7) rated slightly higher. The critical factors of quality difference between these treatments were odor and presence of rot. No wilting, mold or loss of center quality was apparent.

Changes in the rate of deterioration with length of previous cold storage was apparent for some treatments but no definite trends were established. At the 80 day cold

Figure 6: Quality Changes of Prepackaged Lettuce in Warm Storage



Top: Samples after 20 days at 33°F, plus 2½ and 5 days at 80°F.
Center: Samples after 40 days
Bottom: Samples after 80 days

storage period several of the usually top ranking treatments, such as 2, 3, 5 and 7, developed noticeable off odor and/or rot in 5 days of warm storage. This caused them to be rated lower than the high transmission acetate films which deteriorated mainly with respect to wilting. However, treatment 6 remained of better quality than all other treatments. Variations in quality between treated and untreated controls, X versus DX, were not significant. Again, the limitations of the graphs imposed by the small number of samples must be recognized.

(4) Graph Relationships:

(a) Weight loss versus wilting:

A comparison of the subjective evaluation, namely wilting, with percent weight loss data showed that nearly all samples termed "severely wilted" had weight losses of more than 8%, while those termed "wilt not noticeable" had losses of less than 2.5% in weight. The separation of "some wilt" and "slight wilt" in terms of weight losses was not clearly defined by the results. Division of the weight loss data given in figures 1 and 2 into three distinct categories was made to show the above relationships. This is illustrated by the dotted lines in each graph.

(b) Flavor score versus percent carbon dioxide: The borderline for pronounced off flavor lies

between 1.5 and 2.0 in the four point score system outlined in methods and materials. The carbon dioxide values for samples having flavor scores of 1.5 or less can be separated by a straight line from those carbon dioxide values having higher flavor scores. This off-flavor borderline was shown in Figure 3. The line had a negative slope in Figure 3 (cold storage) which indicated that in prolonged storage less carbon dioxide can be tolerated without definite off flavor formation. For warm storage the line had a positive slope between zero and $2\frac{1}{2}$ days which indicated that rather high carbon dioxide concentrations can be tolerated without pronounced off-flavor development. After five days of warm storage the carbon dioxide concentration of all samples having an acceptable flavor dropped. Thus a wide range on the CO_2 ordinate was left without values so that a flavor borderline could not be drawn with justification.

It must be noted that in no case did carbon dioxide accumulation improve the flavor between 10 and 120 days of storage. This statement applies to all vegetables tested.

(c) Comparison of Stapled, Punctured, and Completely Sealed Bags of Identical Film Types: No pronounced difference between stapled and sealed bags of high transmission films was noticed in either cold or warm storage. This was to be expected since carbon dioxide and weight losses were parallel.

In the case of samples in low transmission films significant differences were noted between punctured and stapled units if compared to the corresponding sealed treatments. The lettuce in sealed packages generally received lower quality ratings. This was caused by the differences in the amount of carbon dioxide accumulation between the two groups. Carbon dioxide and presumably oxygen transmission rates were so much lower for the sealed bags that pronounced off flavors resulted in the produce. Protection against moisture loss was about equally high in all cases.

The combination of high carbon dioxide transmission and low moisture vapor transmission shown by the punctured and stapled films was found to be highly desirable so that lettuce in these films were rated among the highest for overall quality. An even higher gas transmission rate without sacrificing a low M.V.T. would be desirable after removal from cold storage since some of the above treatments showed carbon dioxide accumulation in warm storage. Perhaps more than four holes would provide this condition. Such a trend was indicated since treatment number two showed a higher quality rating than the single hole puncture and the tent flap which allowed more accumulation of carbon dioxide.

(d) Disinfection versus Quality:

1) Mold: None of the wrapped samples showed noticeable mold development while both the disinfected and not disinfected unwrapped controls became moldy during storage.

This pointed to storage contamination as the source of mold infection. Thus no conclusions can be drawn regarding the mold inhibiting power of the disinfection treatment coupled with packaging. Without the protective action of a wrapper the mold inhibiting power of a treatment was nil as was evidenced by the mold development on the chemically treated unwrapped samples (DX).

ii) Rot: It is difficult to estimate the value of disinfection for rot control without considering in each case the type of film and wrapping technique used together with disinfection. Less rot was evident in the acetate window packed samples than in the corresponding treatments which were not disinfected. The chemically treated samples packed in sealed bags (treatment 10) exhibited severe decay probably due to the high carbon dioxide concentration prevalent in this type of film. The same type of injury could also be observed in the corresponding not disinfected treatment 14. It may be assumed that the chemical was not the cause of the breakdown but no information regarding its germicidal power was available under the circumstances.

Treatment 18 (disinfected acetate packs) showed no rot but the corresponding not disinfected acetate treatment 15 was also free of rot. This was possibly due to the low relative humidity and low CO_2 present in these packs.

It must be emphasized again that it was difficult to differentiate between microbiological and physiological

breakdown and therefore the relationships indicated above require confirmation by means of a detailed bacteriological study before recommendations regarding disinfection treatments can be made with respect to decay or rot.

iii. Odor: Generally off odors were indicators of incipient spoilage due to bacteriological or physiological breakdown. Disinfected window bag samples in many cases received better odor scores than corresponding samples which were not chemically treated. This did not apply to treatments 10 and 18 for the same reasons as outlined for rot in the preceding section.

Illustrated in Plate XII are samples of the best, control, and poorest treatments of head lettuce after 120 days of cold storage.

c. Tomatoes.

(1) Transpiration.

(a) Cold Storage.

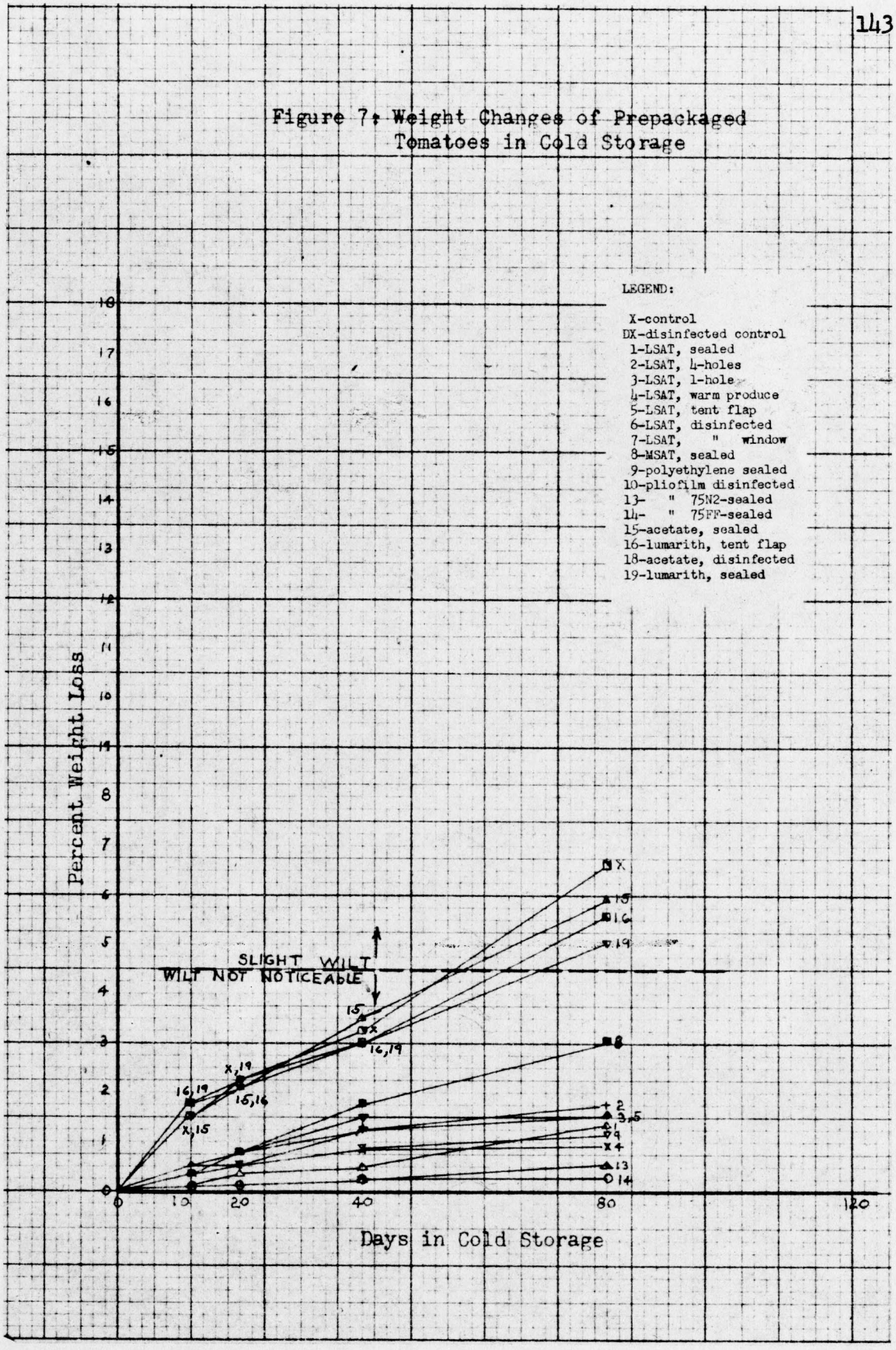
Weight loss data in Figure 7 show a picture different from that described for lettuce in Figure 1. In the case of tomatoes the unwrapped controls lost weight at a rate about equal to the acetate units while in the case of lettuce treatment X showed greater losses than the high transmission samples. The rate of weight loss in acetate films between 10 and 80 days was about the same for the two vegetables. However, the absolute change was less for tomatoes since the per

Plate XII

Prepackaged Head Lettuce After 120 Days of Cold Storage Showing Best, Control and Poorest Treatments

Control Best Poorest

Figure 7: Weight Changes of Prepackaged Tomatoes in Cold Storage



cent weight loss for the first ten days was lower for the high transmission films. Again, all other treatments, except number 8, showed small weight losses all of which were below 2½%.

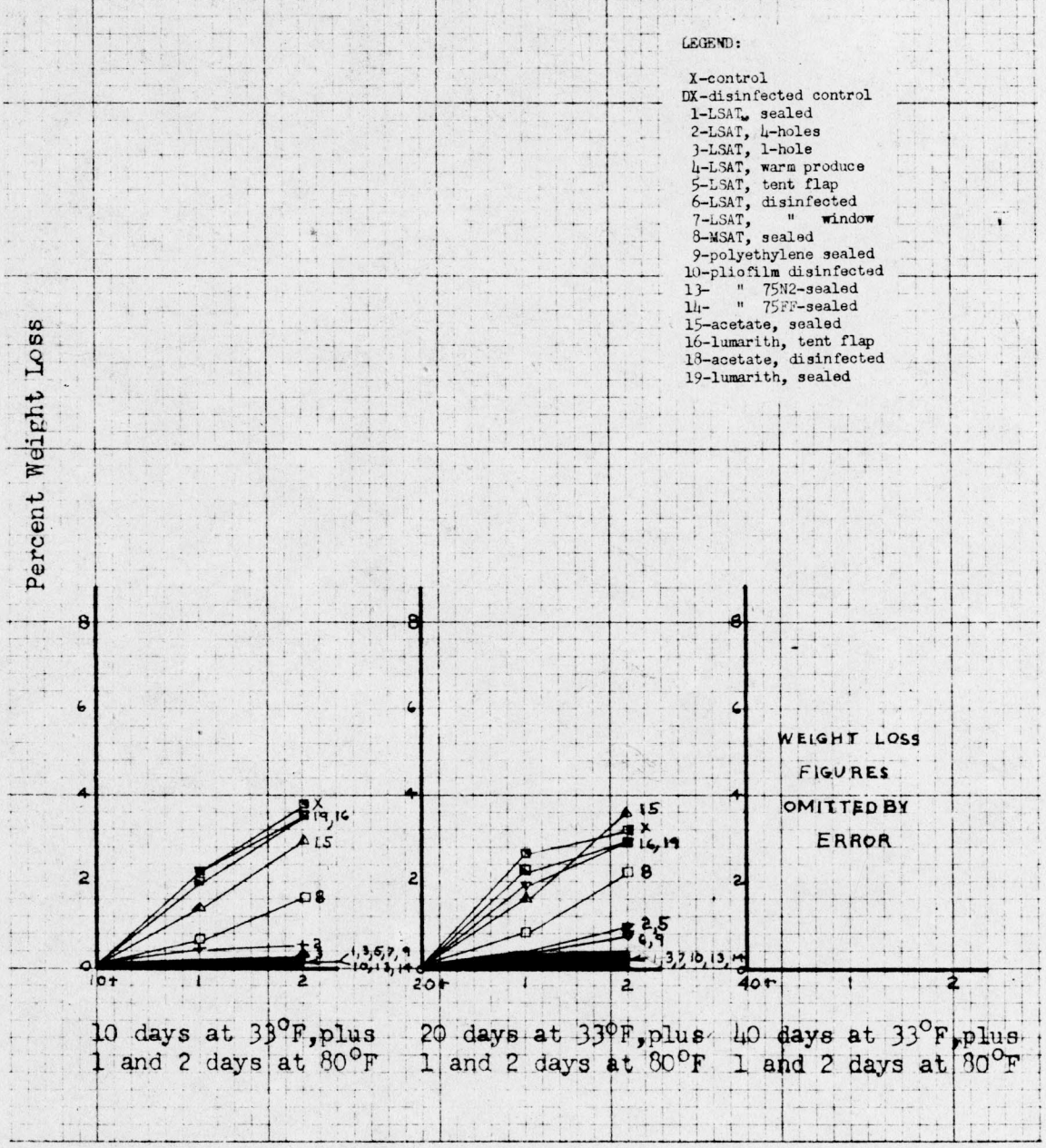
(b) Warm Storage.

It was learned that tomatoes deteriorate rapidly after removal from cold storage so that the transpiration losses had to be studied within two days following removal of the product from refrigerated temperatures. The data presented by figure 8 show weight losses of tomatoes for 10 + 1 + 2 days and 20 + 1 + 2 days of storage where the first number of a group represents the number of days the product was held in cold storage and the following numbers represent the days on which the produce was analyzed after being in warm storage.

Since lettuce was held in warm storage for 2½ and 5 days a direct comparison of results was not possible. However, relative comparisons were made. In general, tomatoes showed greater weight changes in warm storage than in cold storage. Lettuce had also displayed this tendency. The controls and acetate wrapped treatments showed losses that were about equal to each other as well as being the samples with the greatest amount of change. On the other hand, the unwrapped lettuce controls had shown even greater losses than the high transmission treatments.

All other treatments underwent weight losses of

Figure 8: Weight Losses of Prepackaged Tomatoes in Warm Storage



less than 2% during two days of warm storage. It was further noted that there was little difference between the weight changes that occurred in warm storage regardless of the length of time the tomatoes were held in cold storage.

Observations for transpiration losses were not made for the 40 + 1 + 2 period due to an error of ommission.

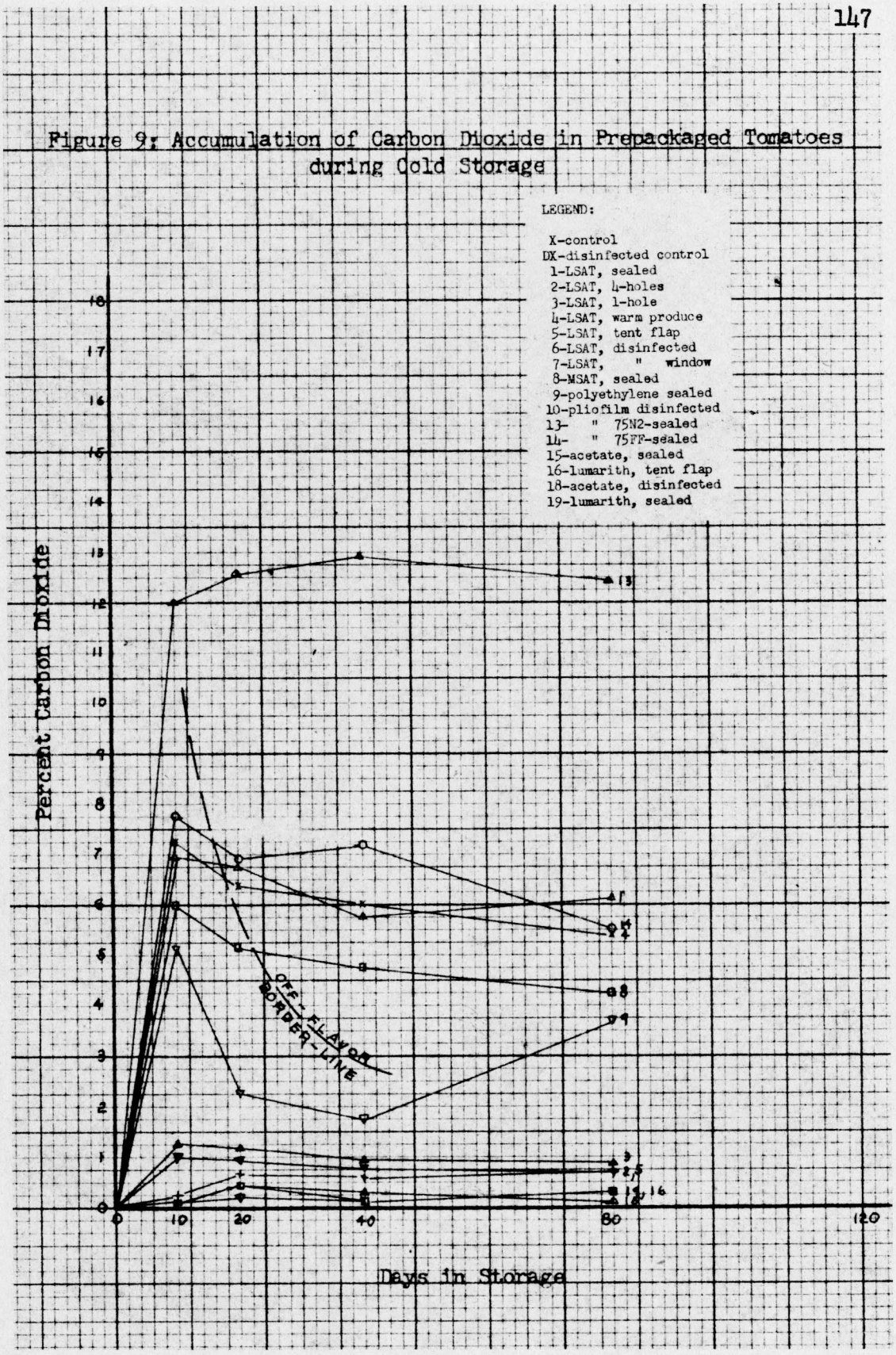
(2) Respiration.

(a) Cold Storage.

In figure 9 the concentration of carbon dioxide within the packages of tomatoes held in cold storage are given. It can be observed that the level of CO_2 remains practically constant after the first ten days. At the same time there is a definite grouping of certain films, in a manner similar to that for lettuce. But the particular treatments that fall within each group are different. Also, the same treatments fall at a level of carbon dioxide concentration different from that for lettuce.

For example, treatment 13 contained the greatest amount of carbon dioxide for both lettuce and tomatoes but the accumulation for tomatoes was only half that produced by lettuce. Treatment 14 showed about equal concentration of the gas for both products. At the same time treatments 1 and 4 fell within the same grouping as 14 but those contained twice the quanity of gas as the corresponding lettuce samples. The fact that little difference existed in the analysis of treatments 1 and 4 indicated that for

Figure 9: Accumulation of Carbon Dioxide in Prepackaged Tomatoes during Cold Storage



tomatoes carbon dioxide accumulation is the same regardless of whether the product is cooled before packaging.

The third grouping of treatments occured with the medium gas transmission films of polyethylene and LSAT cellophane. The carbon dioxide content of these samples was slightly higher than with lettuce. The fourth group contained less than 1.5% CO_2 and consisted of film treatments 2, 3, and 5, having punctures or tent flaps. And lastly, the acetate wrapped samples had less than 0.5% CO_2 within the bags.

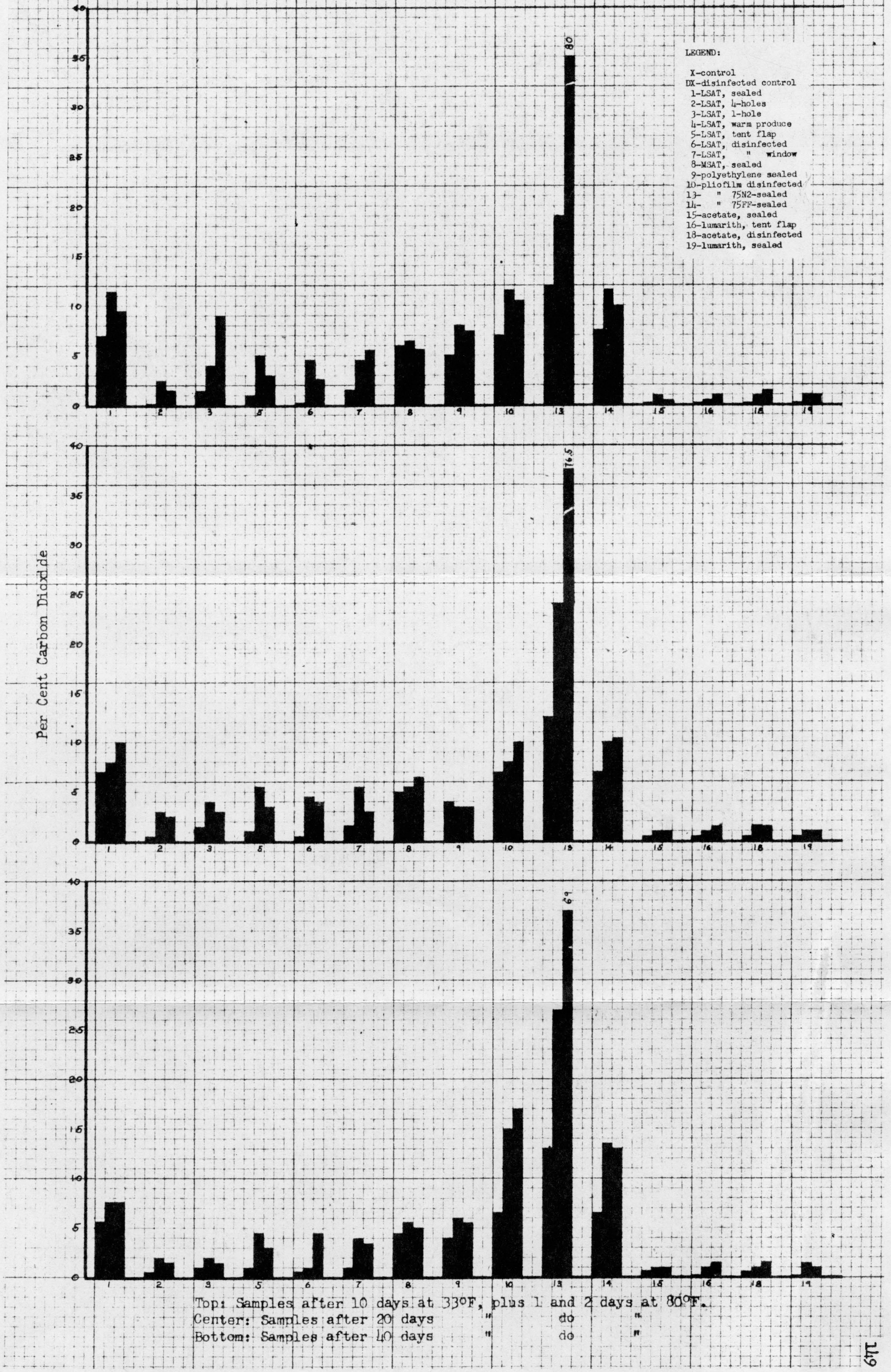
(b) Warm Storage.

Carbon dioxide accumulation in warm storage tomatoes produced the same relative rank among the various treatments as occured in cold storage. But the division of treatments into various levels of concentration was rather indistinct for the samples held at 80° F. See Figure 10. However, treatment 13 accumulated the greatest quantity of the gas while the acetate treatment contained the lowest, as was observed also for cold storage samples.

A maximum carbon dioxide level was indicated by the characteristic increase after the first day of warm storage followed by a slight decrease at the second day. Although true for most treatments this statement does not apply to the acetate variations.

Treatments 1 and 4 again exhibited close similarity,

Figure 10: Accumulation of Carbon Dioxide in Prepackaged Tomatoes in Warm Storage



Top: Samples after 10 days at 33°F, plus 1 and 2 days at 80°F.
Center: Samples after 20 days " do "
Bottom: Samples after 40 days " do "

number 2 was slightly higher than the acetate treatments but lower than in other bags, and the LSAT sample showed relatively less accumulation of carbon dioxide in warm than in cold storage. The effect of disinfection on the respiration products of tomatoes was not clear. Also, there was no relation between the time of previous cold storage and warm storage increases.

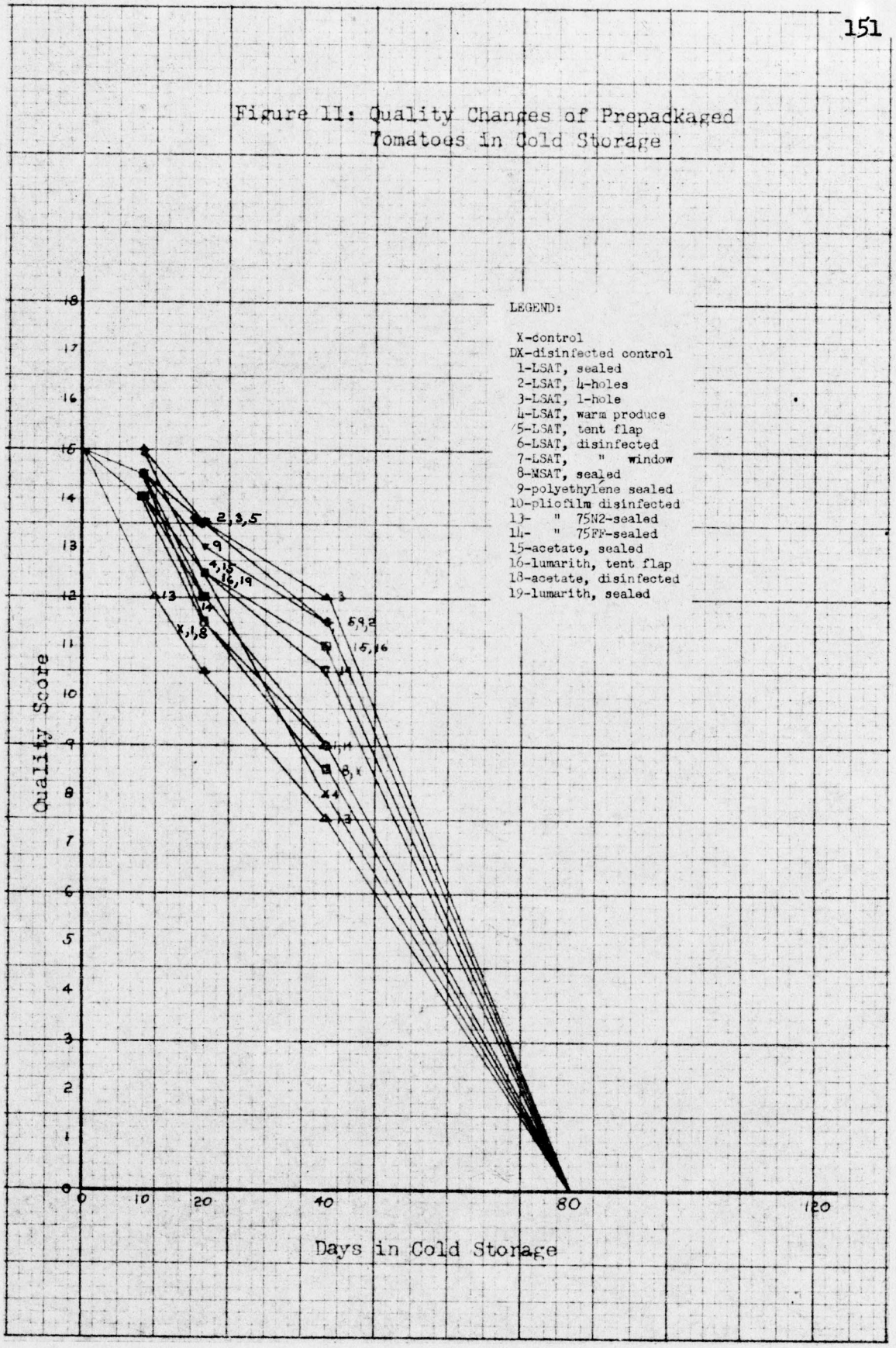
(3) Quality.

(a) Cold Storage.

Tomatoes were judged for quality after 10, 20, 40, and 80 days in cold storage. For the first ten days the condition of all samples except treatment 13 was very good and varied no more than one score point. Treatment 13 possessed a slight off flavor and consequently received a lower score. After the second cold storage interval all samples showed some decrease in quality. Treatment 13 had poor flavor and showed other signs of breaking down while treatments 1 and 14 had become soft and were slightly off in odor within the package. The control showed definite mold. All other samples remained within one score point of one another.

After being held forty days at 31-32° F, the prepacked tomatoes could be placed into two quality groups; the one containing the tightly sealed treatments, except for polyethylene. The former had off flavor and odor and had some rot but very little mold, and the other group

Figure 11: Quality Changes of Prepackaged Tomatoes in Cold Storage



consisted of the remaining treatments such as polyethylene, punctured, tent flaps, and acetates which had considerable mold present. The acetates were not quite as acceptable as the other treatments within that same group. The unwrapped controls were badly molded and somewhat shriveled.

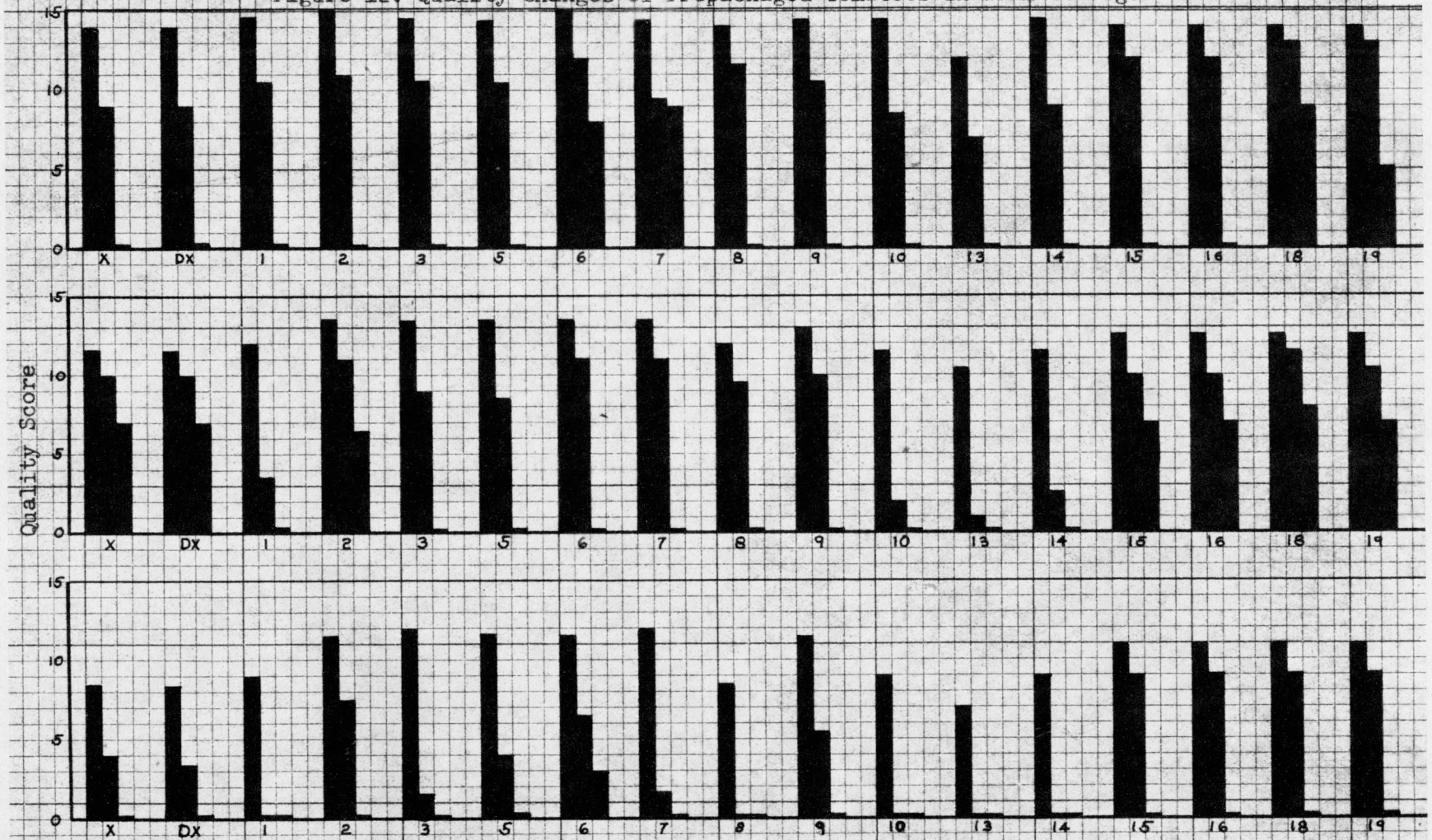
At eighty days, the quality of cold storage tomatoes was very poor. All samples were severely molded and rotted so that they were quite unacceptable. The presence of a score of 6.5 for treatment 6 should be pointed out since it was previously included only in the warm storage tests. Treatment 6 indicated the possibility of an advantage in the use of a disinfectant for tomatoes since the sample had less mold than others in the series.

In general the quality of tomatoes dropped at a rate similar to that for lettuce up to 40 days of storage.

(b) Warm Storage.

In figure 12 the quality of tomatoes held in warm storage one and two days is given. Quality losses were rapid after ten days in cold storage. Not only the tightly-sealed packages but also the punctured, stapled and window bag treatments were not well tolerated by the product so that off flavors and odors were produced by the 10 + 1 storage period. The acetate treatments were better quality but exhibited mold on the product. The unwrapped treatments were heavily molded in comparison. On

Figure 12: Quality Changes of Prepackaged Tomatoes in Warm Storage



Top: Samples after 10 days at 33°F, plus 1 and 2 days at 80°F.
Center: Samples after 20 days
Bottom: Samples after 40 days

the other hand the disinfected acetate treatment 18 had the best quality at all times after one day in warm storage. After two days at the warmer temperature, all samples were badly deteriorated. Again the disinfectant treatment was slightly better than most of the other treatments but it too was poor in quality, having some mold, rot and off odor present.

In general at the 20 + 1 + 2 period the ranking of treatments was like that observed for the 10 + 1 + 2 interval. The treatment 18 was slightly better than the others and after the second day of warm storage all samples were poor. At the 40 + 1 interval all samples received rather low quality scores while number 18 still remained the best. But all 40 + 2 treatments were completely spoiled.

(4) Graph Relationships.

(a) Weight Losses Versus Wilting.

After eighty days in cold storage some shrinkage was observed for tomatoes of acetate and control treatments. But these were the only samples which showed wilting at any time. See figure 7. In warm storage there was no noticeable shrinkage after one day for any sample. The weight losses were also low then. However, by the second day of warm storage the weight losses were large enough to have caused shrinkage in the tomatoes but the extent of decay and softening in the vegetable made it

impossible to determine the correlation of weight loss and wilting.

(b) Flavor Score Versus Per Cent Carbon Dioxide: A flavor borderline like that described for lettuce was drawn on the graph of carbon dioxide values for tomatoes, figure 9. This curve has a negative slope during the storage interval from zero to forty days which means that as the storage time increased the level of carbon dioxide at which off flavors were present in the tomatoes decreased. Furthermore, the sharper incline of the curve during the first twenty days of storage indicates that the tolerance of high carbon dioxide levels changed most rapidly in the early storage days. No curve was drawn on the graph after the forty day observations since the produce had deteriorated to the point where it was inedible.

A corresponding line was not drawn for warm storage conditions since other factors such as mold and rot caused flavor changes in addition to the effect of carbon dioxide. Also, certain samples in low transmission films were off flavored at the time they were placed in warm storage so that no line of demarcation was possible.

It was also noted that the amount of carbon dioxide present in the package at time of removal from cold storage affected the resulting flavor of the products in warm storage. For example, from 10 + 0 to 10 + 1 days, treatments 5 and 14 both increased 3.7% in CO_2 but treatment 14

was off flavored while treatment 5 was not. See figure 10.

(c) Comparison of Stapled, Punctured and Completely-Sealed Bags of Identical Film Types: No differences between the high transmission stapled and sealed film (treatments 16 and 19) were observed.

Treatments 1, 2, 3, and 5, in which the low transmission MSAT film was used, showed definite differences in some cases. All were of approximately equal quality after ten days cold storage despite the fact that the sealed treatment was considerably higher in carbon dioxide content. After the 20 and 40 day intervals the three unsealed variations were much higher in quality since the carbon dioxide values were lower than treatment 1 although the losses in weight were nearly equal. At 80 days cold storage, all four treatments were poor quality due principally to mold and rot in the samples. Differences among the three unsealed treatments were not apparent in cold storage.

At the 10 + 1 and 10 + 2 observation periods all samples lost in quality about equally regardless of carbon dioxide variations which were higher in treatment 1 than in the others. But after the longer previous cold storage intervals, the sealed treatment decreased in quality rapidly. Among the unsealed treatments the bag with four punctures produced the best quality. It had the lowest CO_2 values but weight losses were about equal with those of

treatments 3 and 5.

(d) Disinfection Versus Quality.

The effect of disinfection on prepackaged produce was studied in warm storage since it was believed differences would be most apparent at that temperature.

i) Mold: More mold was observed in treatment 15 than in the corresponding disinfected acetate film. No mold developed in either of the pliofilm treatments 10 and 14. This was probably due to the high concentration of carbon dioxide and therefore the possible effect of the disinfectant was overshadowed.

Among the MSAT variations between disinfection and no disinfection there were no consistent results obtained between treatments 2, 3, and 5 and treatments 6 and 7 so that a statement regarding possible improvements is not warranted.

ii) Rot: No evidence that rot or decay was reduced by the disinfectant used was obtained.

iii) Odor: Since better aroma was observed for treatment 18 than for treatment 15, it was believed that disinfection may have promoted this condition. In the case of samples 10 and 14 no statement regarding disinfection and odor is possible since extensive rot was present in both.

d. Carrots.

(1) Transpiration.

(a) Cold Storage.

Per cent weight loss for carrots as given in figure 13 shows trends very similar to those given for lettuce in figure 1. A slight difference was indicated by a more rapid weight change in the early storage periods for the unwrapped carrot samples.

(b) Warm Storage.

Transpiration losses in warm storage are illustrated in figure 14 for 20 + 7 + 14, 40 + 7 + 14 and 80 + 7 + 14 storage periods. It is apparent that the high transmission film and control samples lost weight less rapidly than lettuce after being placed into the warm temperature cabinet. The unwrapped control samples showed losses from 23% at the 20 + 14 interval to 28% at the 80 + 14 period. Despite the slower rate of loss the relative rank of the various treatments to each other remained the same in warm as in cold storage. It was found that for carrots in general the changes after fourteen days in warm storage about equaled those changes after 120 days in cold storage.

The low M.V.T. films allowed the samples to lose only 2%, 2½%, and 4½% moisture after the 20 + 14, 40 + 14, and 80 + 14 storage intervals. This indicated a greater tendency toward weight loss after the longer cold storage

Figure 13: Weight Changes in Prepackaged Carrots in Cold Storage

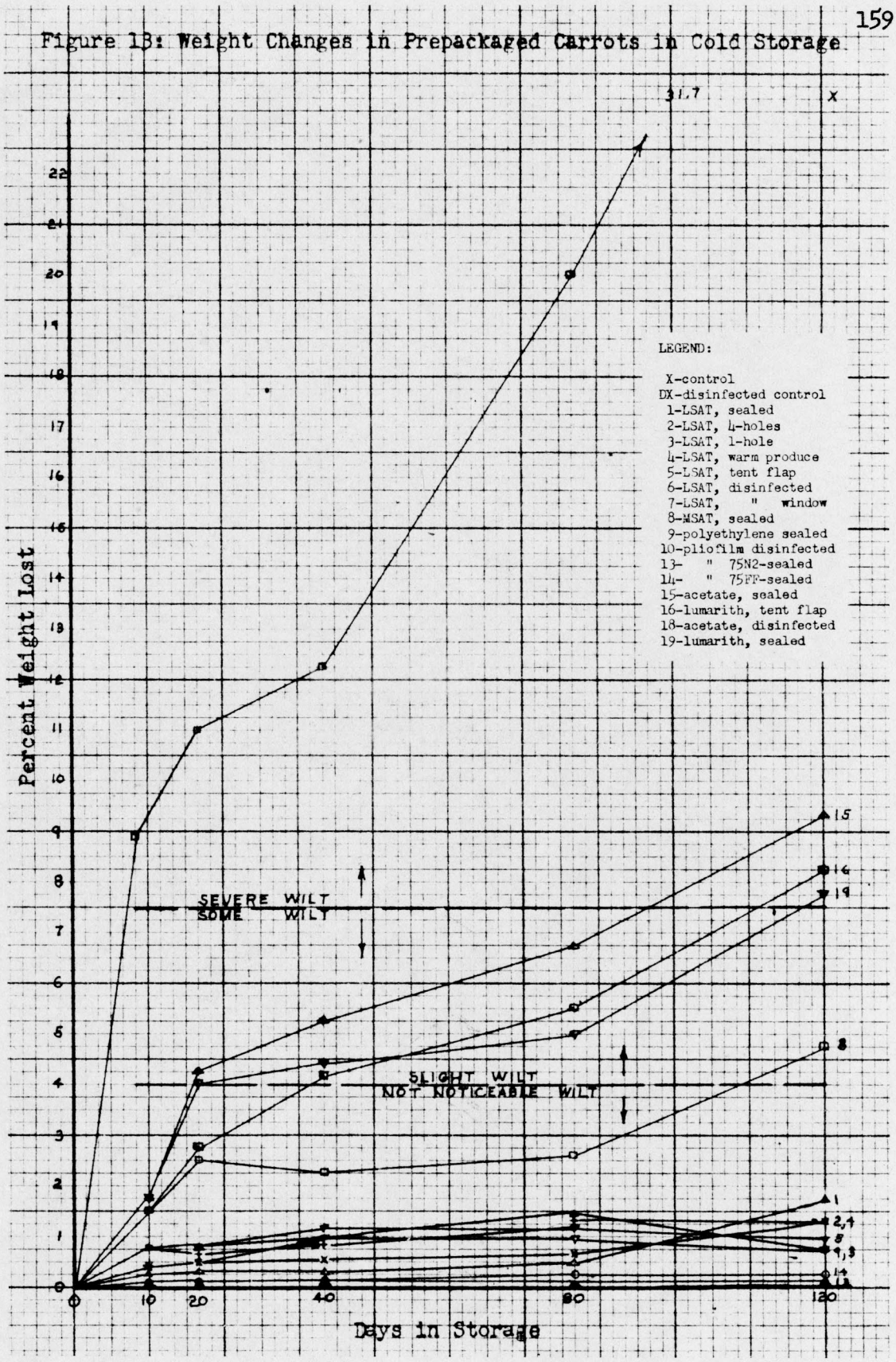
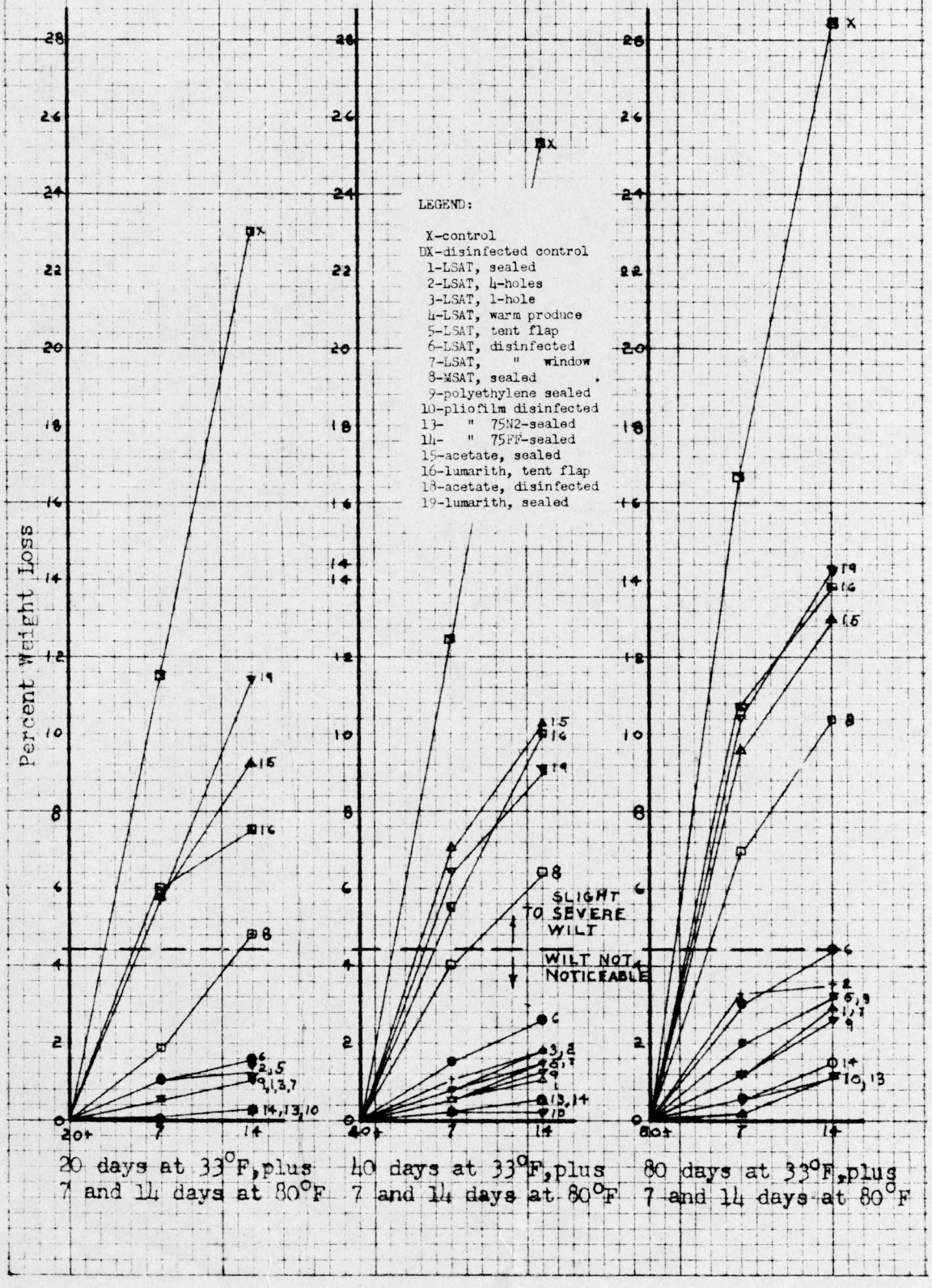


Figure 14: Weight Changes of Prepackaged Carrots in Warm Storage



periods. Carrots in films having punctures, staples, or windows exhibited slightly greater losses than carrots in corresponding tightly-sealed films. This difference was not definite until after the 80 + 7 period and even then was not pronounced.

(2) Respiration.

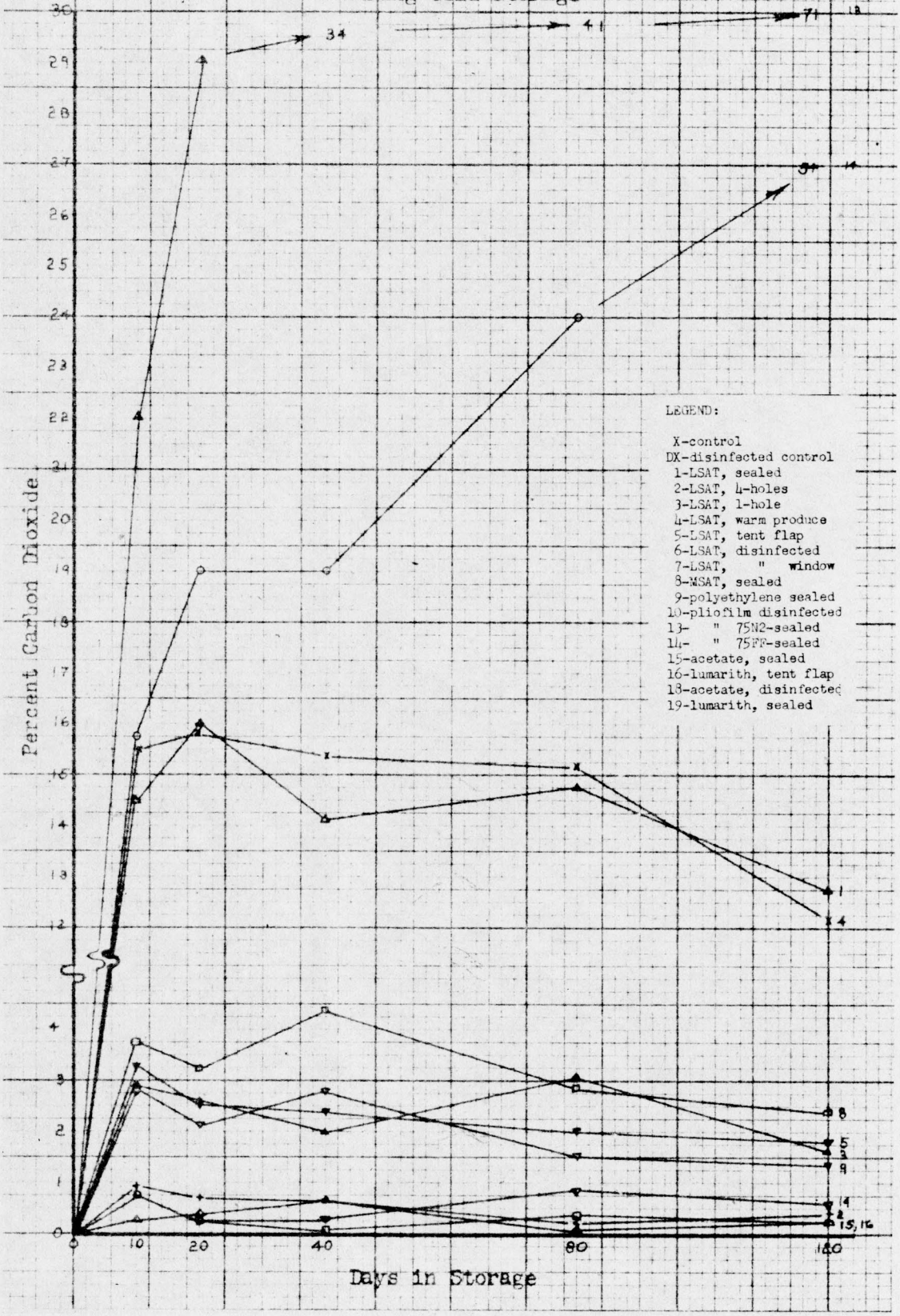
(a) Cold Storage.

The accumulation of carbon dioxide in carrot packages of the low gas transmission films was greatest for all vegetables tested. This is illustrated in figure 15. Parallel increases in the carbon dioxide content were apparent for other carrot treatments but to a more limited extent.

Grouping was evident again but in a manner which followed that for lettuce more strictly than did the tomato samples. Treatment 13 accumulated a high concentration of carbon dioxide; treatment 14 followed with a lesser amount; while treatments 1 and 4 were located at a third level with no difference between them. This agreement between treatments 1 and 4 indicates no difference after 10 days of storage between produce packed warm and that pre-cooled.

Group 4 consisted only of treatment 8 which was located at the 4% CO_2 level. Below treatment 8 were treatments 3, 5, and 9 which were somewhat higher than the acetates and 4 puncture samples. This last group contained less than 1% CO_2.

Figure 15: Accumulation of Carbon Dioxide in Prepackaged Carrots during Cold Storage



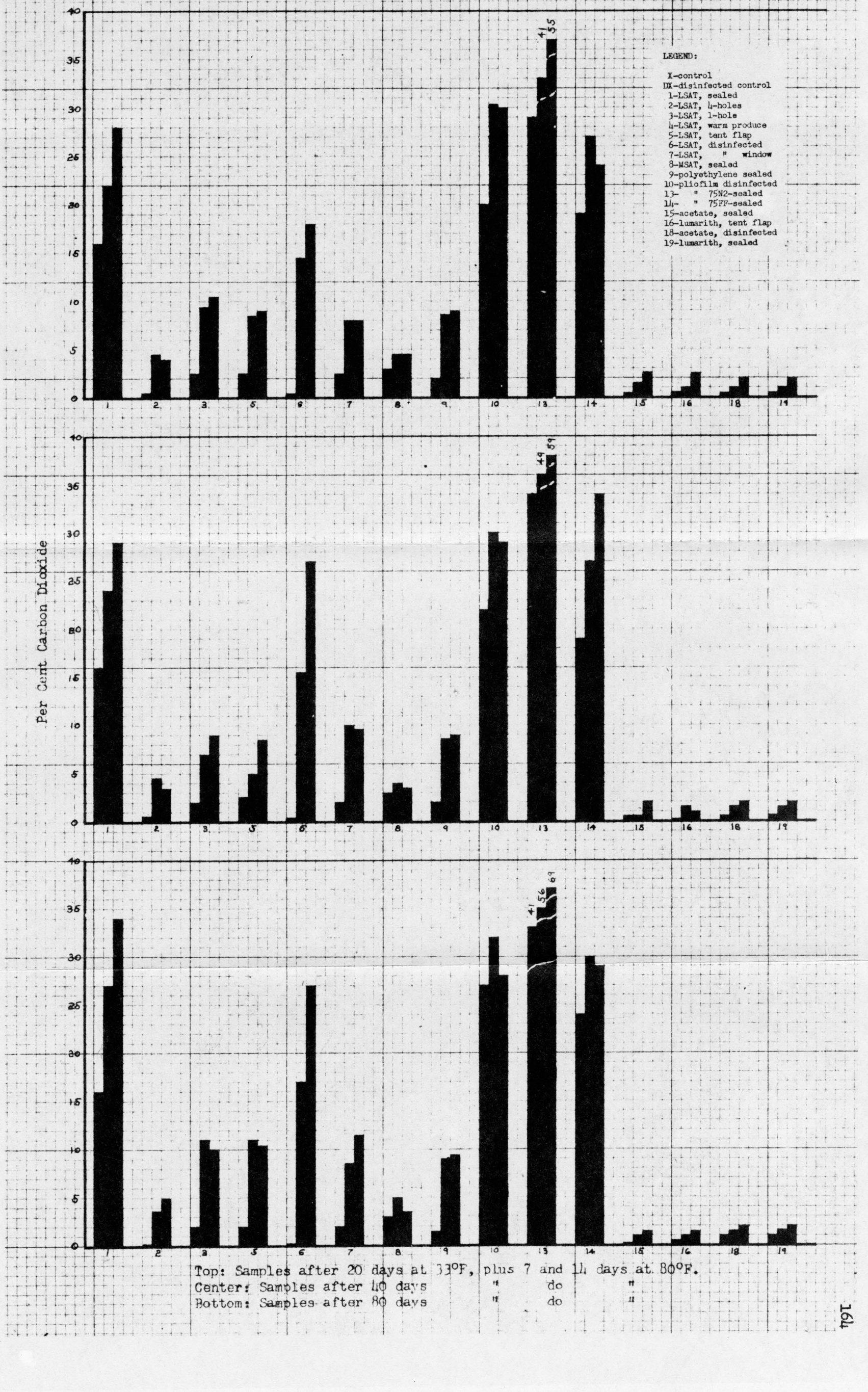
Except for treatments 13 and 14 there was no increase in the carbon dioxide content of the packages with increased storage time. Instead there appeared to be a slight decrease during the latter part of storage.

(b) Warm Storage.

The longer warm storage intervals for carrots make it rather difficult to compare their respiration values with other products. It was observed, though, that the carbon dioxide figures were high as they also were for cold storage. The absence of the characteristic "hump," that is the sudden rise and fall of the gas level, immediately following removal from cold storage may have been due to the fact that the samples were not analyzed until after seven days at 80° F so that this characteristic may have been missed.

The unusually high amount of carbon dioxide in treatment 6 (figure 16) is inexplicable and perhaps was due to an error in the experiment. The number 8 treatment is somewhat low with respect to relative rank of the samples even though the actual amount of gas present was greater in the warm storage period than in cold. On the other hand, the four puncture samples contained considerably more carbon dioxide than the acetate treatments. No particular difference was observed for the disinfected samples and their corresponding not disinfected treatments. Again, the length of time carrots were held at the low temperature did

Figure 16: Accumulation of Carbon Dioxide in Prepackaged Carrots in Warm Storage



Top: Samples after 20 days at 33°F, plus 7 and 14 days at 80°F.
Center: Samples after 40 days " do "
Bottom: Samples after 80 days " do "

not affect the rate of carbon dioxide accumulation of the warm storage samples.

(3) Quality.

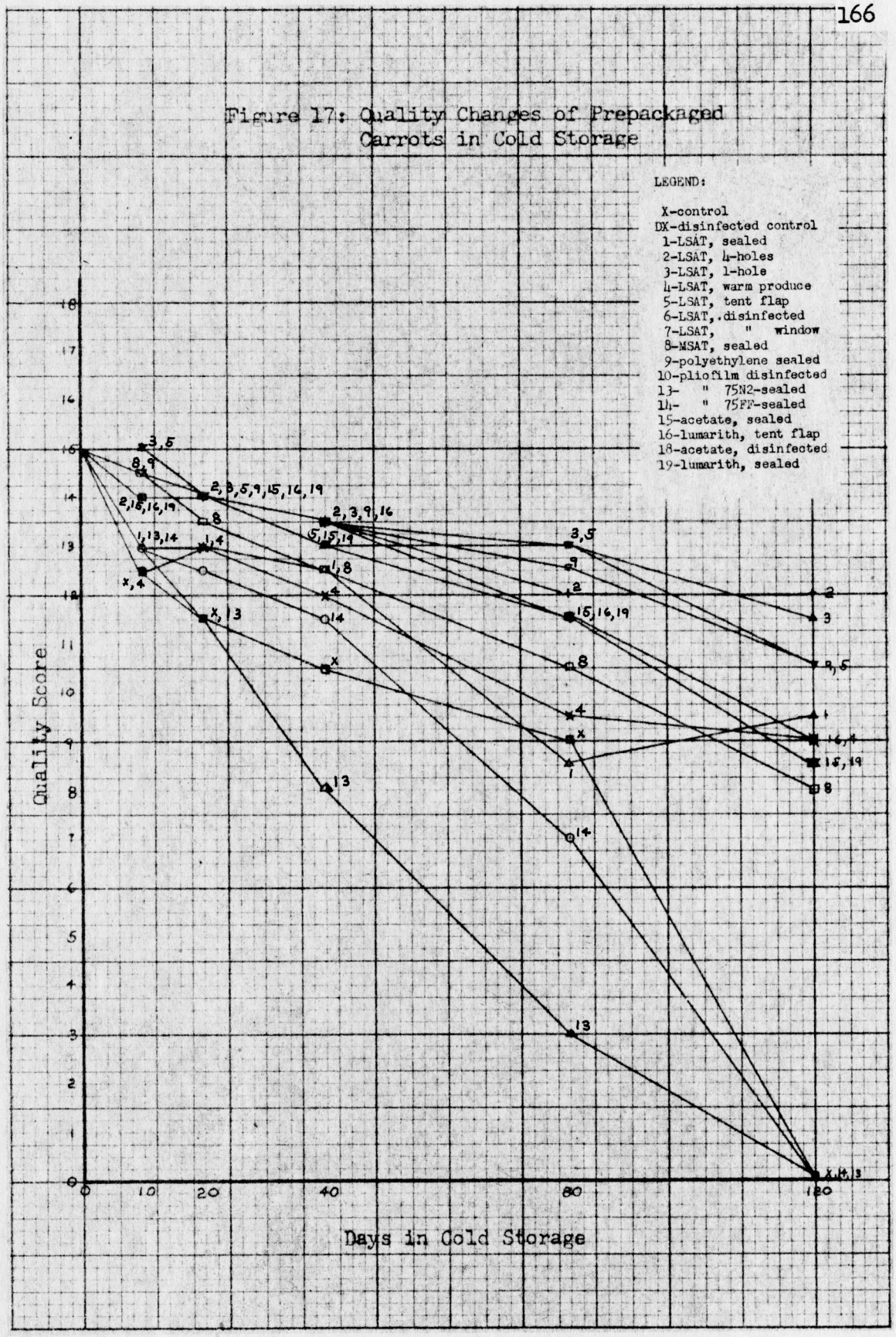
(a) Cold Storage.

The quality of prepackaged carrots showed less pronounced differences than tomatoes, especially after the longer periods of storage. At the same time the rate of change in quality was less than that observed for lettuce particularly for those treatments having the best quality within the series.

The treatments 13 and 14 showed a rapid loss in quality in both color and aroma and after 20 days a noticeable off flavor appeared. This was not true for the carrots in polyethylene film. The rapid decrease for the controls was due to the occurrence of mold and wilt. There was no difference between treatments 1 and 4 at any time while treatment 8 corresponded to them after 20 days with respect to odor and flavor. The acetates, not sealed MSAT and polyethylene films, caused less changes in carrot quality than other treatments and until 80 days of storage the differences between the treatments within this group were very small. But after the 80 days interval, the carrot quality in acetate wraps decreased due to wilting.

After 120 days the wilting for the acetate treatment was quite pronounced. Treatments 5 and 9 possessed slight off odor and rotted root tips which the punctured

Figure 17: Quality Changes of Prepackaged Carrots in Cold Storage

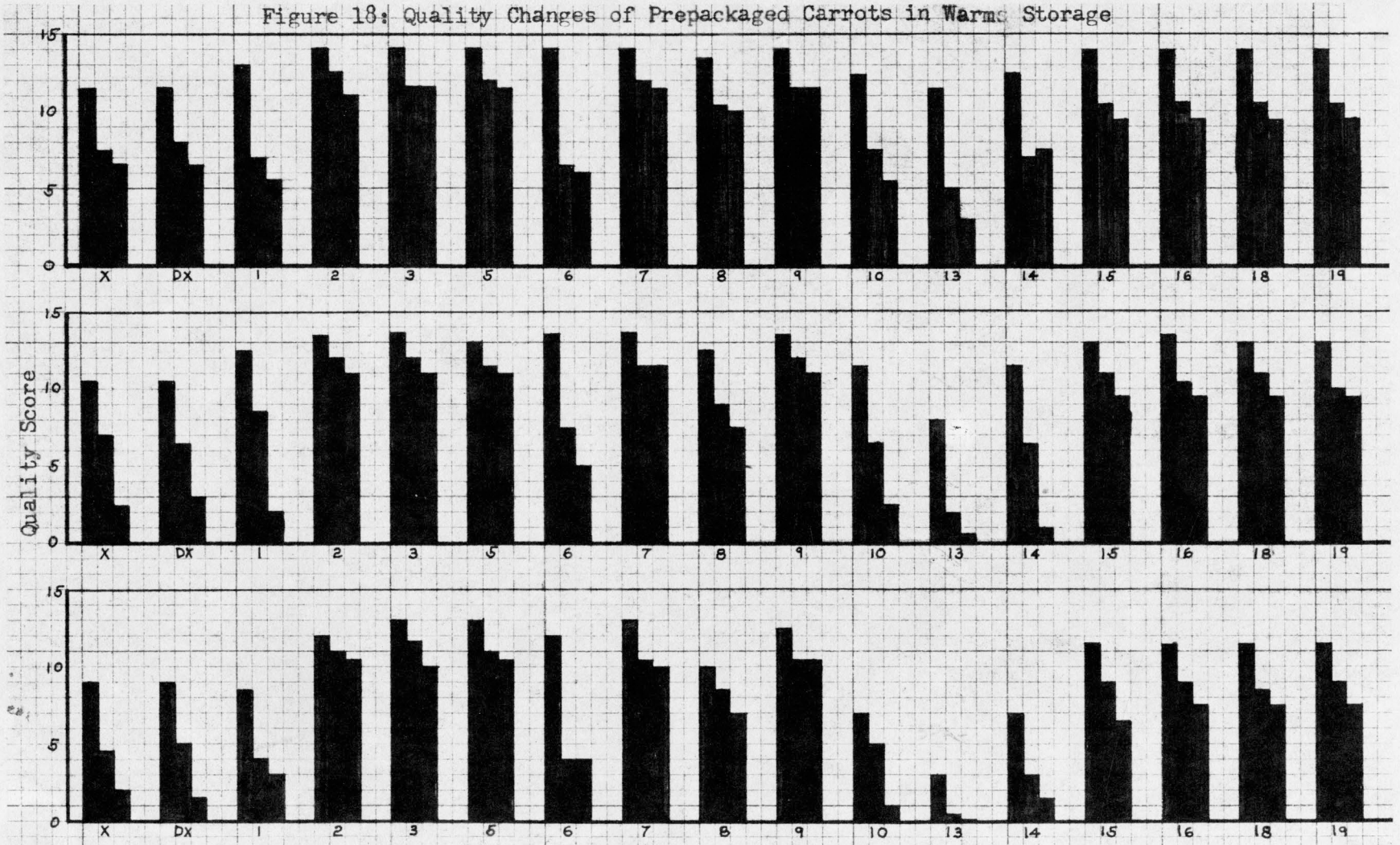


treatments did not have and consequently the latter received higher quality scores.

(b) Warm Storage.

Quality of carrots in warm storage was evaluated after seven and fourteen days. See figure 18. Again, as in other factors, the length of previous cold storage did not affect the rate of change of quality for carrots. After one week of warm storage both unwrapped treatments were wilted and were moldy. Treatments 1, 13, and 14 were injured in quality due to changes in color, odor, and flavor. Treatment 10 was also poor, which illustrated that the use of a disinfectant had not improved the keeping quality of these carrots. The fact that the window bag treatment was poor, as was also reported for the cold storage evaluation, suggested an experimental error since with all other vegetables it placed among the top ranking treatments for quality along with numbers 2, 3, 5, and 9. Slight rot on root tips and sprouting were factors which caused losses in quality for the last named treatments. Disinfection did not improve the quality of numbers 7 and 18. The decrease in flavor and wilting which occurred among the acetate treatments caused them to be lower rated than the punctured MSAT treatments.

Figure 18: Quality Changes of Prepackaged Carrots in Warm Storage



Top: Samples after 20 days at 33°F, plus 7 and 14 days at 80°F.
Center: Samples after 40 days
Bottom: Samples after 80 days

(4) Graph Relationships.

(a) Weight Losses versus Wilting.

A good correlation between the weight loss and wilting of carrots held in cold storage was found. Three distinct groups similar to those noted for lettuce could be observed on the weight loss graph which corresponded to "severe wilt," "slight" to "some wilt," and "no noticeable wilt" of the subjective evaluation.

In warm storage only two groups could be separated with assurance, namely no noticeable wilt and all others.

(b) Flavor Score versus Per Cent Carbon Dioxide: In the early periods of cold storage, carrots did not have the development of off flavors at the high levels of carbon dioxide. It was not until the 80 and 120 day intervals that pronounced off flavors were observed but only for treatments having greater than 12% CO_2 concentration. All other treatments had no off flavors at any time but the CO_2 accumulation was below 3%. Because no information was obtained with respect to flavor between the 3 and 12% CO_2 levels, a borderline could not be drawn with justification.

In general an inverse relationship between oxygen and carbon dioxide content was observed for each treatment. An exception to this statement is true for treatment 8 in which the low concentration of carbon dioxide as well as

low oxygen was found. The absence of sufficient oxygen is the probable explanation for the off flavor development despite the relatively small concentration of carbon dioxide. This phenomenon was also observed in the berry experiments for this particular film.

In warm storage the carbon dioxide present in all the treatments increased considerably. However, these increases were well tolerated by samples in high gas transmission films but those treatments having a high concentration at the time of submittal to the warm storage conditions soon became off flavored.

(c) Comparison of Stapled, Punctured and Completely-Sealed Bags of Identical Film Types: No difference for carrots in the stapled and sealed lumarith film was obtained. The same had been found true for tomatoes and lettuce.

Samples in the sealed MSAT held at 32° F had higher carbon dioxide values and were lower in quality than samples of treatments 2, 3, and 5. Weight losses were small for both groups. Treatment 1 averaged 0.5% loss and treatments 2, 3, 5, averaged 1.0% loss during 120 days of cold storage.

In warm storage carrots in the sealed and the unsealed low transmission films shows the same relationships as found in cold storage. Treatments 2, 3, and 5 were

better than treatment 1 in quality and lower in carbon dioxide. Among the unsealed group the four punctured bag was consistently lower in carbon dioxide but not consistently better in quality.

(d) Disinfection versus Quality.

i) Mold: Since the only samples of carrots to become moldy were the treated and untreated controls, no information was gained with regard to prepackaging plus disinfection. It is possible that the simple washing operation was sufficient to clean the carrots and that the controls were contaminated in storage.

ii) Rot: Carrots packed in the acetate film did not show significant rot, therefore, no comparison of the disinfectant treatment was possible.

Treatments 10 and 14 both showed severe rot but since the concentration of carbon dioxide was very high in both the rot was probably due to physiological damage and not bacterial decay.

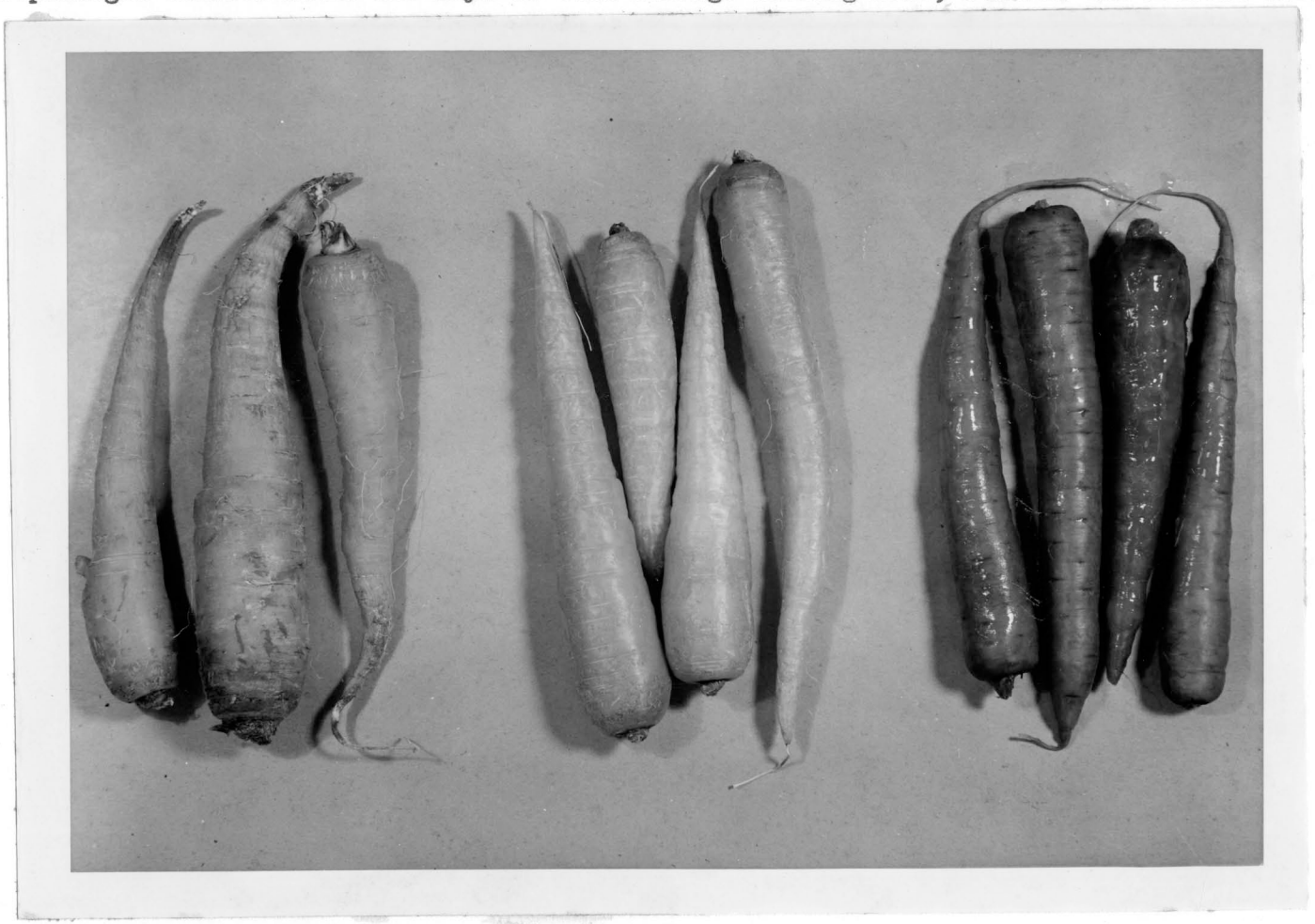
Although there was no apparent injury in treatments 3 and 7, there was no significant improvement in the condition of number 7. Most samples showed slight rot on the root tips.

iii) Odor: No improvement in the maintenance of natural aroma by disinfection was observed.

Illustrated in Plate XIII are samples of the best, control, and poorest treatments of carrots after 120 days

Plate XIII

Prepackaged Carrots After 120 Days of Cold Storage Showing Best, Control and Poorest Treatments



Control Best Poorest

of cold storage.

e. Celery.

(1) Transpiration.

(a) Cold Storage.

In figure 19 the weight losses shown for the unwrapped controls were significantly lower than those given for carrots and lettuce up to forty days of storage, and the losses in the celery controls were only slightly higher than the losses for the samples in acetate. After forty days a sharp rise for the controls made the weight losses about equal to those for the carrots and lettuce. Acetate treatments (15, 16, and 19) had consistently higher losses than the corresponding carrots and lettuce acetate treatments. Weight losses for samples in low transmission films were considerably lower, as usual. In general the per cent loss for each sample was about twice as much as that for carrots and lettuce which increased the differences between the samples. However, losses in low transmission wraps fell below 5% at all times.

(b) Warm Storage.

For celery the warm storage holding periods were the same as those for lettuce--that is, 20 + 2½ + 5, 40 + 2½ + 5, and 80 + 2½ + 5. Weight loss results as shown in figure 20 are similar to those obtained for lettuce. However, the unwrapped celery

Figure 19: Weight Changes in Prepackaged Celery in Cold Storage

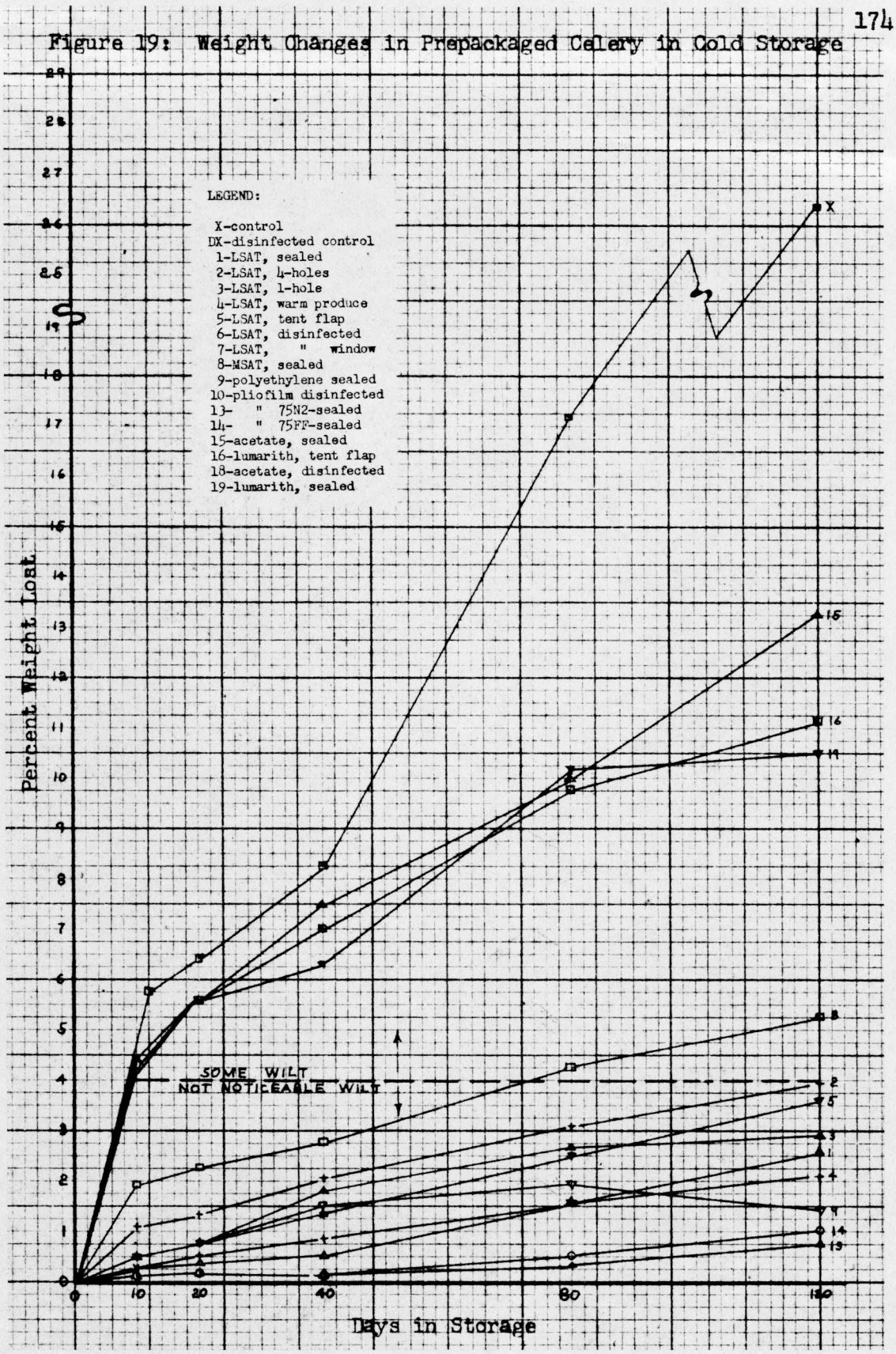
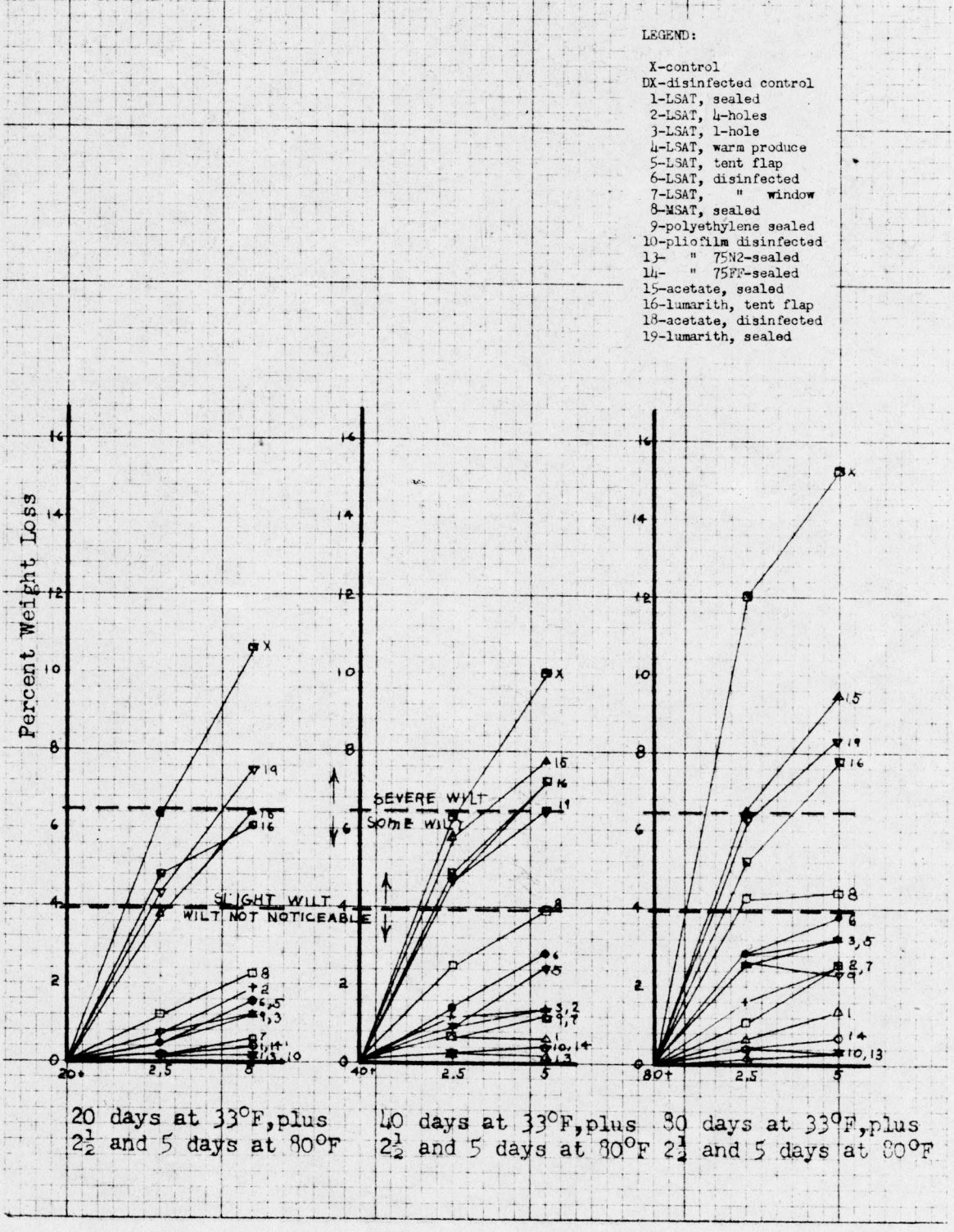


Figure 20: Weight Losses of Prepackaged Celery in Warm Storage



control samples lost less weight in both warm and cold temperature storage than did the lettuce controls. Again, as with other products, celery showed a trend toward greater weight changes in warm storage after longer holding at the cold temperature. This was true irrespective of film type.

(2) Respiration.

(a) Cold Storage.

Figure 21 illustrates the carbon dioxide content of prepackaged celery for 120 days of cold storage. Certain treatments show similar concentrations of the gas so that groupings were obtained like those described for lettuce. The low gas transmission treatment numbers 13, 14, 1, and 4 contained twice the quantity of carbon dioxide as the same treatments did for lettuce. The acetate treatments together with treatment 2 ranked equally with the lettuce samples while those for 3, 5, 8, and 9 showed slightly more gas accumulation, particularly with longer periods of storage.

(b) Warm Storage.

Carbon dioxide changes for celery in warm storage are given in figure 22. It will be observed that the relative carbon dioxide values in cold storage were greater than those for lettuce but in warm storage the opposite was true. At the same time there was little or no change in the positions of the various

Figure 21: Accumulation of Carbon Dioxide of Prepackaged Celery during Cold Storage

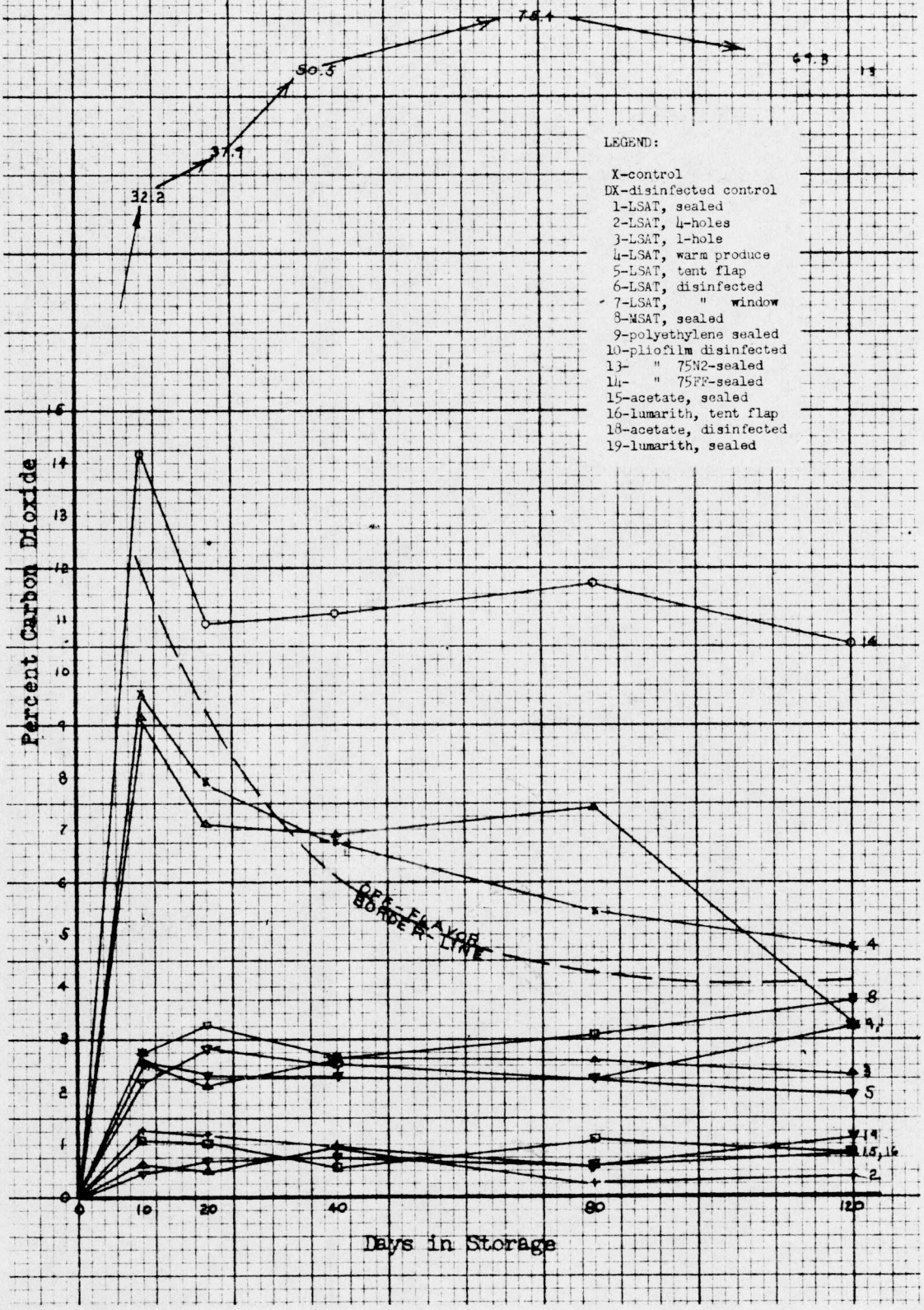
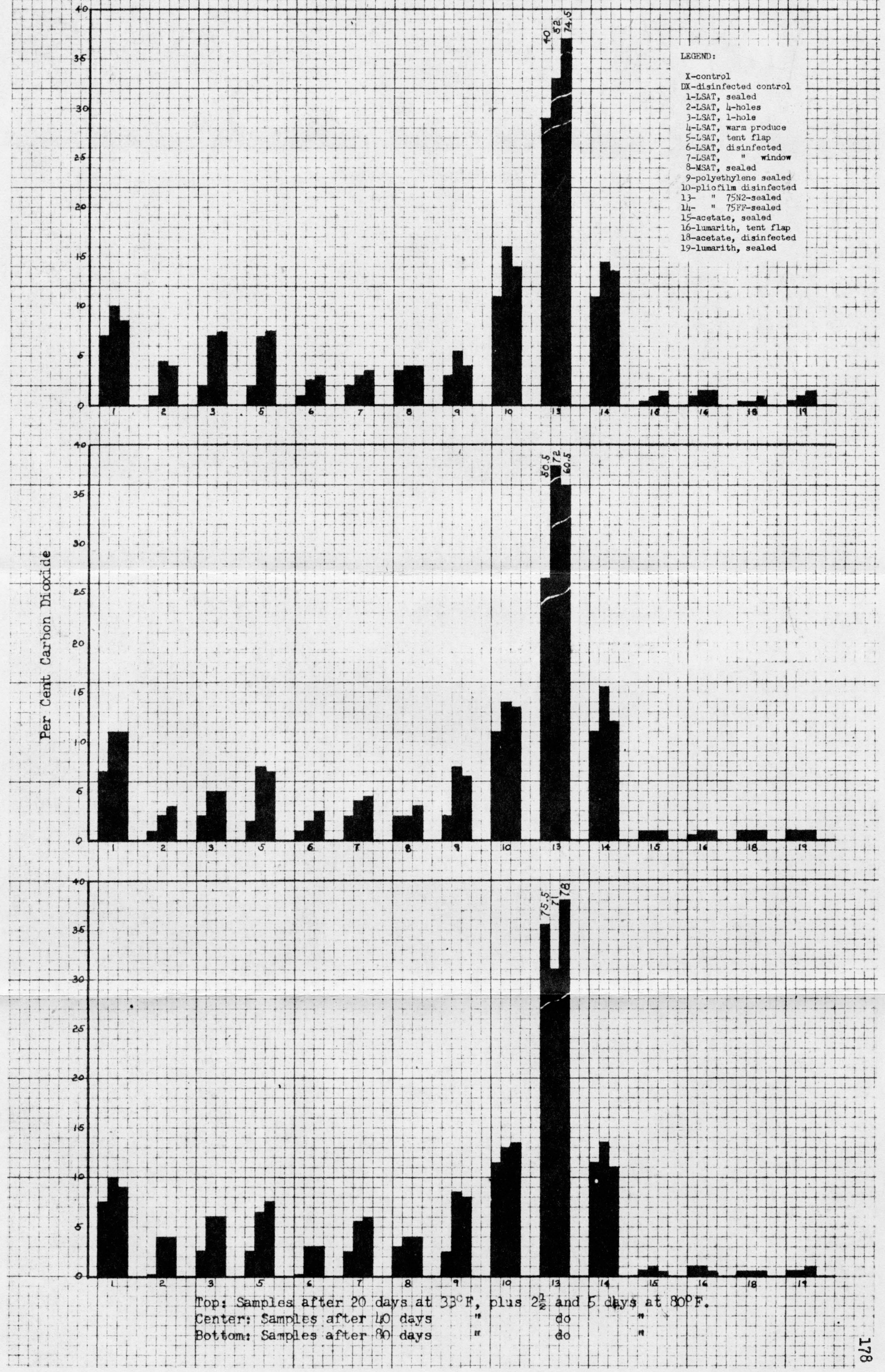


Figure 22: Accumulation of Carbon Dioxide in Prepackaged Celery in Warm Storage



Top: Samples after 20 days at 33°F, plus 2½ and 5 days at 80°F.
Center: Samples after 40 days " do "
Bottom: Samples after 80 days " do "

treatments with respect to each other.

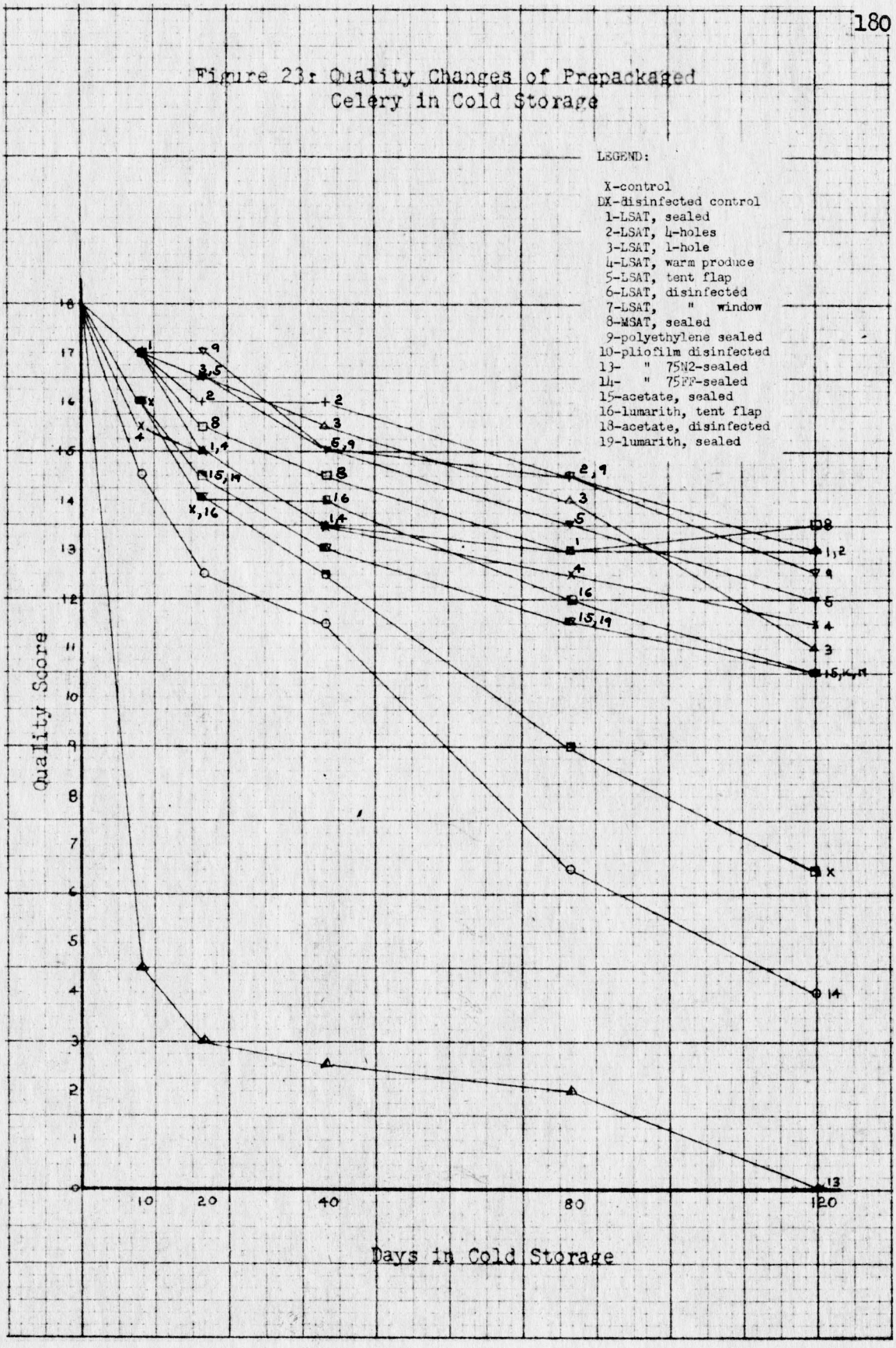
The low gas transmission treatments were the only ones which showed the familiar "hump" soon after being placed into warm storage. The four hole MSAT treatment resembled the tent flap MSAT more nearly than it did the acetate treatments. The latter retained less than 1.5% CO_2 in warm storage. Contrary to transpiration losses, there was no tendency for greater carbon dioxide accumulation in warm storage after the longer periods of cold storage.

(3) Quality.

(a) Cold Storage.

Figure 23 indicates the cold storage quality of celery. In general the decrease in quality with time proceeds at a rate similar to that observed for lettuce. The celery treatments received scores which placed them in the same relative positions as lettuce. Treatments 13 and 14 were exceptions to the preceding statement since they showed injury sooner and to a greater extent. The acetate packed treatments were all about equal in the extent of wilt and pithy stalks and in turn were very like the controls with regard to general quality. Usually treatments 2 and 9 received the highest quality scores except at the 120 day test period. At that time the results are somewhat confusing since the off flavor and off odors present in treatments 1 and 8 at previous storage

Figure 23: Quality Changes of Prepackaged Celery in Cold Storage



intervals were absent so that those treatments were equal in quality to numbers 2 and 9. Since the carbon dioxide content of treatment 1 was also low it is believed that possibly the seals of these particular packages were imperfect.

(b) Warm Storage.

The results of quality of warm storage celery as shown in figure 24 indicate that the rate of deterioration and relative rank of treatments were usually the same as those encountered for lettuce. Similarly, the causes of poor scores were alike for the two products.

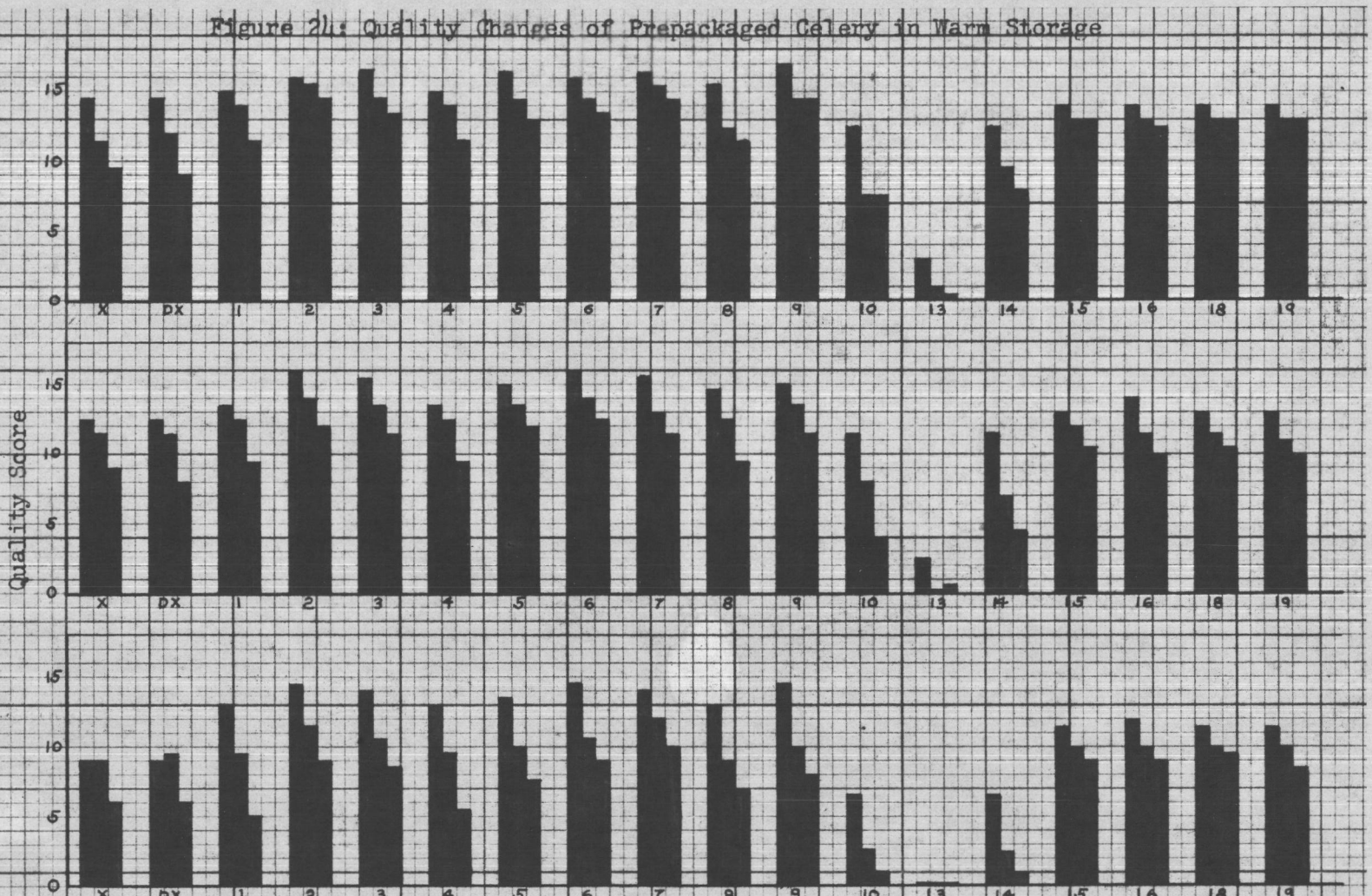
Contrary to results for carrots the effect of increased cold storage intervals was to increase the rate of quality breakdown. Also, the disinfection treatments 6 and 7 were more consistently among the top ranking samples than were the corresponding treatments 2 and 3.

(4) Graph Relationships.

(a) Weight Losses versus Wilting.

All samples of celery which were described as not wilted had weight losses of less than 4%. There was no classification of degrees of wilt possible since some treatments which were described as severely wilted had lost less weight than others described as "some" wilted.

Figure 24: Quality Changes of Prepackaged Celery in Warm Storage



Top: Samples after 20 days at 33°F, plus 2½ and 5 days at 80°F.
Center: Samples after 40 days
Bottom: Samples after 80 days

Figure 20 indicates that for warm storage it was possible to divide celery into the three typical wilt groups on the basis of per cent weight loss provided one observation at the 20 + 5 interval is disregarded.

(b) Flavor Score versus Per cent Carbon Dioxide: For celery, as for lettuce, good correlation between flavor and concentration of carbon dioxide was obtained. Again the negative slope of the curve together with the especially steep section for early cold storage time indicated that higher quantities of the gas were tolerated for short periods of time and that the change in tolerance was most rapid during the first days of storage. However, after 120 days of storage as much as 4% CO_2 could be present in the packages without a noticeable effect on the flavor of the celery. Again treatment 8 behaved differently as explained for the corresponding treatment in carrots.

At room temperature the flavor borderline followed treatment 1 very closely immediately after removal from cold storage, was slightly above 1 after $2\frac{1}{2}$ days and slightly below it after 5 days in warm storage. Those samples having low carbon dioxide values at the time of removal from cold storage did not develop off flavors despite the large amount of carbon dioxide formed. Low quality scores resulted from losses due to other factors.

(c) Comparison of Stapled, Punctured and Completely-Sealed Bags of Identical Film Types.

As was usual with previously discussed vegetables, celery was not noticeably different whether packed in sealed or stapled lumarith film.

Nor was there any apparent advantage between the sealed and unsealed MSAT film after 10 days in cold storage even though treatment 1 was higher than the others in carbon dioxide. However, after 20 days treatment 1 had an off odor and at 40 days an off flavor while treatments 2, 3, and 5 were about equally better than 1. Weight losses varied but without noticeable wilting among treatments 2, 3, and 5 and the level of carbon dioxide was consistently lower for treatment 2 so that after the longer storage periods the four puncture bag produced slightly better quality, than treatments 3 and 5.

At 80° F storage the relative changes in weight loss among the low transmission variations were similar to those described for cold storage. The sealed film always produced a poorer product while treatments 2, 3, and 5 were approximately equal in quality even though treatment 2 had less carbon dioxide accumulation.

(d) Disinfection versus Quality.

i) Mold: Results for celery were similar to those obtained for lettuce and carrots. That is, no mold developed on any of the prepackaged samples while the controls both became

Plate XIV Prepackaged Celery After 120 Days of Cold Storage, Left: Control - Center: Best - Right: Poorest

contaminated in storage.

ii) Rot: No pronounced difference was noticed between samples 15 and 18. Both exhibited slight decay on a few outer stalks which possibly may have been due to natural dying. Treatments 10 and 14 were badly rotted and also very high in carbon dioxide which may have caused the breakdown. Although some rot appeared in most of the samples of treatments 2, 3, 5, 6, and 7 it appeared that there was slightly less in the last two which were disinfected prior to packaging. But there was some doubt whether there was a real improvement in them.

iii) Odor: Treatments 15 and 18 both possessed natural aroma; treatments 10 and 14 had bad odor, while treatments 2, 3, 5, 6, and 7 showed some differences but the results were too erratic to be relied upon.

Illustrated in Plate XIV are samples of the best, control, and poorest treatments of celery after 120 days of cold storage.

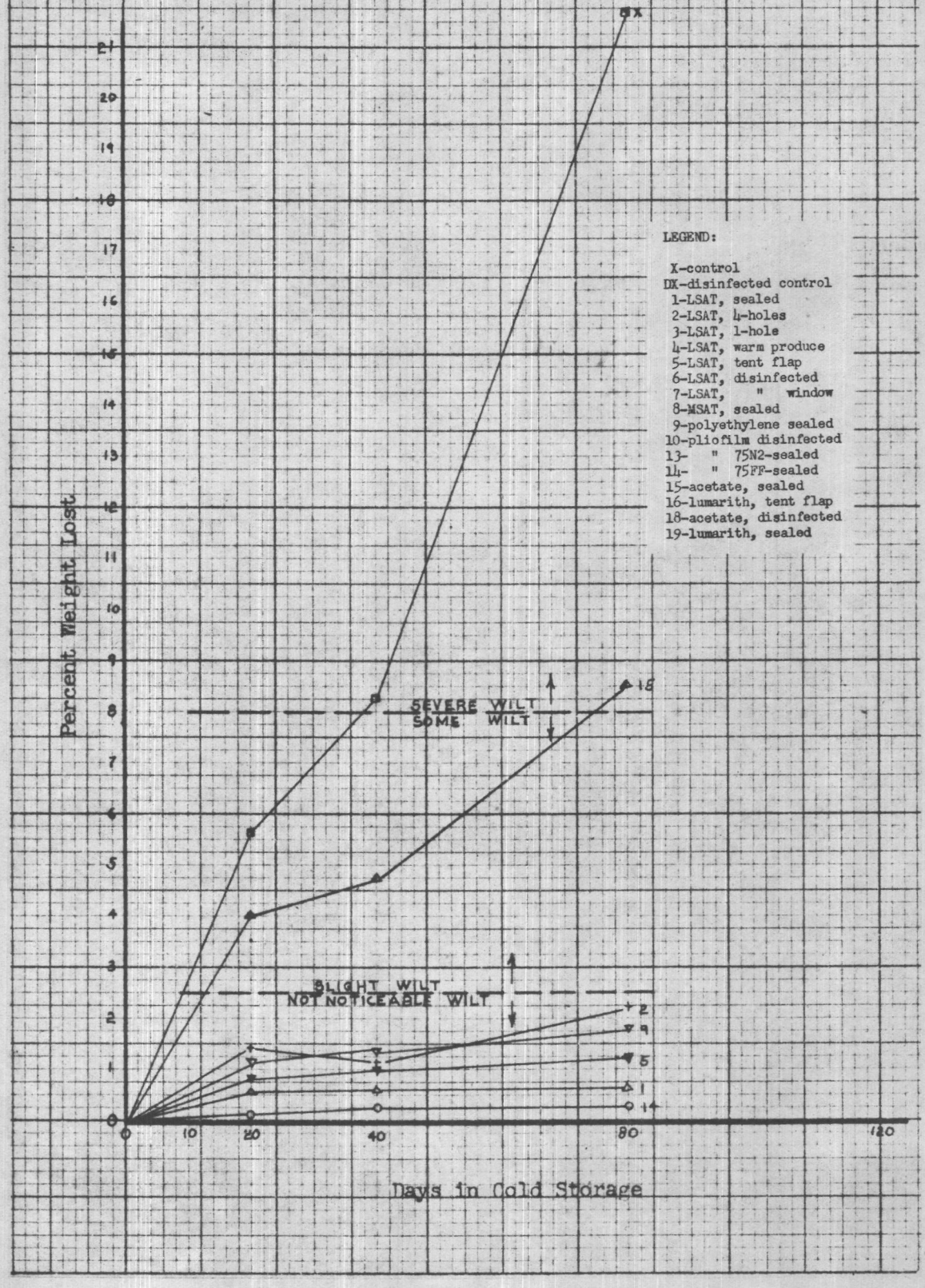
f. Cauliflower.

(1) Transpiration.

(a) Cold Storage.

Since a smaller number of films was tested and fewer storage periods were used, the general appearance of the graphs was somewhat altered from those previously discussed.

Figure 25: Weight Changes of Prepackaged Cauliflower in Cold Storage



The unwrapped and acetate wrapped samples showed weight losses (figure 25) similar to those for celery. All other treatments showed losses typical for low M.V.T. wraps resembling those obtained for lettuce, tomatoes, and carrots.

(b) Warm Storage.

Results of transmission losses of cauliflower are reported in figure 26 for 2 and 4 days in warm storage. Since analyses for warm storage changes were made only after the 40 day cold storage period, it was not possible to determine the effect of cold storage time on warm storage changes. But it was observed that the changes which were charted followed a pattern that was similar to that obtained for celery with the exception that the control and treatment 15 were subject to somewhat greater losses.

Warm Storage Changes of Prepackaged Cauliflower
after 40 days at 33°F, plus 2 and 4 days at 80°F

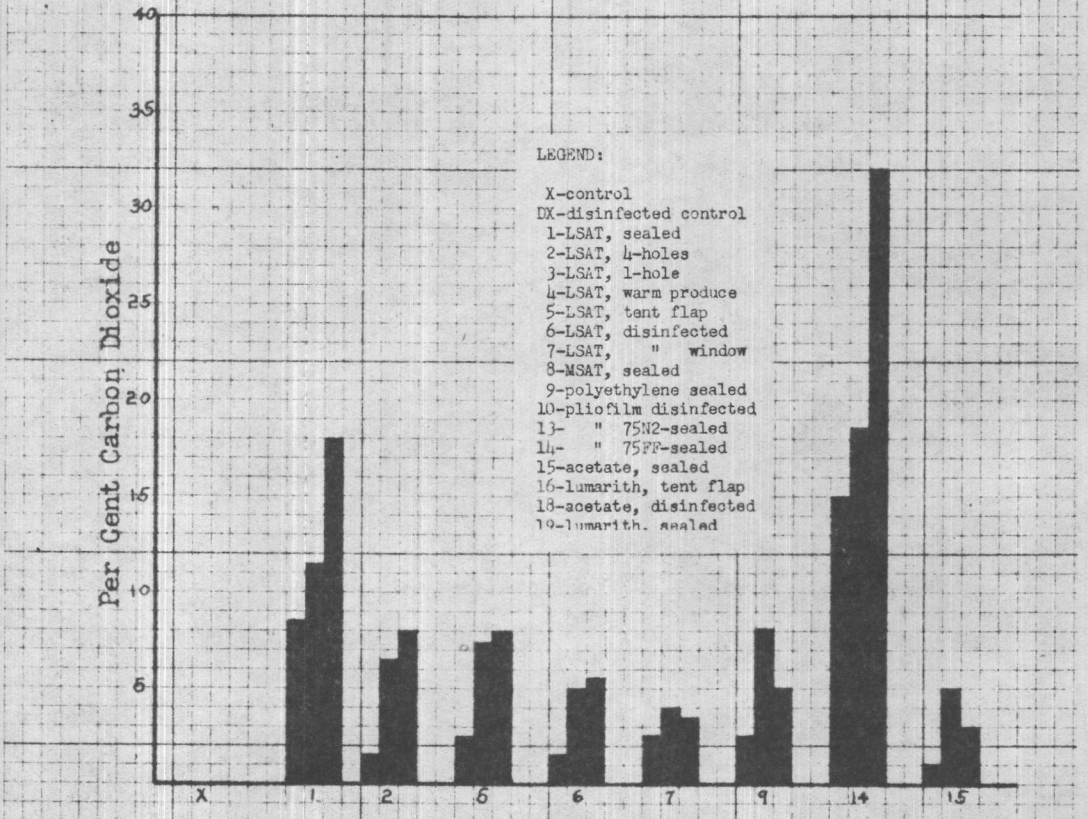


Figure 28: Carbon Dioxide Accumulation

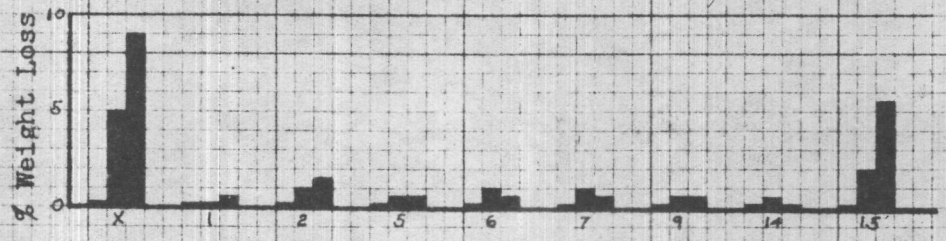


Figure 26: Weight Losses

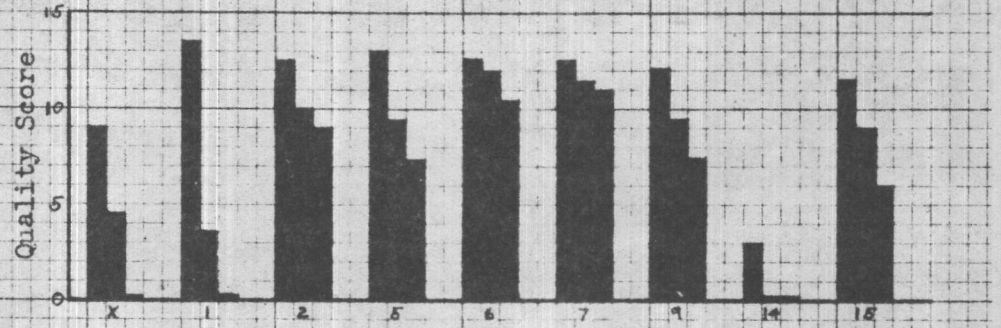


Figure 30: Quality Scores

(2) Respiration.

(a) Cold Storage.

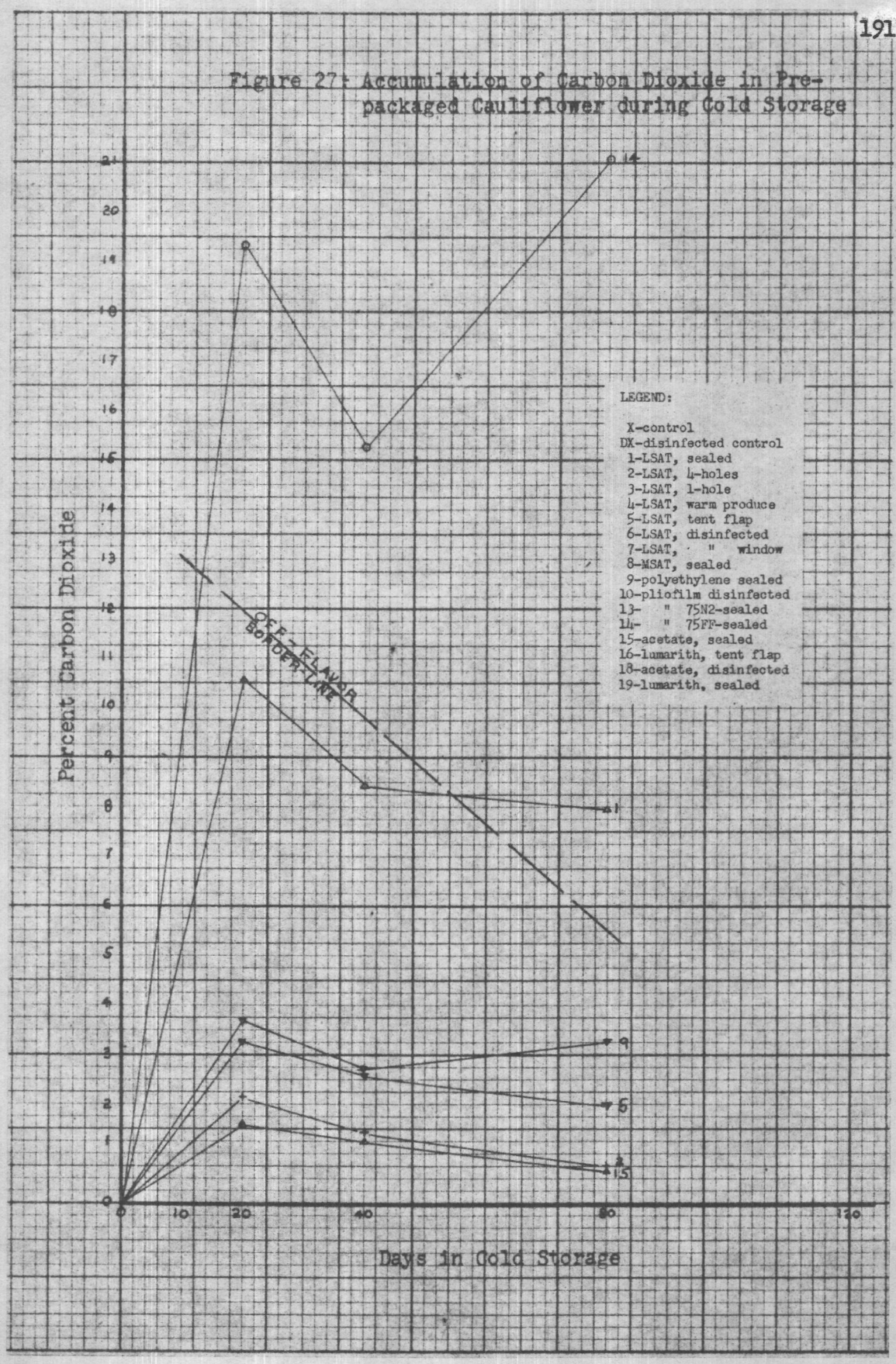
In figure 27 are reported the concentrations of carbon dioxide for cauliflower which had been stored at 32-33° F. It can be observed that the level of carbon dioxide present in the low gas transmission samples is lower for this vegetable than for carrots and higher than for celery. The high gas transmission films allowed gas accumulations similar to those for celery; treatments 5 and 9 had approximately 3% CO_2 while treatments 2 and 15 contained about 1% CO_2. There was no important increase in concentration for any treatment after 20 days of cold storage.

(b) Warm Storage.

Carbon dioxide values for low gas transmission treatments of cauliflower were similar to those for lettuce. Both products exhibited a steady rise in concentration during warm storage and both products showed "humps" or leveling off for some treatments other than the low transmission type.

More than usual carbon dioxide was found in the acetate treatments though it should be recognized that this statement was based on two observations only. Positive indications of benefit derived from disinfection prior to packaging were obtained after four days of warm storage

Figure 27. Accumulation of Carbon Dioxide in Pre-packaged Cauliflower during Cold Storage



where the level of carbon dioxide was lower than for corresponding treatments without disinfection.

Acetate films allowed greater diffusion of the gas than the MSAT films with four punctures. The latter behaved more nearly like packages which had been stapled and polyethylene which had been sealed. Treatment 7 showed the lowest accumulation of gas among the MSAT films.

(3) Quality.

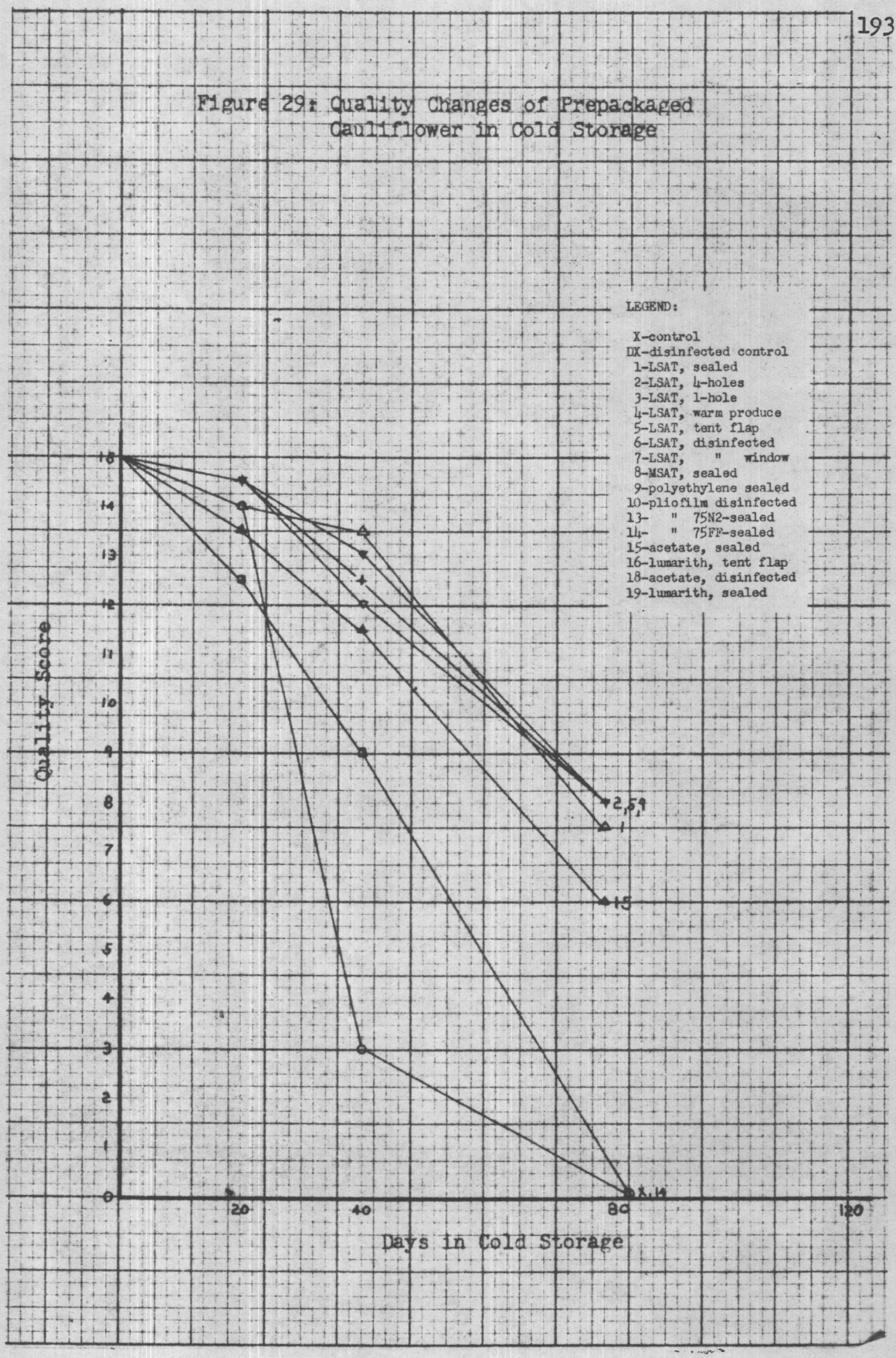
(a) Cold Storage.

Except for treatments 14 and controls the quality losses in cauliflower were very gradual for the first forty days of cold storage. See figure 29. The occurrence of wilt and loss of good color in the controls and the development of off flavor and odor in treatment 14 are factors which caused deterioration during the forty day storage interval. After the 40 day period, all samples lost quality rapidly. At the 80 day interval, treatment 1 which was best at 40 days due to good color and turgidity still possessed good color but was off flavored. The same general trend was observed for treatments 2, 5, and 9. Although the color was not as well rated and off odors were present, there was no off flavor noticed.

(b) Warm Storage.

The quality of cauliflower was observed only at the 40 + 2 + 4 intervals. See figure 30.

Figure 29: Quality Changes of Prepackaged Cauliflower in Cold Storage



The unwrapped control and also treatments 1 and 14 were unsaleable after two days in warm storage. The controls were poor in color, shriveled and molded while the samples of 1 and 14 had off flavor and odor. The acetate treatment 15 had a condition very similar to the controls but was less shriveled and less molded. Treatments 2, 5, and 9 possessed better color but had slight off odors while treatments 6 and 7 had good aroma and therefore consistently received better quality scores.

(4) Graph Relationships.

(a) Weight Losses versus Wilting.

Cauliflower treatments held in cold storage were easily separated into three groups on the weight chart (figure 25) with respect to extent of wilt. In warm storage the same was true but the exact position of the borderline could not be located since the number of points were insufficient to indicate its probable position.

(b) Flavor Score versus Per Cent Carbon Dioxide: A straight line denoting the border for flavor change was drawn for cauliflower in cold storage. This line like those described for other vegetables shows that greater carbon dioxide tolerance is present during the shorter storage periods. For example, more than 10% CO_2 produced no off flavored cauliflower after 20 days in cold storage but 9% CO_2 at the 80 day interval was accompanied by off flavor.

The same relationship as that described for other vegetables was true for this one in warm storage. With low initial quantities of carbon dioxide subsequent increases were well tolerated but for treatments such as 1 and 14 off flavors appeared in warm storage.

(c) Comparison of Stapled, Punctured and Completely-Sealed Bags of Identical Film Types: No comparison of high transmission seals was possible since treatment 19 was not included in the study on cauliflower.

For the low transmission group the single puncture variable, treatment 3, was omitted also. In the early cold storage periods the quality of treatments 1, 2, and 5 was about equal although the carbon dioxide content was not. The quality of all three treatments was rather high due to retention of good color especially in treatment 1 and no apparent wilt despite the fact that weight losses of 2 and 5 were greater than the sealed treatment losses.

After 40 days in cold storage, treatment 1 was best in color and flavor. Treatments 2 and 5 were poorer in color. It is believed that the higher concentration of carbon dioxide in the sealed variation was responsible for the retention of the white color in the product.

After 80 days cold storage, all samples had an off odor and treatment 1 had a slightly off flavor but good color.

In warm storage treatment 1 dropped in quality rapidly. It developed off odor and off flavor. Treatments 2 and 5 had fairly good color while 5 developed more off odor than 2. The carbon dioxide accumulation in treatment 1 steadily increased through the warm storage period while for treatments 2 and 5, the typical maximum point was not obtained at the 40 + 2 period. Weight losses for the sealed and the tent flap samples were less than for the four puncture units though all were below the stage for noticeable wilt.

(d) Disinfection versus Quality.

i) Mold: Only treatments 6 and 7 of the disinfection group were studied in the cauliflower experiment. However, since treatment 15 and the controls were moldy while treatments 2, 5, 6, and 7 were without mold, no conclusions were drawn.

ii) Rot: Definitely less rot was present in treatments 6 and 7 than in treatments 2 and 5 thus pointing to a possible beneficial effect of disinfection toward control of rot in cauliflower.

iii) Odor: Results very similar to those mentioned under rot were obtained for odor. This may mean that odor is an indirect measurement of the effectiveness of disinfection.

Illustrated in Plate XV are samples of the best, control, and worst treatments of prepackaged cauliflower after 40 days of cold storage.

Prepackaged Cauliflower After 10 Days of Cold Storage
Showing Best, Control and Poorest Treatments

Top Left = Best Treatment
Top Right = Poorest Treatment
Bottom Left = Control

g. Chopped Salad Mix.

(1) Transpiration.

(a) Cold Storage.

An inspection of figure 31 will show that rapid weight changes were obtained for the unwrapped controls and acetate wrapped samples of salad mix. These losses are greater than for all products except spinach. All other treatments produced losses typical for low M.V.T. wraps, being less than 4% after all storage periods. It is interesting to note that the greatest moisture loss occurred during the first twenty day storage interval after which time only small, if any, losses resulted.

(b) Warm Storage.

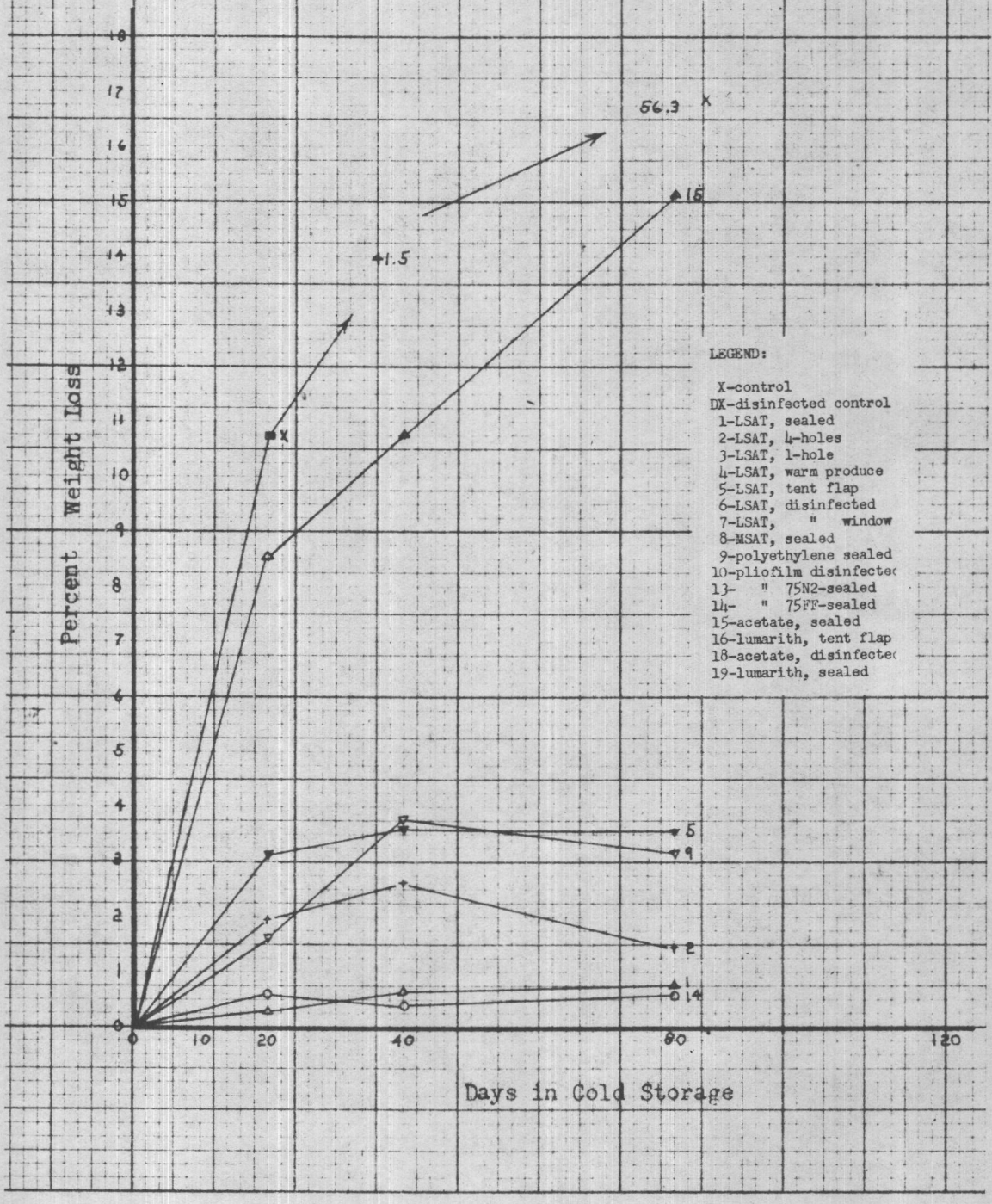
Transpiration losses for chopped salad mix during warm storage are given after one cold storage interval only. These are shown in figure 32. Severe losses in the controls were obtained which were five times as great in warm storage as those produced at the refrigerated temperature. The acetate film, treatment 15, prevented extensive losses as found in the control while all other treatments reduced losses to below 1%.

(2) Respiration.

(a) Cold Storage.

In figure 33 the carbon dioxide values for chopped salad mix in cold storage are given. The

Figure 31: Weight Changes of Prepackaged Salad Mix during Cold Storage



Warm Storage Changes of Prepackaged Salad Mix
after 40 days at 33°F, plus 1 and 2 days at 80°F

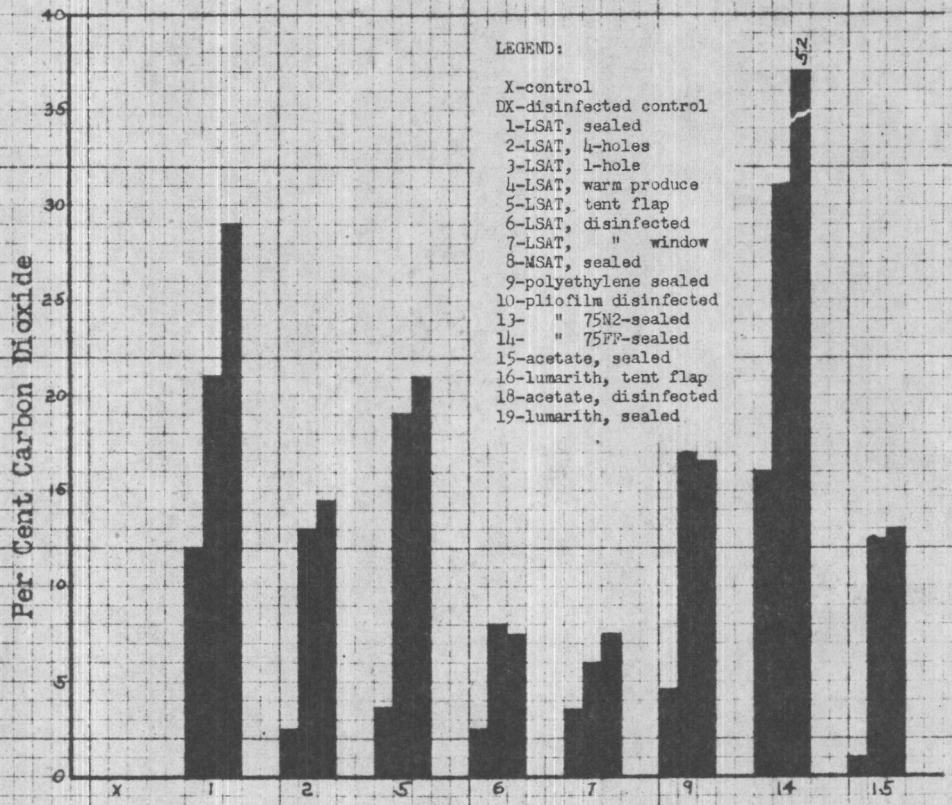


Figure 34: Carbon Dioxide Accumulation

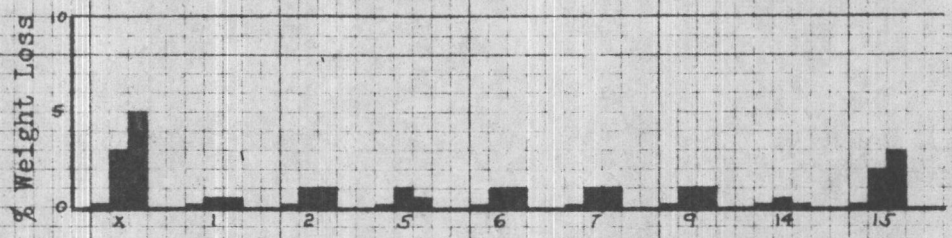


Figure 32: Weight Losses

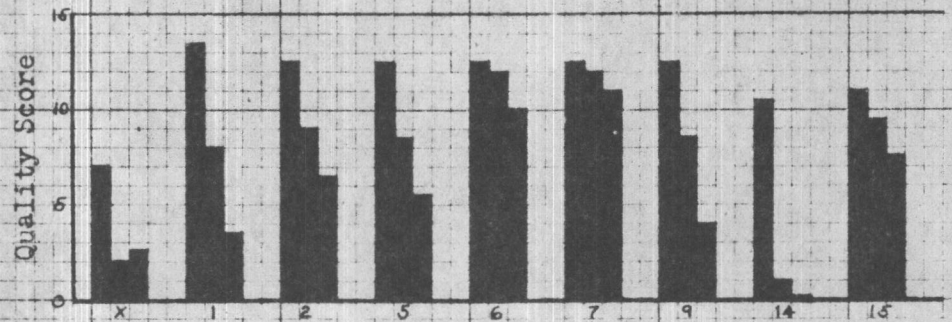


Figure 36: Quality Scores

low gas transmission treatments produced results like those reported for cauliflower while the high transmission samples showed accumulations of carbon dioxide greater than for any other vegetable.

(b) Warm Storage.

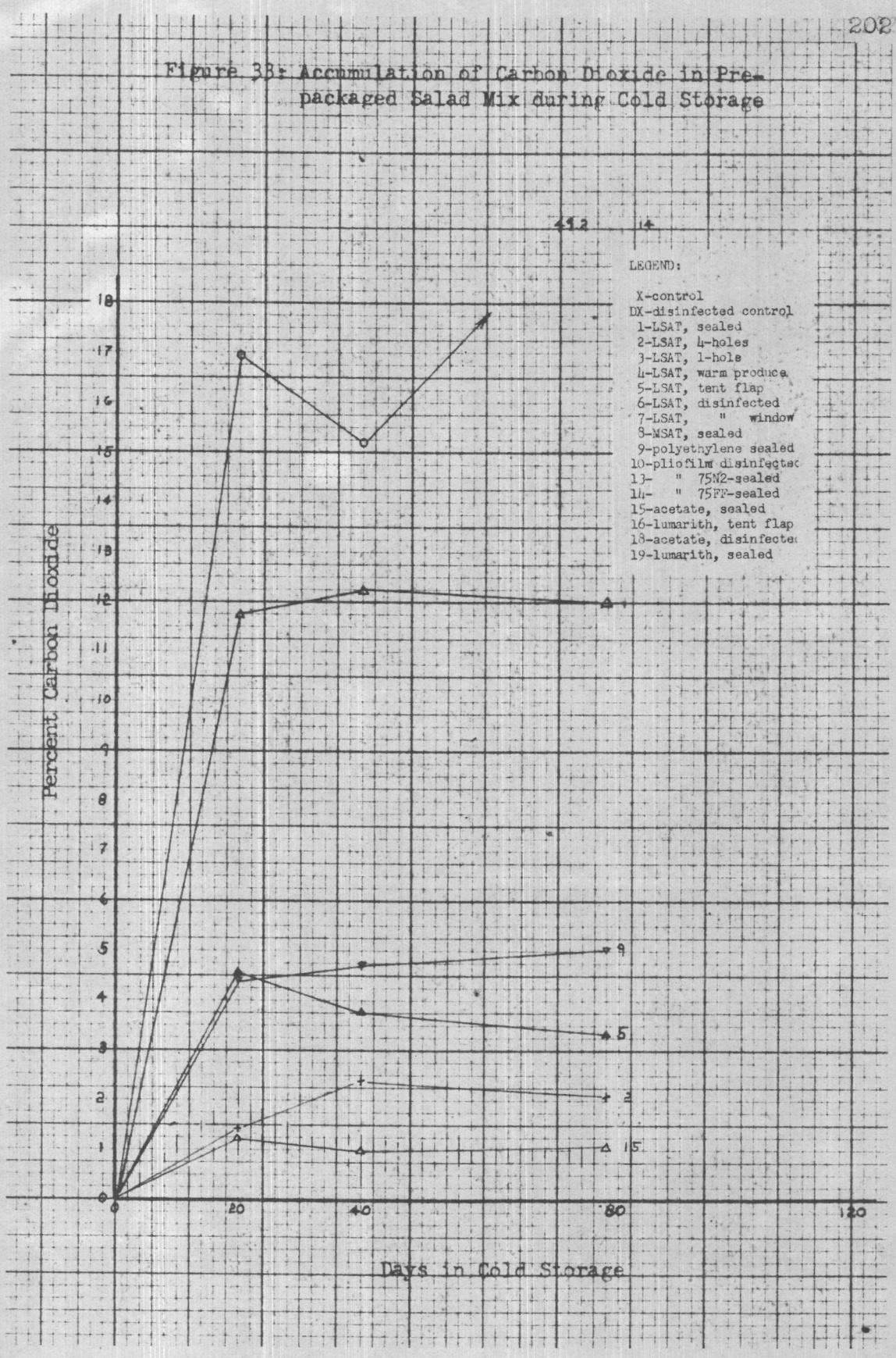
After one and two days of warm storage, analyses for carbon dioxide in chopped salad mix were made. Values obtained are reported in figure 34. The salad mix showed low tolerance to warm storage and rapid increases of carbon dioxide within the packages after one day of storage. These increases were even greater than those observed for tomatoes under the same conditions. Even the acetate treatments contained relatively large amounts of carbon dioxide. It is believed that disinfection decreased the tendency for carbon dioxide accumulation found in treatments 6 and 7. It is also believed that the continued rise of carbon dioxide in treatment 14 was caused by decomposition of the product rather than an increased rate of respiration while the leveling off of the curve for other treatments represented a probable decreased rate of respiration caused by the accumulation of carbon dioxide.

(3) Quality.

(a) Cold Storage.

Quality scores for chopped salad mix were similar to those reported for cauliflower. The

Figure 38: Accumulation of Carbon Dioxide in Pre-packaged Salad Mix during Cold Storage



MSAT film treatment 1 was best quality until at 40 days an off odor developed. Treatment 14 had equally good color, developed poor aroma after 40 days, and poor flavor after 80 days of storage. But the controls and acetate treatments soon developed a dark appearance and were shriveled at the first storage period.

(b) Warm Storage.

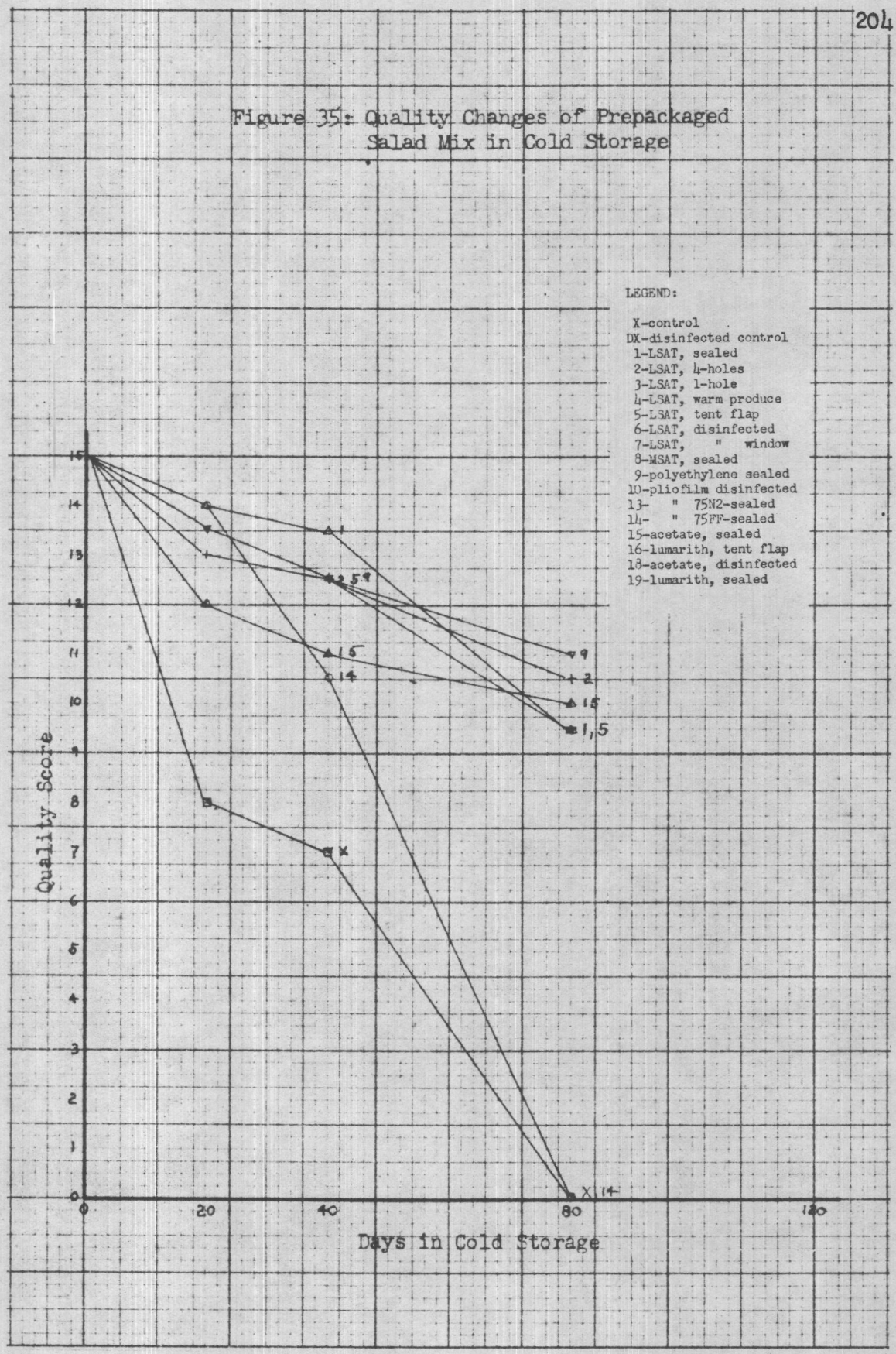
Chopped salad mix was evaluated for quality after forty days in cold storage coupled with one and two days at 80° F. See figure 36. The control treatment became very dry and brown. Treatment 14 developed pronounced off flavors and odors. Treatments 1, 2, 5, and 9 possessed fair to good color but had slight off odors after one day and slight off flavor as well as off odor after two days in warm storage. The acetate treatment 15 had poor color and became progressively drier with time. Treatments 6 and 7 were rated highest as they were for cauliflower. Their color was fair and no off odor or flavor was present.

(4) Graph Relationships.

(a) Weight Losses versus Wilting.

For chopped salad mix in cold storage only the terms severe wilt and no wilt could be separated on the basis of sample weight changes. This distinction was easily made although it was not shown graphically since the limited number of observations made

Figure 35: Quality Changes of Prepackaged Salad Mix in Cold Storage



it impossible to locate the borderline with assurance.

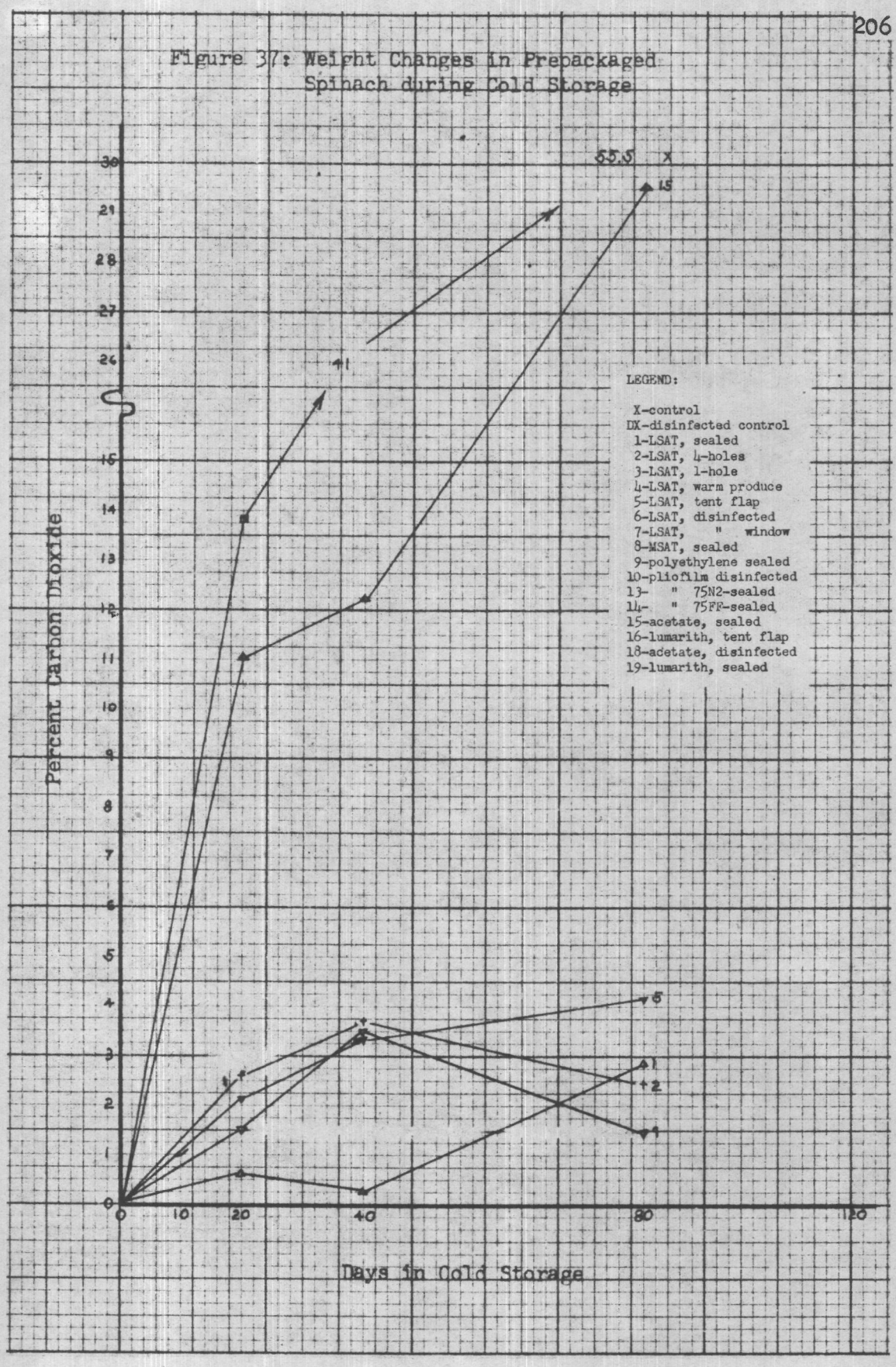
On the other hand in warm storage the three usual divisions of degrees of wilting were distinguishable in terms of weight losses.

(b) Flavor Score versus Per Cent Carbon Dioxide: Too few observations were made to draw a line of demarcation for flavor of chopped salad mix on the carbon dioxide graph. However, the mix did not have off flavors accompanying the relatively high gas figures. Treatment 14 was the only treatment having an off flavor and that was noticed only at the 80 day cold storage interval.

The carbon dioxide increases that accompanied one day of warm storage were also well tolerated except for treatment 14. Other factors were responsible for quality losses. Better quality scores were obtained for treatments 6 and 7 which had the lowest carbon dioxide values and no off flavor. After two days at 80° F carbon dioxide tolerance by the samples was lowered so that all except 6 and 7 had slight off flavors. Again the disinfection treatments 6 and 7 showed less of the gas than any other treatment.

(c) Comparison of Stapled, Punctured and Completely-Sealed Bags of Identical Film Types: Only variations in the MSAT film were compared. Results were similar to those obtained for cauliflower. It is believed

Figure 37: Weight Changes in Prepackaged Spinach during Cold Storage



the accumulated carbon dioxide in treatment 1 kept the product a better color until forty days of cold storage. The quality of the sealed product was slightly better than treatments 2 and 5 after 20 days and definitely better after 40 days. Likewise the carbon dioxide values for 1 were higher than 5 which were higher than 2 after 20 and 40 days in cold storage. At the 80 day evaluation it was learned that all samples had poor quality; treatments 1 and 5 had off odors while treatment 2 was slightly better in odor though poorer in color.

In warm storage the quality after one day was poor for all samples.

(d) Disinfection versus Quality.

i) Mold: There was no mold development on any samples of chopped salad mix.

ii) Rot: Treatments 6 and 7 showed slightly less, if any, rot than the corresponding not disinfected treatments 2 and 5.

iii) Odor: Again, as described for cauliflower, odor was slightly better for the disinfected treatments than for treatments 2 and 5.

h. Spinach.

(1) Transpiration.

(a) Cold Storage.

Moisture losses for spinach (figure 37) were quite similar to those obtained for chopped

Warm Storage Changes of Prepackaged Spinach
after 40 days at 33°F, plus 1 and 2 days at 80°F

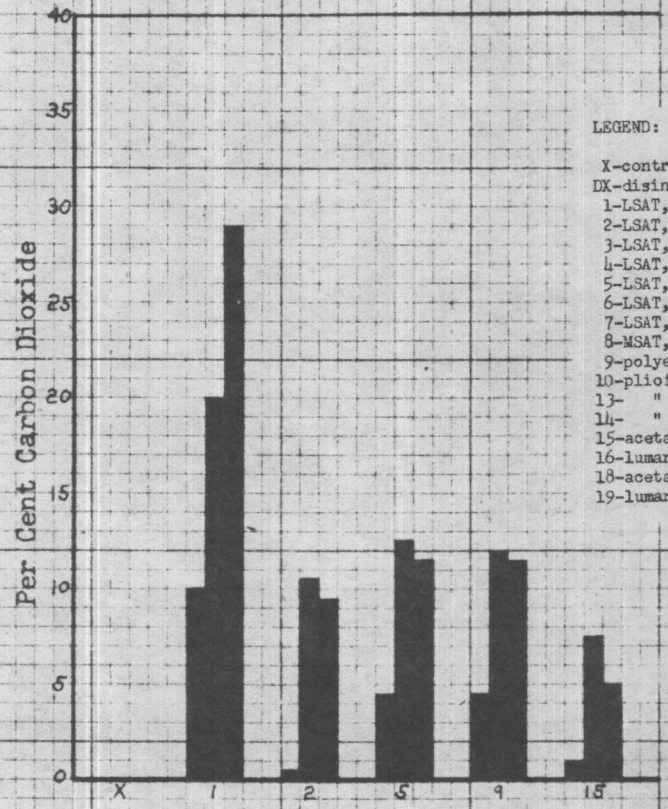


Figure 40: Carbon Dioxide Accumulation

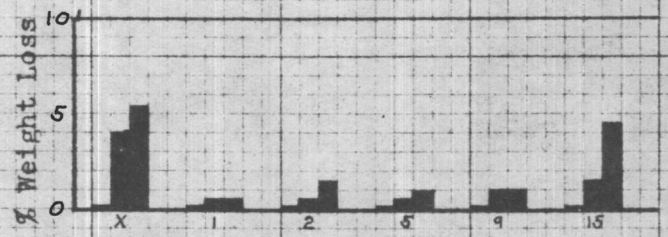


Figure 38: Weight Losses

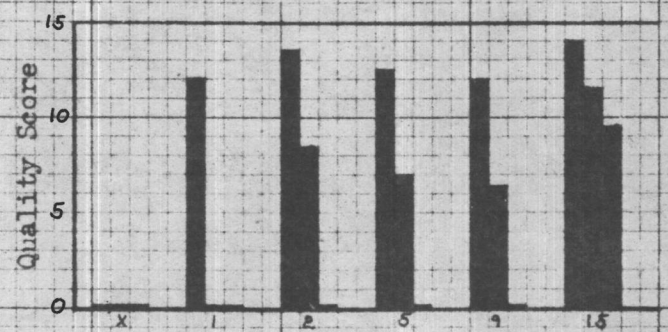


Figure 42: Quality Scores

salad mix. A difference was found for the controls and high transmission wrapped spinach which showed greater losses than the corresponding salad mix samples.

(b) Warm Storage.

Transmission data for spinach in warm storage were obtained from samples held at 33° F for 40 days. It was found that average weight losses for low M.V.T. films incurred after two days at room temperature were approximately equal to those lost during 20 days in cold storage. Spinach weight losses after two days of warm storage were slightly less than tomato weight losses for 20 + 2 days and about the same as those for celery after 40 + 2.5 days of storage.

(2) Respiration.

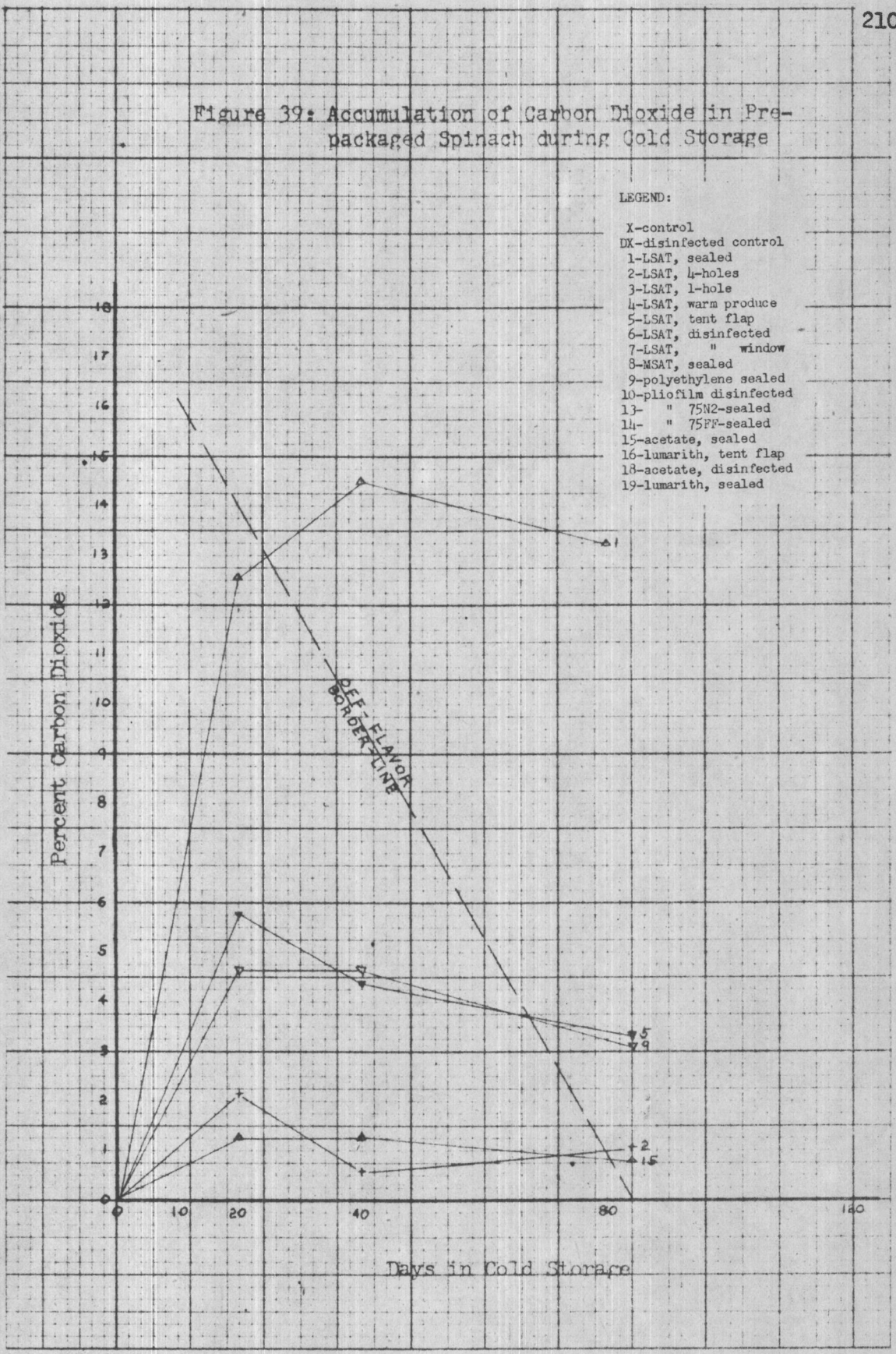
(a) Cold Storage.

Carbon dioxide accumulation, figure 39, for treatment 1 was very high and similar to that produced by carrots treatment 1. Somewhat higher values than usual were observed for the 20 day cold storage period for treatments 5 and 9 and also numbers 15 and 2. However, following the 20 day interval the concentration dropped to the levels generally recorded for those treatments.

(b) Warm Storage.

Figure 40 shows the warm storage respiration values for prepackaged spinach. Carbon dioxide figures are similar to those found for chopped salad

Figure 39: Accumulation of Carbon Dioxide in Pre-packaged Spinach during Cold Storage



with respect to both rate of accumulation and relative position of the treatments to one another. No disinfection treatments were included in the study on spinach. The characteristic "humps" were present for all treatments, even the high gas transmission acetates.

(3) Quality.

(a) Cold Storage.

Prepacked spinach held at 32° F for twenty days showed that treatments 15 and 2 were better than other samples. The control samples were severely wilted while the treatments 5, 9, and 1 were poor in color and possessed off odors. After the 40 day storage interval all samples had decreased in quality considerably while at 80 days all were unacceptable.

(b) Warm Storage.

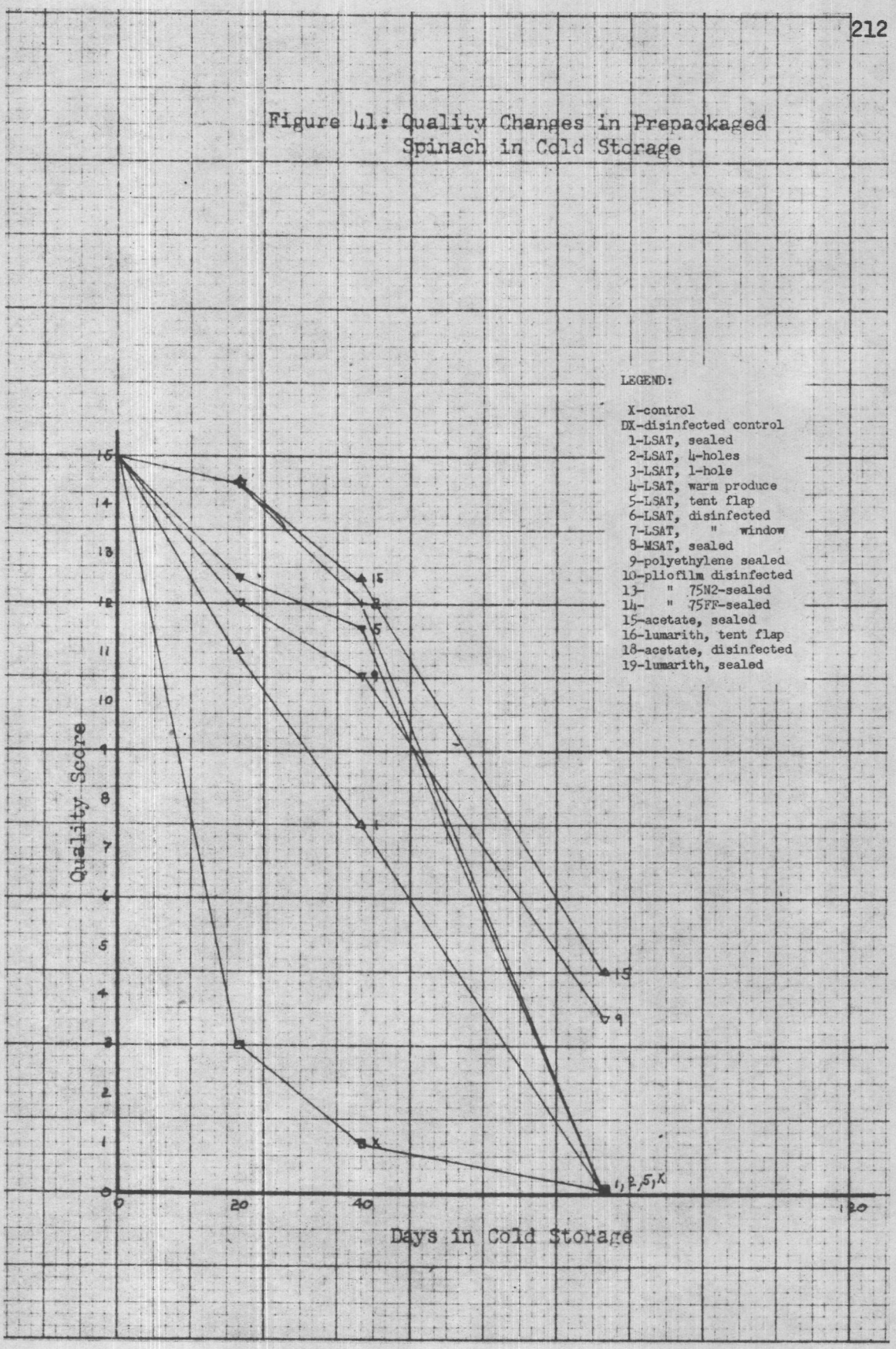
In warm storage the quality of spinach decreased rapidly. See figure 42. No results were available for the effect of disinfection since that treatment was not included in this series. Treatment 15 was best quality but even that was slightly dry and had some yellow leaves after the first day of warm storage. It became worse due to off odor by the second day. All other treatments were quite poor in color, rot, and flavor.

(4) Graph Relationships.

(a) Weight Losses versus Wilting:

The results of weight loss in

Figure 41: Quality Changes in Prepackaged Spinach in Cold Storage



spinach as compared to wilting were very like those reported for chopped salad. For cold storage one division into two groups was possible while for warm storage two divisions into three groups existed.

Good correlation of the two factors was noted but again no borderlines were drawn because of too few points.

(b) Flavor Score versus Per Cent Carbon Dioxide: Spinach did not show off flavor development with high carbon dioxide accumulations for short storage times but for longer storage periods the opposite was true. As an illustration, at 20 days and 12.5% CO_2 there was no off flavor while at 80 days and less than 1% CO_2 the spinach was inedible. Unquestionably the presence of rot in the produce also affected the flavor score after 80 days storage.

In warm storage only treatment 15 remained with acceptable flavor after one day. All others either increased the accumulation at a greater rate (treatment 2), or had a higher concentration to begin with (treatments 5 and 9), or both (treatment 1) ao that off flavors were present.

(c) Comparison of Stapled, Punctured, and Completely-Sealed Bags of Identical Film Type: Only variations in closure of MSAT film were investigated. All treatments showed a poor product quality accompanied by

high levels of carbon dioxide so that after 20 days in cold storage only treatment 2 remained good. The tent flap package had a slightly off odor while the completely-sealed package was definitely off in odor. The carbon dioxide level at the 20 day interval was higher for treatment 5 than 2 and much higher for treatment 1.

All three samples were poor after 40 days at 32° F; treatment 1 was off flavored and poor in appearance while treatments 2 and 5 had off odor and poor color.

The weight losses incurred in cold storage were not very different for the various treatments at any time.

In warm storage the carbon dioxide within the packages accumulated rapidly. For treatment 1 a steady rise was observed during warm storage while treatments 2 and 5 exhibited the usual trend of a maximum concentration followed by a slight drop in per cent carbon dioxide. After the 40 + 1 interval the sealed package had poor flavor, odor and appearance while treatments 2 and 5 had poor odor and appearance. After two days all were bad.

(d) Disinfection versus Quality.

No results are reported since no disinfection study was included in the spinach series.

Illustrated in Plate XVI are samples of the best, control, and worst treatment of prepackaged spinach after 40 days of cold storage.

Plate XVI
Prepackaged Spinach After 40 Days of Cold Storage
Showing Best, Control and Poorest Treatments

Top = Poorest Treatment
Center = Best Treatment
Bottom = Control

3. Berries:

a. Method of Presentation of Data.

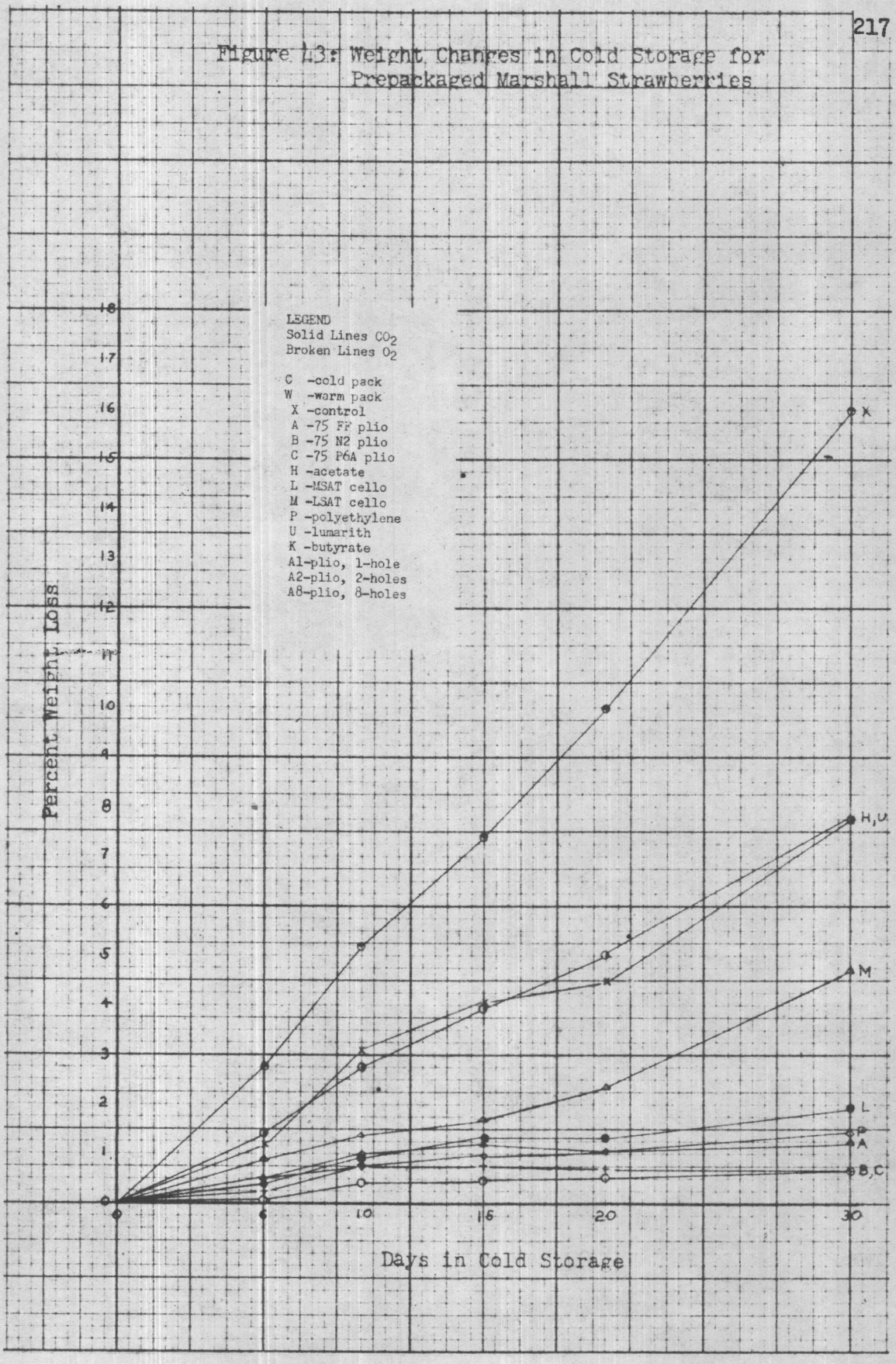
Again, data have been presented in the form of graphs in preference to tabulation. Line graphs instead of curves were used since the number of points available are too few to predict the true path of the curve. Therefore, the lines merely connect the various points obtained in an effort to show more clearly their positions relative to each other. Each value shown represents one or more determinations. Two types of graphs are given. One represents a comparison of results of either various film types or various treatments of berries held in cold storage. The second represents the results of warm storage after varying cold storage intervals.

For strawberries, raspberries, and boysenberries, (blackberries excepted), both carbon dioxide and oxygen values are reported and the carbon dioxide content is shown by solid lines while the oxygen content is denoted by dotted lines.

Weight losses for both warm and cold storage are shown graphically while quality is presented in tabular form.

While in the case of vegetables a code number was assigned to each treatment, a different system was adopted for berries. Each sample was identified by the code letter of the film in which it was wrapped, (for film codes

Figure 43: Weight Changes in Cold Storage for Prepackaged Marshall Strawberries



see Table 28). In cases where the same film wrap was used but the pretreatment of the sample was varied, a second code letter was prefixed to the film code. For example, berries in Lumarith film (code U) which were air cooled before prepackaging were designated CU while those which were packed warm were coded WU.

Table 27 reports the variations in treatment and film together with the corresponding code letters studied for berry prepackaging.

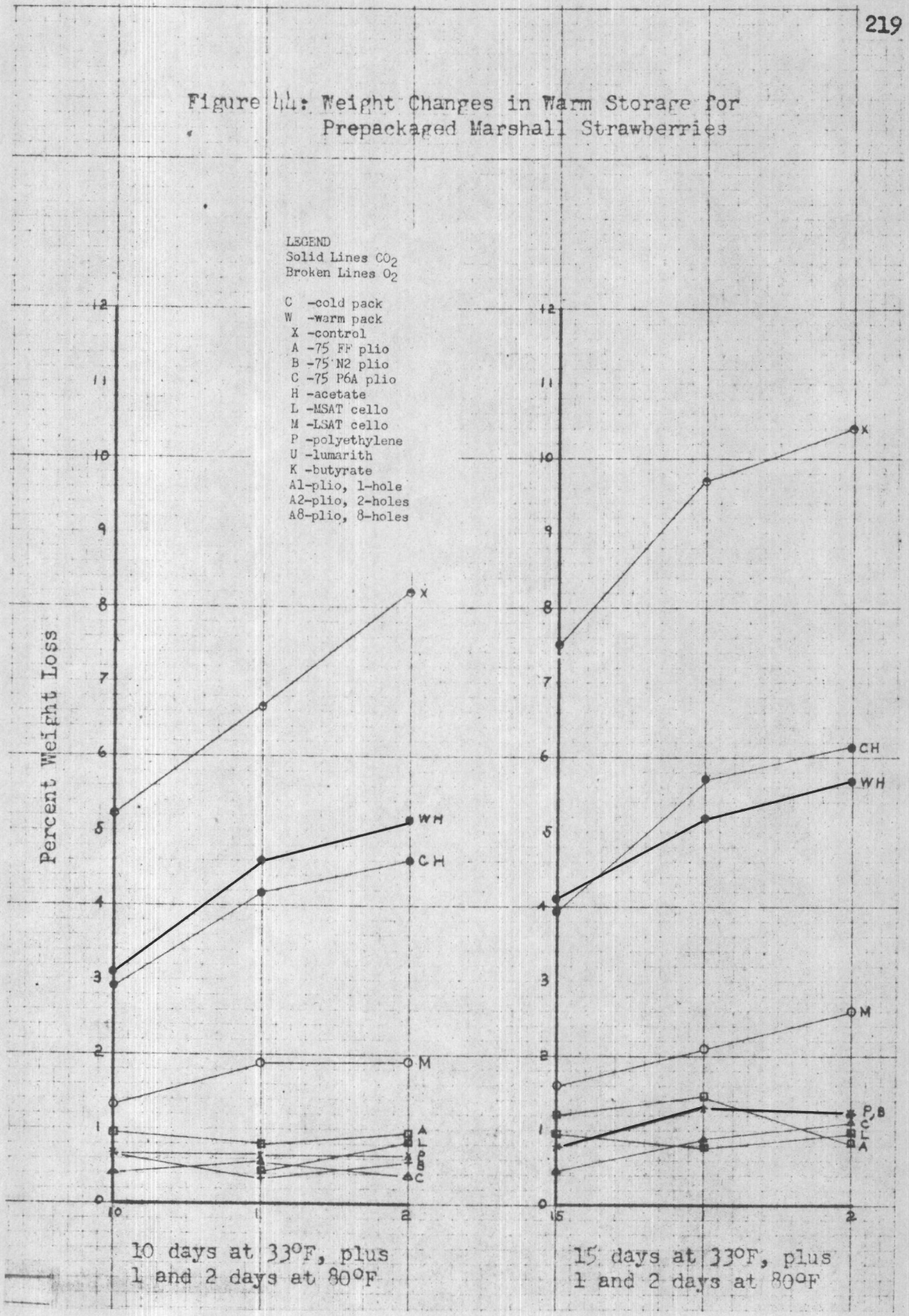
b. Strawberries:

(1) Transpiration.

(a) Cold Storage.

In figure 43 the weight losses of prepackaged strawberries during 6, 10, 15, 20, and 30 days in cold storage are shown. It was observed that noticeable shriveling of the berries did not occur with less than 5% weight loss. After 10 days' storage only the unwrapped control had lost more than 5% moisture while after 20 days both acetate wrapped samples of H and U in addition to the controls showed shriveling. By the time of the 30 day evaluation, samples of X had decreased in weight 16% and samples of U and H had each lost about 8% weight. The remaining treatments (A, B, C, L, and P) lost less than 2% moisture during one month of storage and were not shriveled. Film M provided protection from moisture loss in the intermediate range as was found for vegetables.

Figure 44: Weight Changes in Warm Storage for Prepackaged Marshall Strawberries



(b) Warm Storage.

The weight changes that occurred at 10 + 1 + 2 and 15 + 1 + 2 days in warm storage are given in figure 44. The warm storage losses followed the same pattern as that observed for cold storage. That is, the unwrapped control suffered the greatest losses, treatment H followed, while samples in films A, B, C, L, and P showed practically no decrease in weight. For controls and acetate wrapped strawberries the rate of weight loss was roughly three times as great in warm storage as in cold storage. For example, treatment X had lost as much in 2 days warm storage as in 6 days cold storage. On the other hand, the length of time the berries were held in previous cold storage did not affect the rate of weight loss at the high temperature.

(2) Respiration.

(a) Cold Storage.

1. Comparison of films: The oxygen and carbon dioxide content of prepackaged strawberries held at 33° F is shown in figures 45 and 46. Figure 45 gives a comparison of the various films for berries packed while still containing field heat. All films were tightly sealed. In figure 46 a comparison of the three high gas transmission films is given. In this case the berries were first air cooled before packaging. The relative position of films in the two graphs may be

Figure 45: Carbon Dioxide and Oxygen Content in Cold Storage of Prepackaged Marshall Strawberries Packed Warm

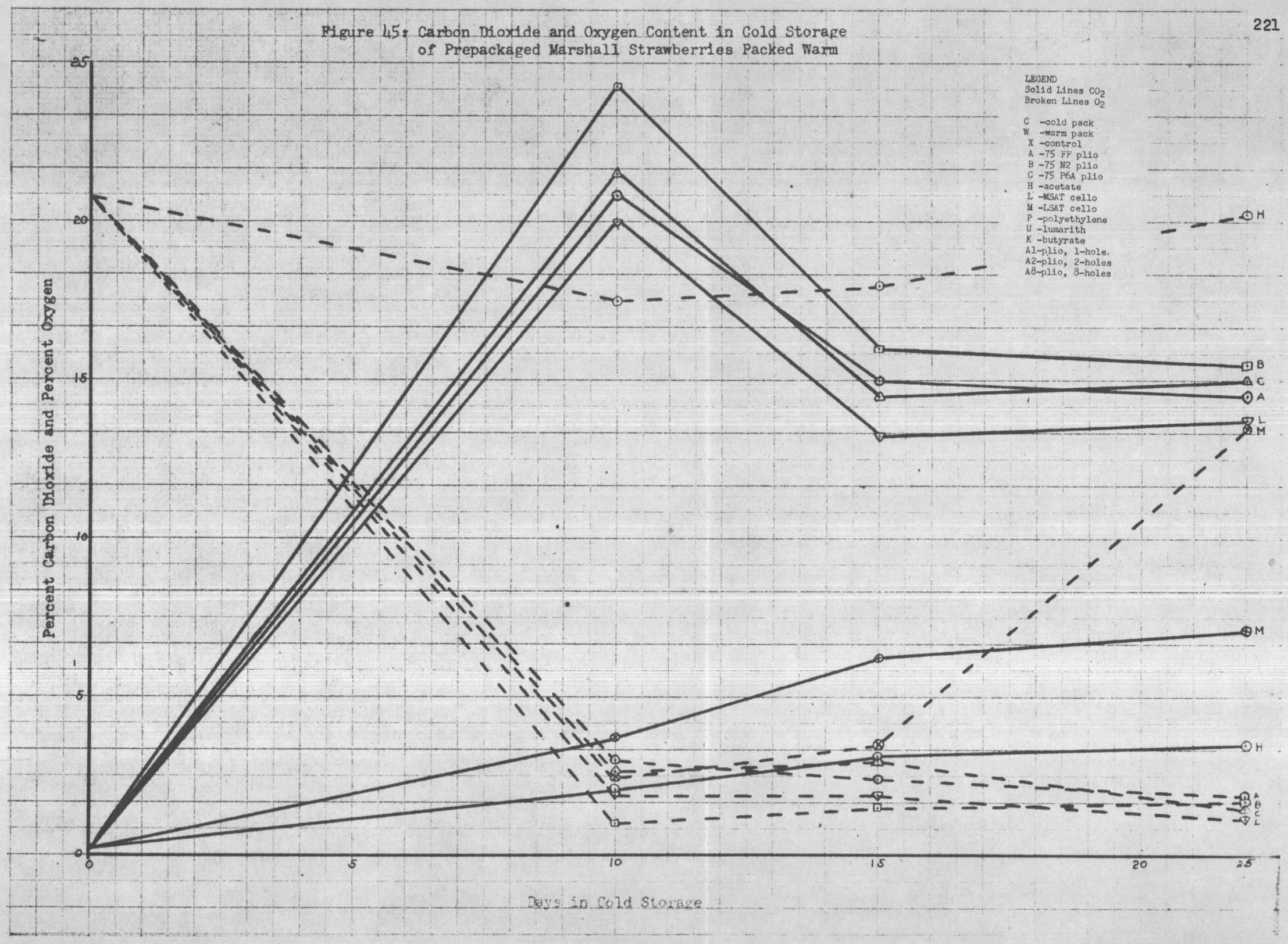
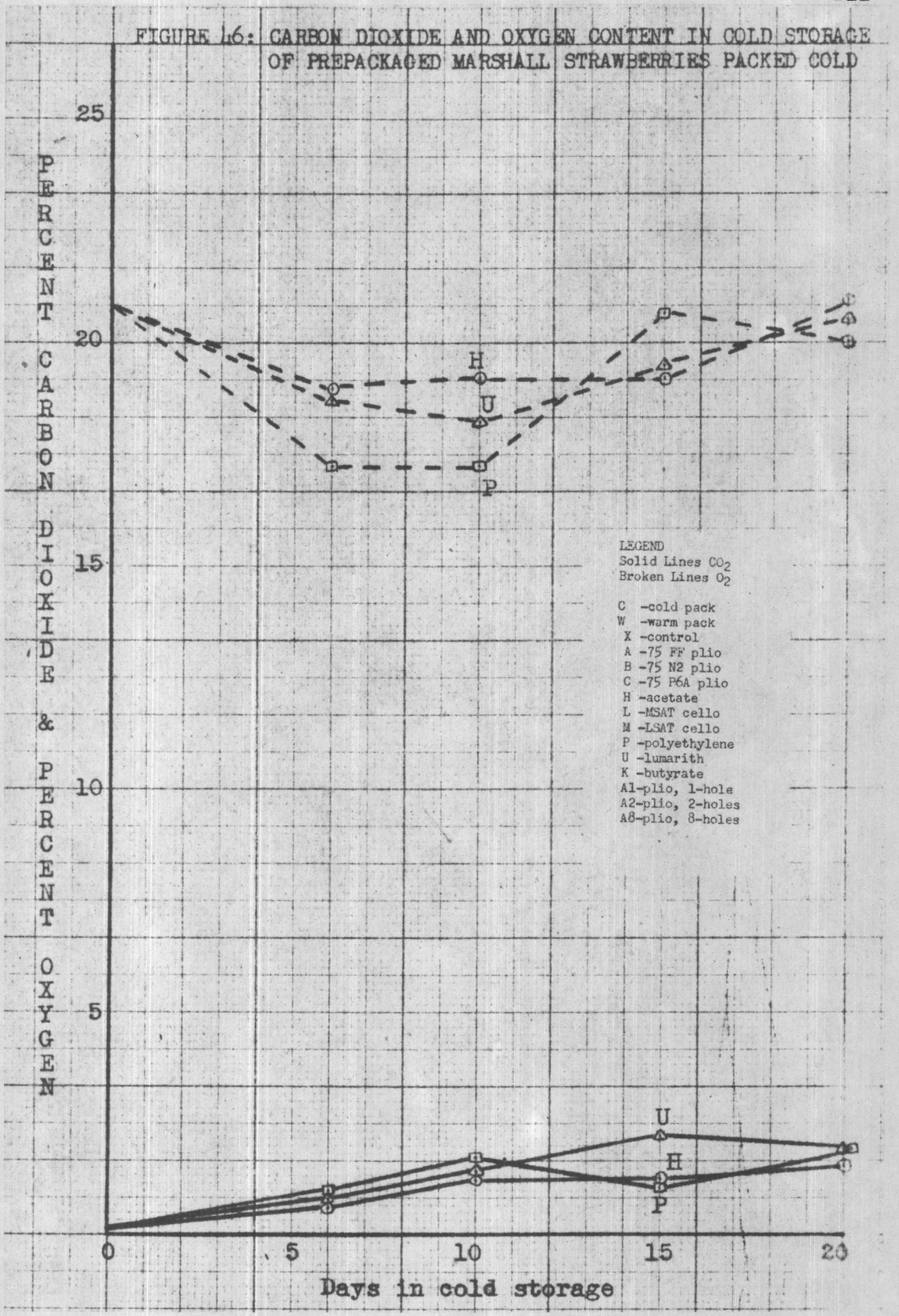


FIGURE 46: CARBON DIOXIDE AND OXYGEN CONTENT IN COLD STORAGE OF PREPACKAGED MARSHALL STRAWBERRIES PACKED COLD



correlated through film H.

By the time of the 10 day storage evaluation, the carbon dioxide accumulation for treatments A, B, C, and L had reached 20% or more. But after that time the amount did not increase, instead in some cases it decreased slightly. Contrary to the conditions found for the first-mentioned group, treatments H, U, and P accumulated carbon dioxide very slowly until after 22 days in storage there was approximately 2% CO_2 present in the packages. Again, the behavior for LSAT film was to place treatment M in an intermediate position with 7% CO_2 after 22 days in cold storage.

In general, the oxygen values correlated well with an inverse relationship to the carbon dioxide values. Assuming 21% O_2 in a package of low gas transmission film at zero storage, a rapid depletion was observed so that within ten days the supply had decreased to below 3% while the amount of carbon dioxide was increased from approximately 0.02% to 20% or more. The one exception to this statement was found in film M. Here both oxygen and carbon dioxide values were rather low after the berries had been stored. This characteristic of the LSAT film was observed in the work with vegetables also. In storage, treatments H, U, and P retained a high oxygen content of values between 17 and 21% while treatments A, B, C, and L were reduced to about 3% O_2. No important differences were

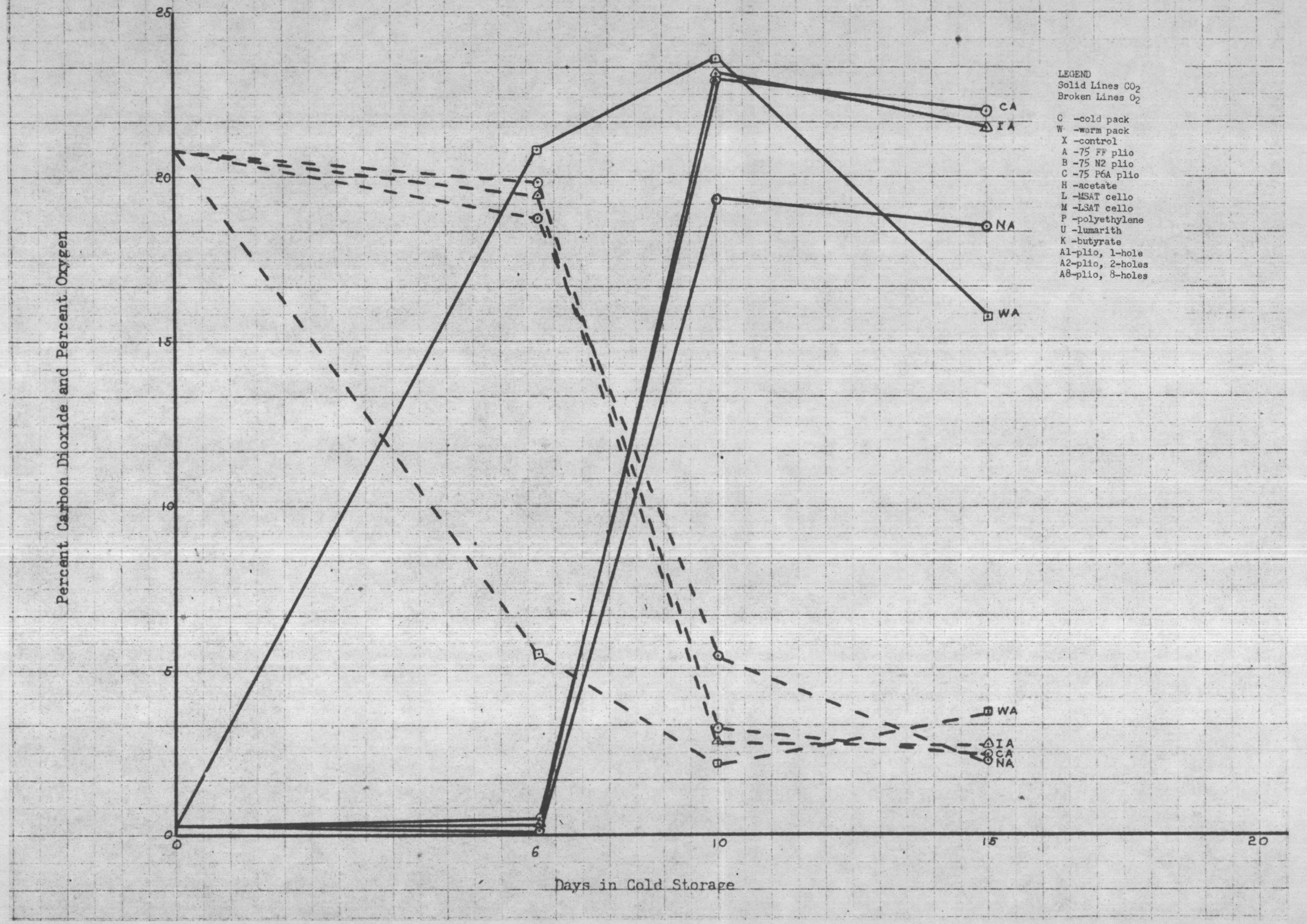
found among the films within either the high or low gas transmission groups.

ii. Comparison of pretreatments:

A comparison of methods of cooling berries was studied using a relatively high and a relatively low gas transmission film, namely cellulose acetate H and pliofilm A. The effect of these pretreatments on the carbon dioxide and oxygen content within the package is shown in figures 47 and 48. Figure 47 represents berries packed in pliofilm after air cooling, ice water cooling, ice water plus a wetting agent cooling, and without cooling. Figure 48 represents berries pretreated in the same manner but packed in the acetate film. Samples were analyzed after 6, 10, and 15 days in cold storage.

It is interesting to observe that after the six day storage interval all the pre-cooled pliofilm samples had practically no carbon dioxide and very high oxygen concentration. Little or no differences among the cold pack treatments were observed. In contrast, the WA sample contained only 5½% O_2 and 21% CO_2 at the same time. But, after 10 days, the analyses showed that all samples were high in carbon dioxide and low in oxygen. This indicated that sometime between six and ten days of cold storage the pre-cooled samples increased the rate of CO_2 accumulation considerably. After the ten day storage period there was little change in the gas content of the packages.

Figure 47: Carbon Dioxide and Oxygen Content in Cold Storage of Marshall Strawberries Variously Cooled before Prepackaging in Pliofilm



It seems most likely that a sudden reduction in the respiration rate of strawberries which was due to the lowering of their internal temperature prior to packaging was responsible for the great variation in the carbon dioxide content between cold packed berries at 6 and 10 days of cold storage. This also accounts for the differences between the warm and cold packed berries after six days' storage, since in the warm packed berries the rate gradually changed after packaging so that a larger quantity of carbon dioxide was accumulated sooner than for the corresponding cold packed fruit.

H. C. Gore (12) reported the following respiration rates for strawberries;

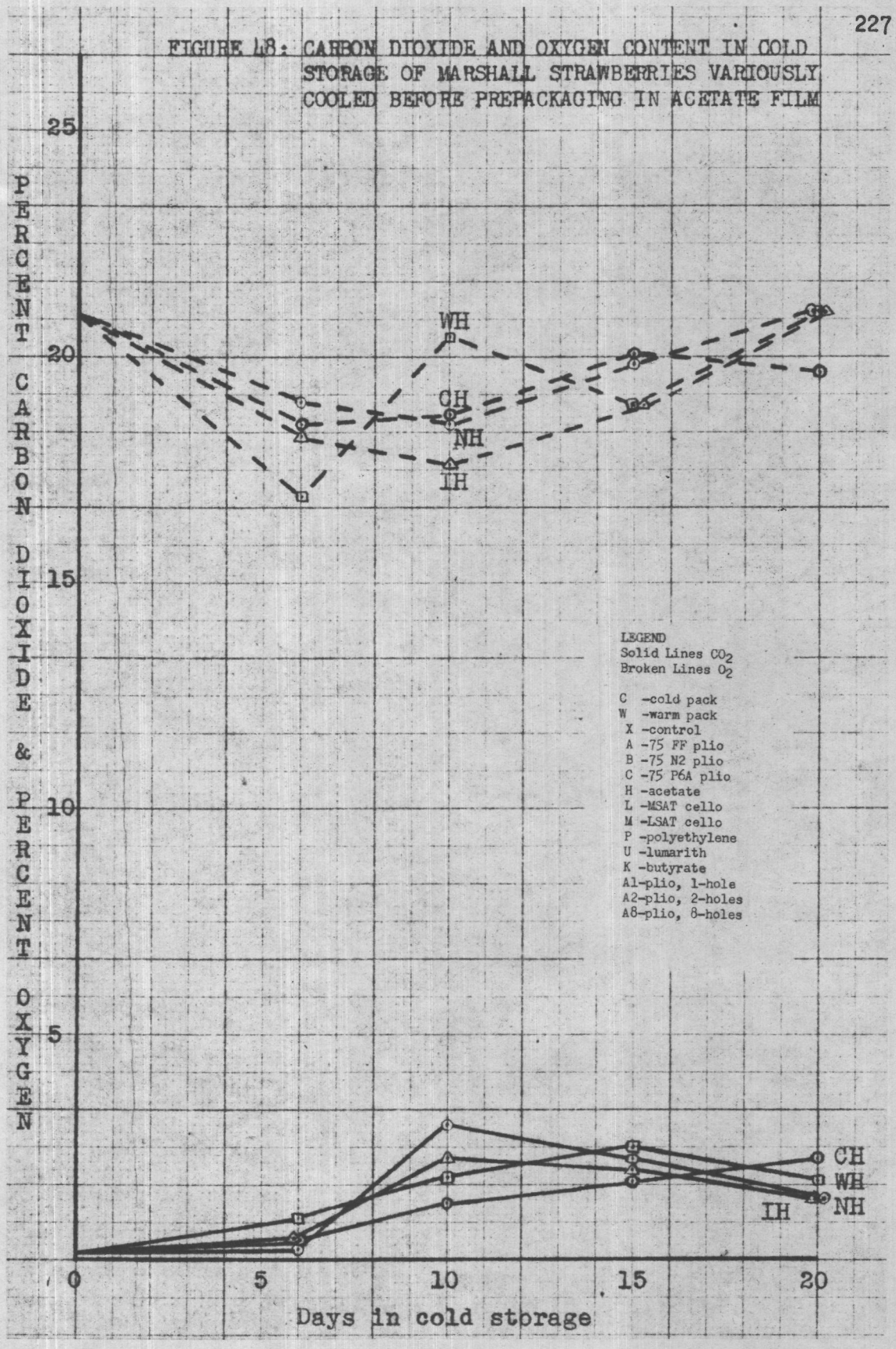
At 26.2° C = 151 mg. CO_2/Kg./hr.

At 2.0° C = 17 mg. CO_2/Kg./hr.

After ten days at 33° F enough carbon dioxide was present in both types of packs to maintain anaerobic respiration. Therefore, differences between them disappeared. This point was found to be important since the flavor of the fruit seems to be affected by high carbon dioxide levels.

No difference between the warm and cold packed samples in acetate was observed. All samples showed a high oxygen and low carbon dioxide content throughout the cold storage period.

FIGURE 48: CARBON DIOXIDE AND OXYGEN CONTENT IN COLD STORAGE OF MARSHALL STRAWBERRIES VARIOUSLY COOLED BEFORE PREPACKAGING IN ACETATE FILM



(b) Warm Storage.

i. Comparison of films:

In figure 49, the effect of various film types on the carbon dioxide and oxygen values for strawberries in warm storage are shown. The berries were held for 10 + 1 + 2 + 3, 15 + 1 + 2 and 20 + 1 + 2 periods at 80° F. Again, similarly to the results in cold storage the films may be classified into two transmission groups. The treatments A, B, C, and L maintained the high level of carbon dioxide they had attained in cold storage. Treatments H and M showed a rapid rise of carbon dioxide after one day in warm storage which was increased to a greater extent after the longer previous cold storage periods. However, the accumulation in treatments H and M always decreased by the second day but remained above the starting point.

The oxygen content of treatment H tended to steadily decrease with storage time and did not reflect the trend of carbon dioxide to pass through a maximum point.

ii. Comparison of pretreatments:

The behavior of pretreated berries in warm storage is shown in figure 50. Only pretreatments wrapped in acetate films were studied since

Figure 49: Carbon Dioxide and Oxygen Content in Warm Storage of Prepackaged Marshall Strawberries Packed Warm

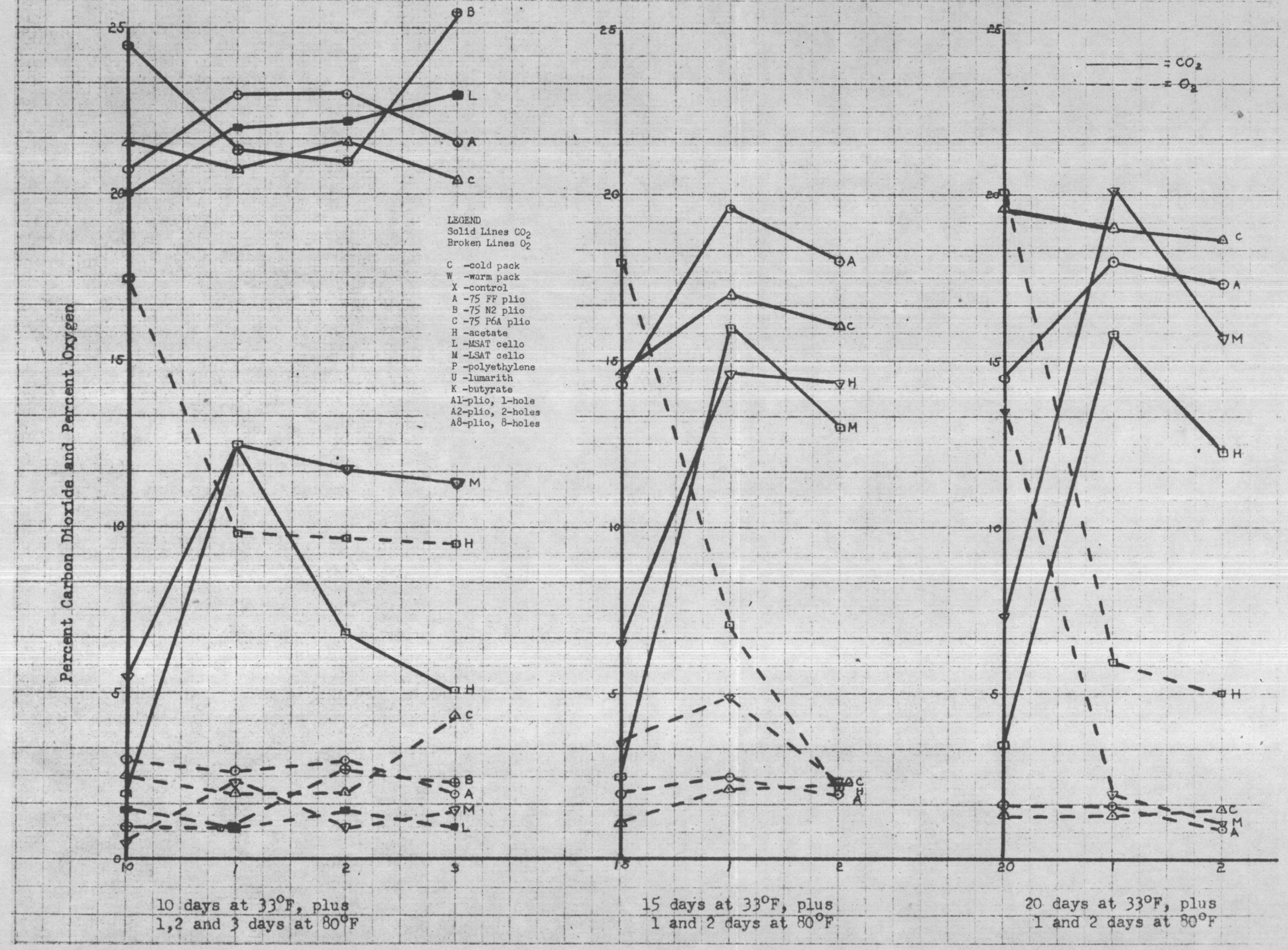
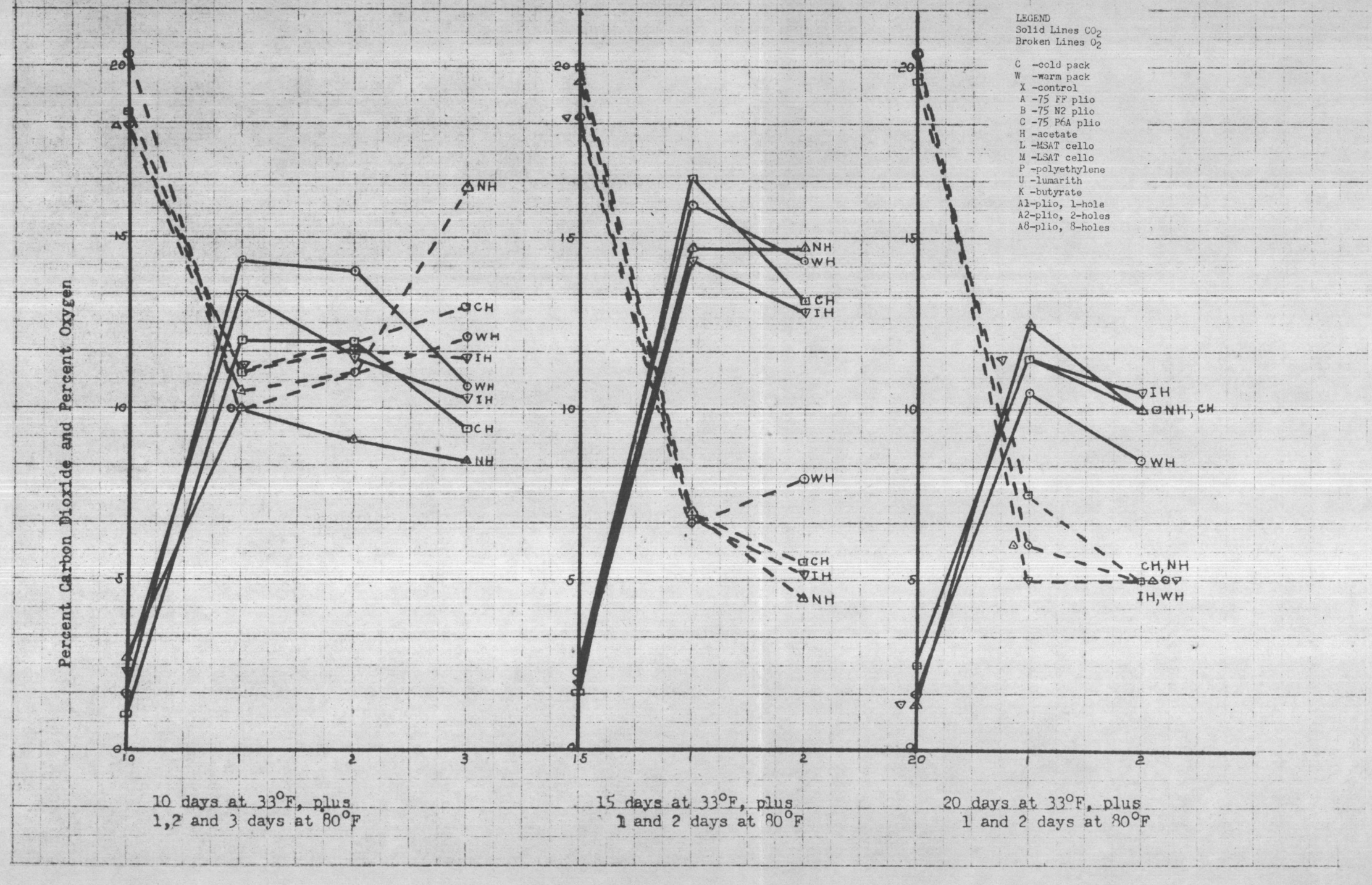


Figure 50: Carbon Dioxide and Oxygen Content in Warm Storage of Marshall Strawberries Variously Cooled before Prepackaging in Acetate Film



those wrapped in pliofilm showed indications of poor quality even in cold storage. In general, there was no difference between the pre-cooled and not pre-cooled samples and they followed a pattern similar to that described for cold storage.

(3) Quality.

(a) Cold Storage.

Table 32 shows the classification of qualify for strawberries held in cold storage from 6 to 20 days. The method for evaluating quality is shown in Table 32 in the section under Materials and Methods.

After six days in cold storage all samples still maintained dessert quality with one exception; treatment WA (warm berries packed in pliofilm), had a slight off flavor. Treatment CA, the corresponding cold pack sample, was not off flavored.

At the ten day evaluation only the acetate wrapped samples of CH, WH, and CU remained as dessert quality. The control was slightly moldy as well as shriveled while treatments P and M were slightly off flavored so that all three were rated commercial quality. The remaining samples of WA, WB, WC, WL, and CA were considered poor due to definite off flavors.

In general, the same quality was observed for the samples after 15 days in cold storage except that samples in films M and P were off flavored and scored poor quality.

By the time of the 20 day evaluation all samples were severely molded, shriveled, or off flavored and considered quite unsalable. Only two samples, CU and CH, received a grade of commercial. They, too, were slightly shriveled and moldy.

A comparison of quality between the warm and cold packed berries in acetate film showed no important differences. For those samples packed in pliofilm, some differences were found but only for the first six days in storage.

Only a few samples were better than the controls. These were the berries packed in acetate films which had less mold and wilt than the unwrapped samples and were without the off flavors associated with the other films.

The two pretreatments involving the use of ice water dips before packaging produced poor quality samples. The sudden cooling of the berries in the 32° F water appeared to cause the cuticle to be damaged so that the fruit was skinned in places. This contributed a poor quality to these series.

TABLE 32

Quality of Prepackaged Strawberries in Cold Storage

Grade	Days in Storage											
	6			10			15			20		
Dessert	CU CP WH WX	CA CH		CU CH WH			CU CH WH					
Commercial	WA			CP WM WX			WX			CU CH		
Poor				WA WB WC	WL CA		CP WM WA WB WC	WL CA		WX WH CP WM WA	WB WC WL	

(b) Warm Storage.

Prepackaged strawberries held in warm storage showed a deterioration of quality similar to that described for cold storage.

At the 10 + 1 period all samples except CH were below dessert quality due to mold, off flavor, or shriveling. Treatment CH was still very good although treatment WH was rated commercial because of a slight off flavor. After two days all samples were badly molded or shriveled and scored poor quality.

For the 15 day interval the berries decreased in quality more rapidly than at the 10 day period. After 15 + 1 days no sample was of dessert quality while only treatment CH with slight mold was listed as commercial. All others were poor. At 15 + 2 all were very poor.

Again, only the acetate wrapped samples were better than the controls. The merits of treatment prior to packaging were not definite in warm storage.

TABLE 33

Quality of Prepackaged Strawberries in Warm Storage

Grade	Days in Storage											
	10		10 + 1		10 + 2		15+0		15+1		15 + 2	
Dessert	WH CH		CH				WH CH					
Commercial	WM WX		WH				WX		CH			
Poor	WA WB WC WL	CA	WX WM WA WB WC	CA WL 	WX WM WA WB WC	WH WL CA CH	WM WA WC		WH WX WM WA WC		WH WX WM WA WC	CH

(4) Graph Relationships.

(a) Weight Loss versus Wilting.

In cold storage wilting was noticeable but never severe in samples of prepackaged strawberries

of more than 5% weight loss. Below 5% shriveling was not apparent.

In warm storage the extent of shriveling was difficult to appraise because other factors such as mold and decay confused the picture. However, shriveling in the unwrapped controls was very evident.

(b) Flavor versus Per Cent Carbon Dioxide and Oxygen: A comparison of the flavor of strawberries with the carbon dioxide concentration in the package indicated a good correlation between the two factors, especially during the early periods of cold storage. For after the longer intervals, especially 22 days of storage, the evaluation of flavor became difficult if not impossible because decay interfered. A "flavor borderline" was not drawn on the graph of carbon dioxide values since all samples which had off flavors possessed more than $12\frac{1}{2}\%$ CO_2 while those with natural flavor had less than 3% CO_2. This meant that the exact location of the border, which was somewhere between 3 and $12\frac{1}{2}\%$, was not possible to define.

The flavor of the sample wrapped in film M did not correlate well with its carbon dioxide content but instead fell more in line with its oxygen values. Other films correlated with oxygen values as well as with carbon dioxide figures. However, no borderline could be located for oxygen values with assurance since there were too few points in the critical range.

In warm storage a relationship similar to that described for cold storage existed between flavor and carbon dioxide content. The acetate wrapped samples were an exception to the preceding statement. In these, the carbon dioxide level rose sharply in warm storage so that after one day at 80° F, the samples were not always without off flavor. By the second day of warm storage the level of carbon dioxide in acetate wraps decreased from that attained during the first 24 hours in warm storage. Despite this decrease, pronounced off flavors were present for all wraps, even the acetates. Again, the flavor of samples wrapped in LSAT cellophane more nearly followed the oxygen values.

It is important to observe that in no case did the accumulation of carbon dioxide improve the flavor of strawberries.

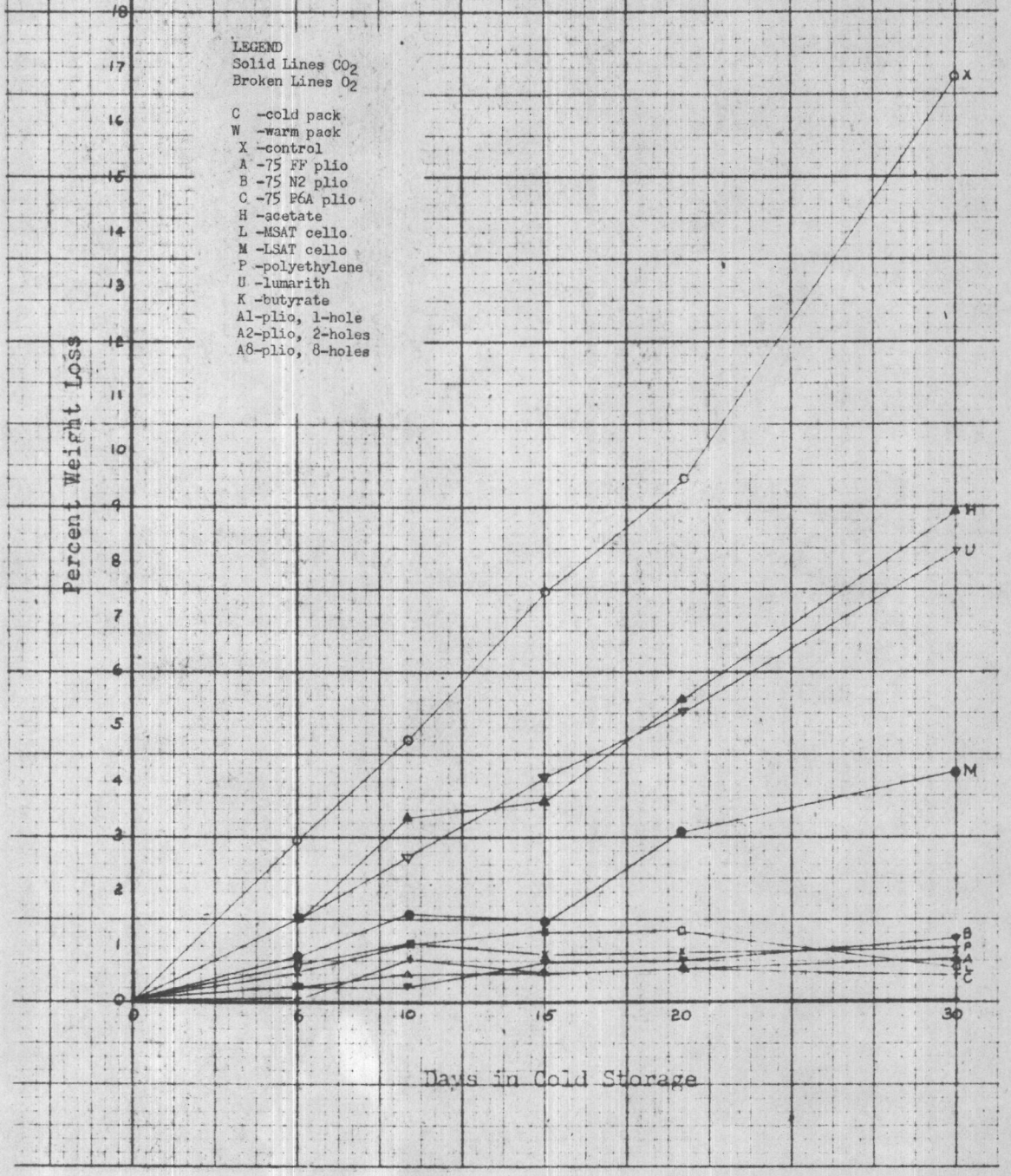
(c) Cold versus Warm Pretreatment.

A comparison of quality of the warm and cold packed berries indicated that a difference existed between them during the early cold storage periods. Thus, at the six day evaluation, the cold packed samples in pliofilm were better than those packed in pliofilm without pre-cooling.

(d) Films versus Mold.

All unwrapped control samples became moldy. The development of mold was prevented

Figure 51. Weight Changes in Cold Storage for Prepackaged Raspberries



entirely by low gas transmission films due to the high concentration of carbon dioxide within the package. For the high gas transmission films such as acetate or polyethylene wrapped samples there was less mold present than in the controls. It is impossible to say, however, whether this was caused by physical protection against storage contamination or whether the slight accumulation of carbon dioxide within the package was sufficient to retard mold growth. Proof would require an additional study in which prepackaged, mold inoculated, samples were compared with non-inoculated berries.

(e) Washing versus Mold.

The addition of a wetting agent to the hydrocooling process was included with the object of facilitating the removal of adhering foreign material. However, the effect of this treatment N on the reduction of mold was not determined because the injury incurred by the sudden chilling was too great.

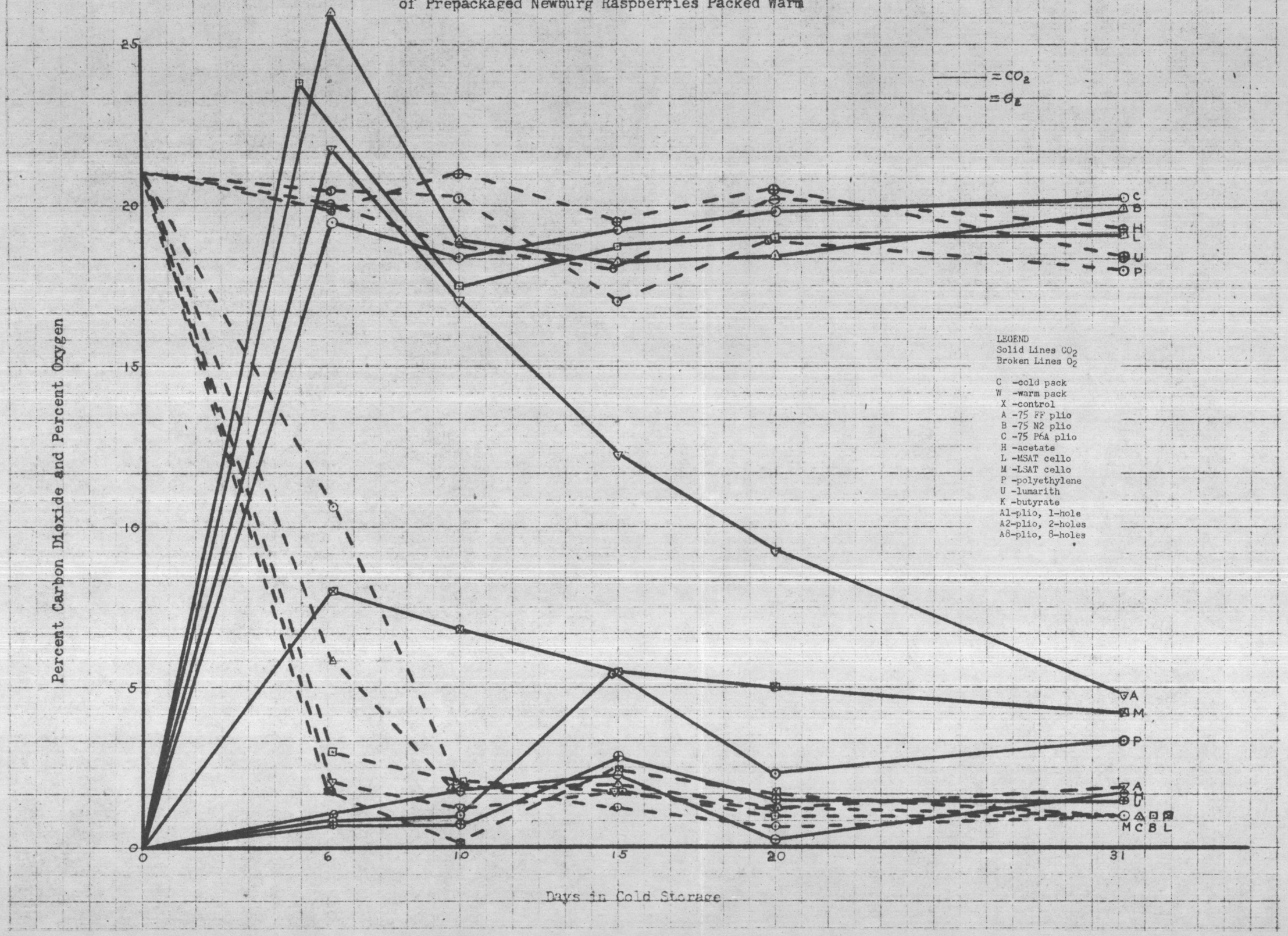
c. Raspberries.

(1) Transpiration.

(a) Cold Storage.

The weight losses for raspberries held in cold storage from 6 to 31 days are given in figure 51. In general, the results were similar to those reported for strawberries; that is, only the controls and acetate packed samples showed considerable weight losses.

Figure 52: Carbon Dioxide and Oxygen Content in Cold Storage of Prepackaged Newburg Raspberries Packed Warm



(2) Respiration.

(a) Cold Storage.

In figure 52 is shown the accumulation of carbon dioxide and the decrease of oxygen for prepackaged raspberries held in cold storage. The results in these graphs also closely resemble those obtained for strawberries with one notable exception. The polyethylene film allowed greater accumulation of carbon dioxide in the raspberry samples. But at the same time, the quantity of oxygen present did not appear equally decreased. The reason for the steady decline of carbon dioxide for treatment A after six days in storage is not known.

The results of cooling before packaging on the carbon dioxide and oxygen content of raspberries are shown in figures 53 and 54. The first graph portrays the effect of packaging in a relatively low transmission film while the second shows the effect of a high gas transmission film.

Treatment WA continued to decrease in carbon dioxide concentration with little change in oxygen after 15 days in cold storage. The sudden change in treatment NA at 20 days is believed to be due to experimental error and not a true difference in sample behavior. Also it can be

Figure 53: Carbon Dioxide and Oxygen Content in Cold Storage of Newburg Raspberries Variously Cooled Before Prepackaging in Pliofilm

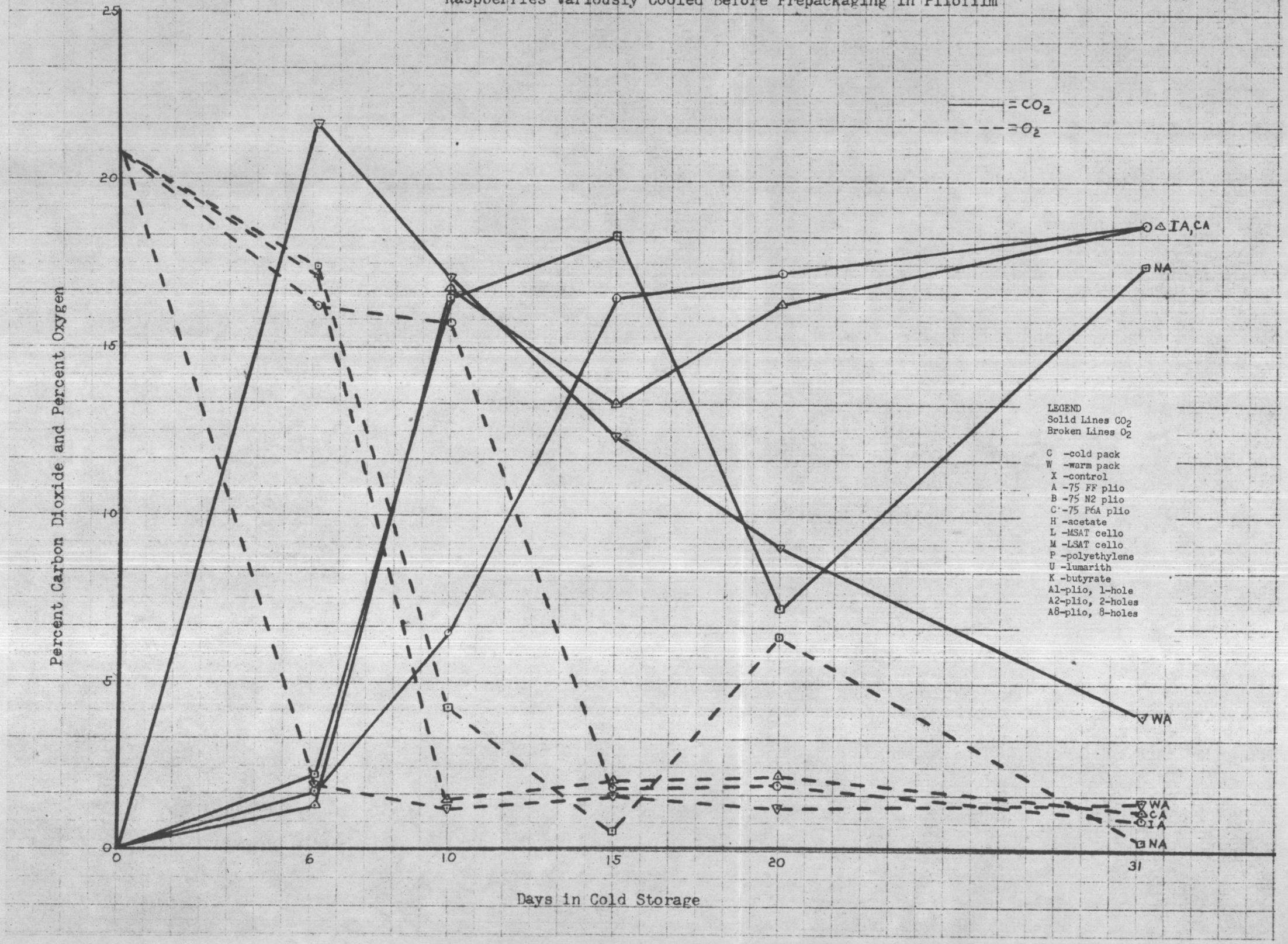
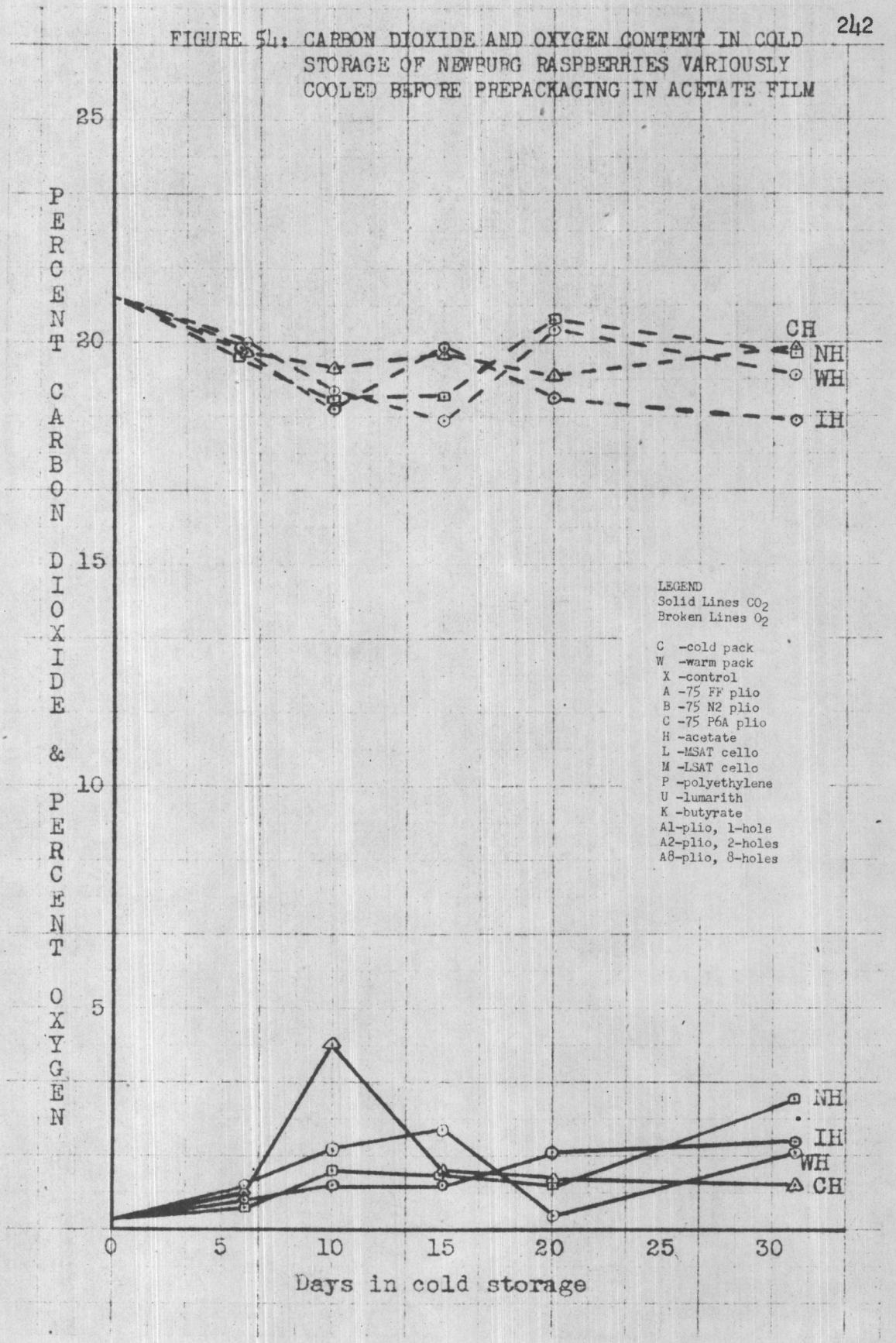


FIGURE 54: CARBON DIOXIDE AND OXYGEN CONTENT IN COLD STORAGE OF NEWBURG RASPBERRIES VARIOUSLY COOLED BEFORE PREPACKAGING IN ACETATE FILM



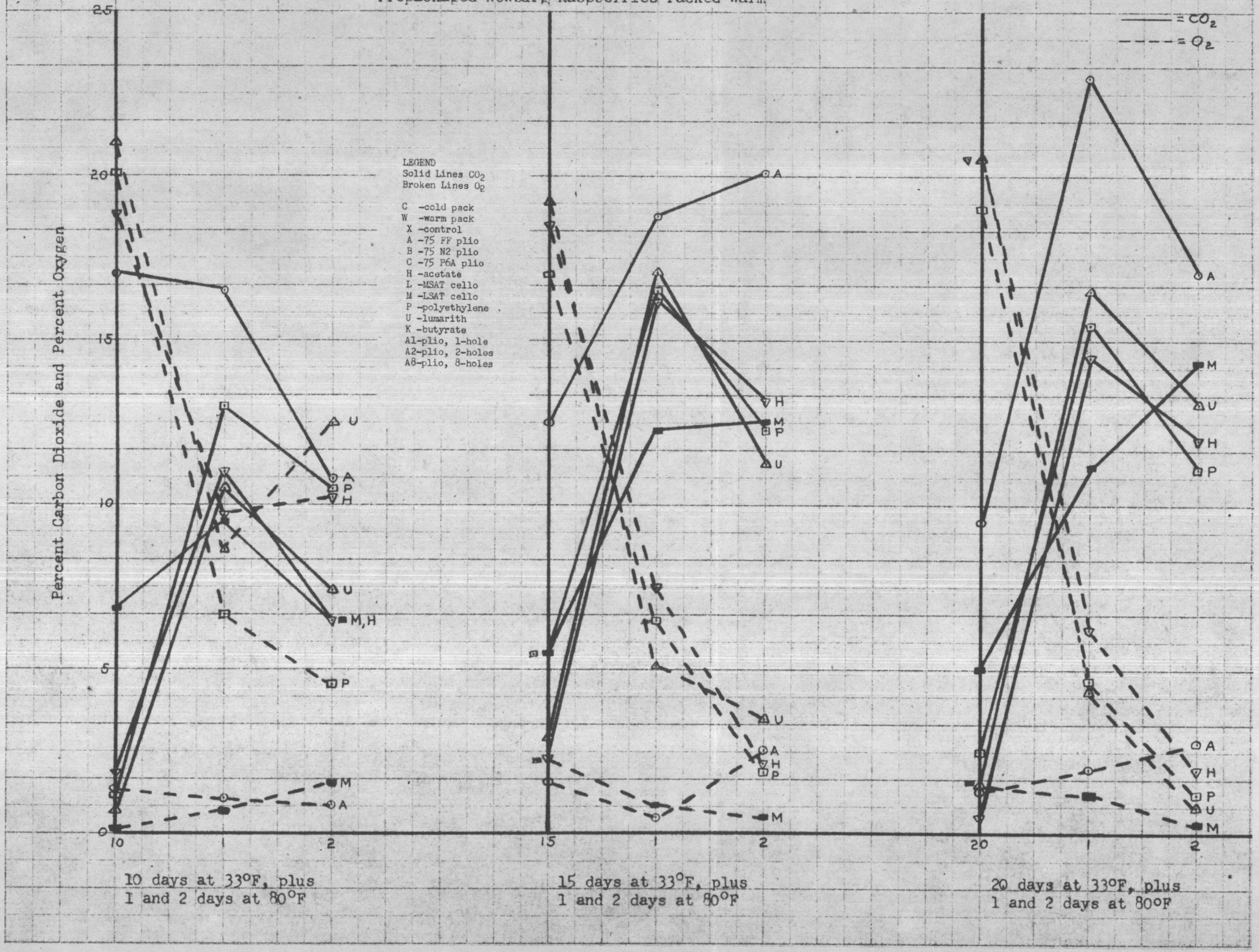
observed that raspberries did not exhibit a lag period of carbon dioxide accumulation immediately following the beginning of storage and then a sudden increase between the six and ten day period as reported for strawberries. Instead a gradual increase was observed. Analyses of the pretreated samples in acetate films showed no important differences from those found for strawberries.

(b) Warm Storage.

The performance of prepackaged raspberries in warm storage is reported in figure 55. The berries were stored for one and two days after each of three cold storage intervals. On the basis of the experience gained with strawberries, only one low gas transmission film was tested in warm storage since this group had not maintained good quality. Therefore, pliofilm A was included only as a reference point for tight films in general.

After one day in warm storage all films caused a rapid rise in carbon dioxide accumulation except for film A there was a slight decrease at the 10 + 1 period. The greatest increase was observed for the polyethylene package in which the CO_2 rose from 1 to 13% in 24 hours. The reduction in the oxygen supply corresponded well with the increase in carbon dioxide. The extremely low oxygen values for samples A and M were not caused by the warm storage but had occurred in cold storage.

Figure 55: Carbon Dioxide and Oxygen Content in Warm Storage of Prepackaged Newburg Raspberries Packed Warm



10 days at 33°F, plus 1 and 2 days at 80°F

15 days at 33°F, plus 1 and 2 days at 80°F

20 days at 33°F, plus 1 and 2 days at 80°F

After the second day in warm storage, all samples with the exception of treatment M decreased in carbon dioxide content, thus illustrating the typical maximum after one day that had been observed for most other products. The oxygen values, on the other hand, continued to decrease from zero to one day and through the second day of warm storage.

Again, it was noted that as the cold storage interval was prolonged, the rate of carbon dioxide increase and oxygen decrease was accelerated. By the 20 + 2 period, the oxygen in the acetate packages was in the same range as that for the LSAT package.

(3) Quality

(a) Cold Storage.

In Table 34 a classification of raspberry quality during cold storage is shown. The rate of deterioration of raspberries was about equal to the rate for strawberries. Actually, only the acetate and polyethylene wraps were suitable for raspberries, and of these only the acetate wrapped samples were better than the controls. The acetate wrapped berries retained dessert quality through 15 days of storage, and were commercial by the 20th and poor quality after a month at 33° F. The controls and polyethylene wrapped samples were dessert quality at 6 days and poor by 20 days in cold

storage. The principal difference between the two groups was less mold and shriveling for the acetate wrapped samples. The remaining samples were poor quality because of off flavor.

Preliminary tests had shown that hydrocooling did not injure raspberries as it did strawberries. Even then the treatments I and N could not be satisfactorily evaluated since poor drainage was obtained for the large scale work. This caused water logging of the packaged berries and subsequent poor results.

TABLE 34

Quality of Prepackaged Raspberries in Cold Storage

	Days in Storage				
Grade	6	10	15	20	30
Dessert	WU CA WH WP CH WU WH WX	CH WU CH			
Commercial	WW	WX WP	WH WX WP	WU CH WH	
Poor	WA WB WC WL	WM WB WC	WL WM WL WA WB WA CA WC CA	WM WL WB WA WC WP WX CA	WM WU WB WL WC WA WX WP WH CA CH

(b) Warm Storage.

For warm storage, as in cold storage, raspberries and strawberries showed strong quality resemblances. In table 35 the listing of raspberry quality in warm storage shows that only the acetate packed berries were better than the controls. Only sample WU was scored dessert quality after the 10 + 1 period. For longer periods in cold storage as well as longer warm storage intervals, the quality decreased rapidly.

TABLE 35

Quality of Prepackaged Raspberries in Warm Storage

Grade	Days in Storage													
	10 + 0	10 + 1	10 + 2		15 + 0	15 + 1		15 + 2		20 + 0		20 + 1		
Dessert	WH WU	WU			WU									
Commercial	WX WP	WH WX	WU WH		WH WX WP	WU WH				WU WH				
Poor	WM WA	WP WM WA	WX WP	WM WA	WM WA	WX WP	WM WA	WU WH WX	WP WM WA	WX WP WM	WA	WU WH WX	WP WM WA	

(4) Graph Relationships.

Since the results obtained for raspberries were quite similar to those described for strawberries, it was not deemed necessary to repeat the discussion. Instead it is pointed out that the relationships between weight losses and wilt, flavor and carbon dioxide, mold and carbon dioxide, and mold and washing were in essence the same as those described for strawberries.

d. Boysenberries:

(1) Transpiration.

(a) Cold Storage.

Prepackaged boysenberries could be divided into three groups with respect to weight losses during cold storage. See figure 56. The unwrapped controls showed the greatest change but this change was not as much as that recorded for strawberries and raspberries. Next in amount of weight loss were the acetate wrapped samples U and H while film M took the usual intermediate place between the acetates and low vapor transmission films such as A, B, C, L, and P. The last mentioned group lost less than 2% moisture during thirty days in storage.

(2) Respiration.

(a) Cold Storage.

The accumulation of carbon dioxide and loss of oxygen in boysenberries is given in figure 57. A comparison of one representative tight film, pliofilm A,

Figure 56: Weight Changes in Cold Storage for Prepackaged Boysenberries

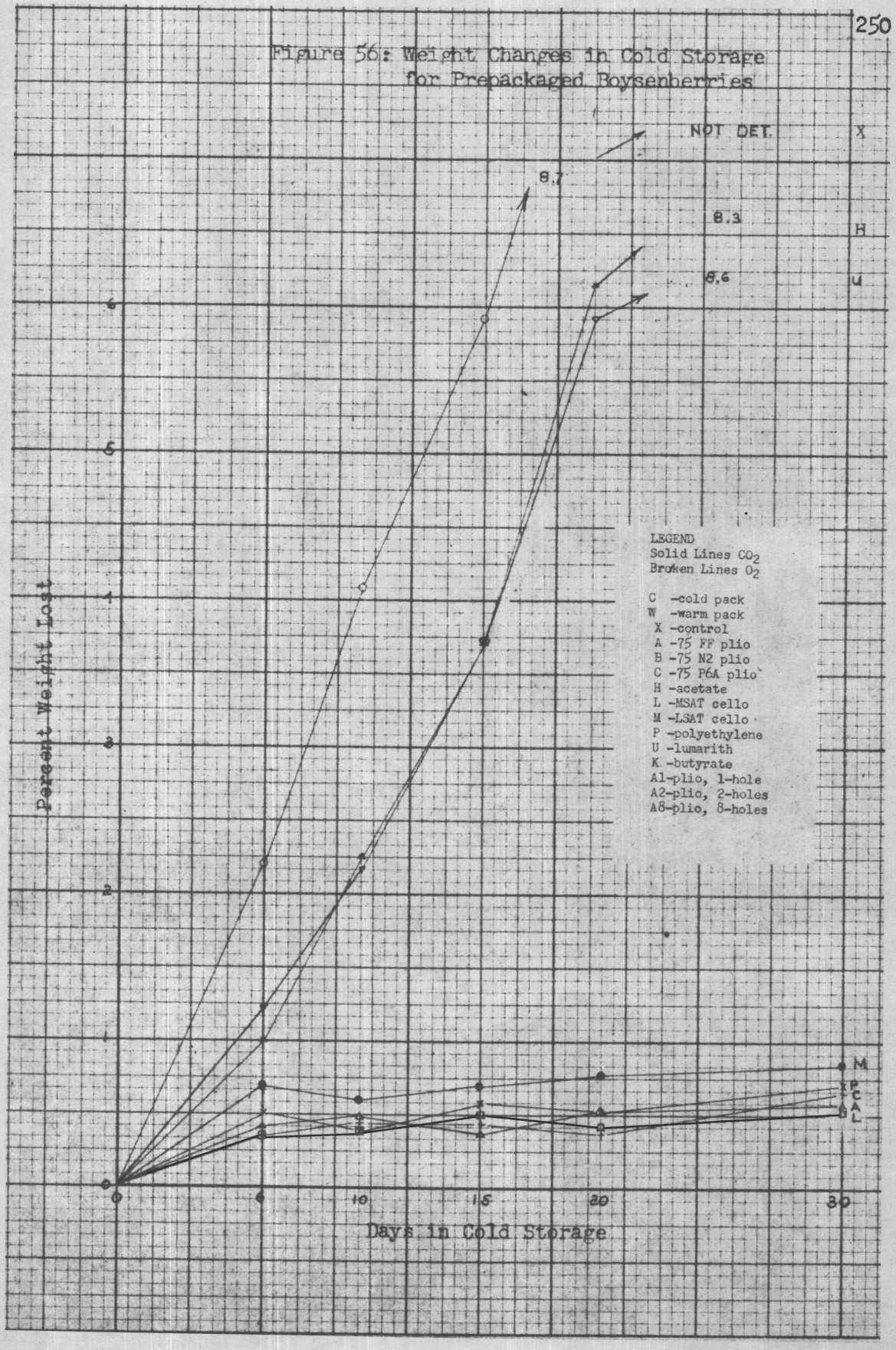
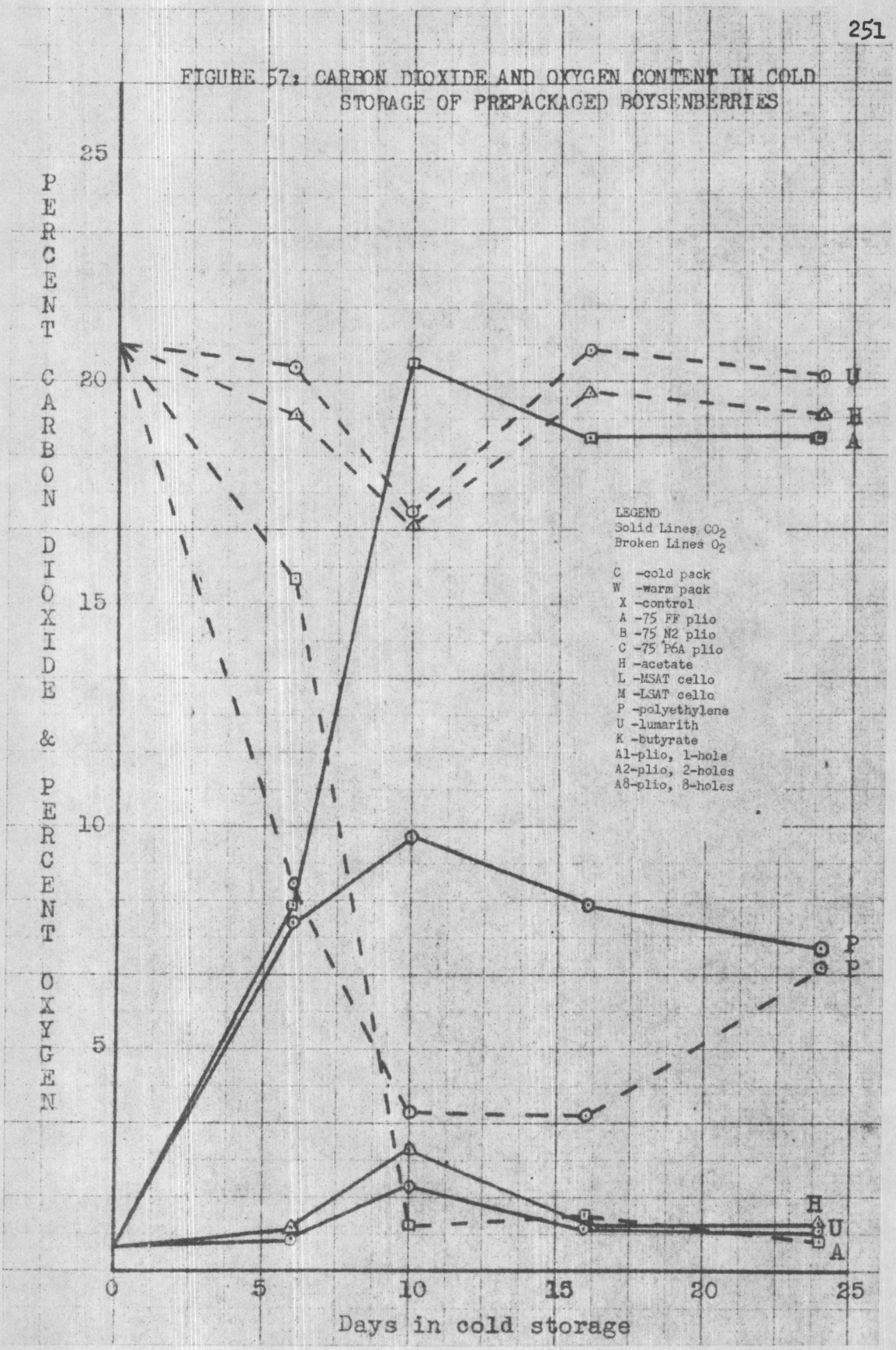


FIGURE 57: CARBON DIOXIDE AND OXYGEN CONTENT IN COLD STORAGE OF PREPACKAGED BOYSENBERRIES



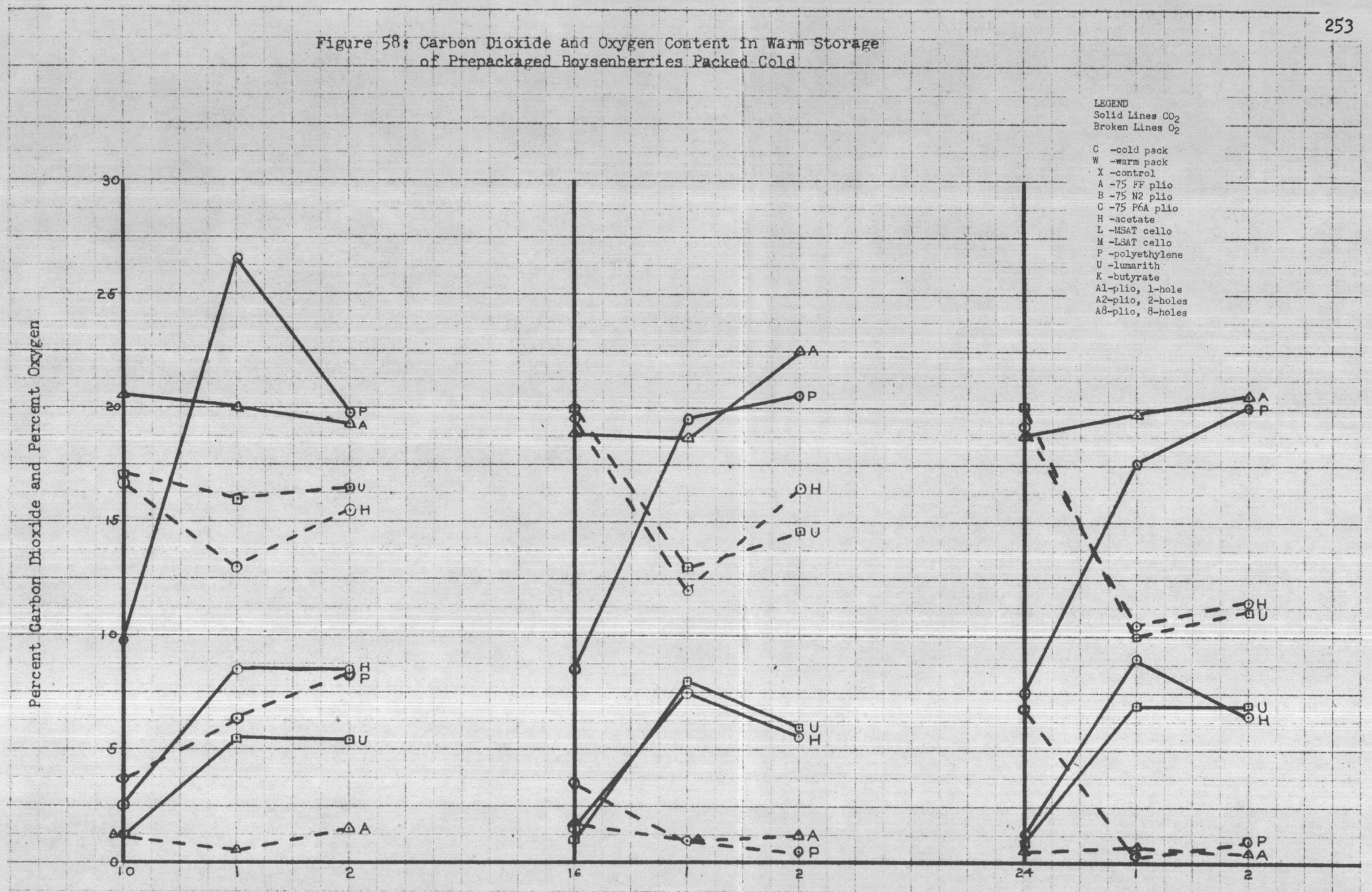
was made with higher gas transmission films which had provided encouraging results with strawberries and raspberries. In general, the values obtained for boysenberries were like those for the other two berry fruits described. The results obtained for the polyethylene wrap corresponded to those obtained with raspberries (approximately 5% O_2 and 10% CO_2) so that the results for strawberries packed in code P are somewhat in doubt. The possibility of poor seals for these strawberry samples exists.

It was found that a gradual accumulation of CO_2 without a pronounced increase in rate at any time occurred for CA. This was similar to the behavior of the corresponding raspberry treatment.

(b) Warm Storage.

Figure 58 shows the warm storage condition of boysenberries with respect to carbon dioxide and oxygen content. Film A retained the high carbon dioxide and low oxygen at all times which had been achieved while still in cold storage. After one day in warm storage treatment CP reached a condition very similar to that of CA. Treatments CU and CH behaved similarly and increased in CO_2 at the rate of 1 to 7% during the first day in warm storage at which time the concentration passed through the maximum point and declined. This peculiarity is probably due to a change in respiration rate and was common to other products studied.

Figure 58: Carbon Dioxide and Oxygen Content in Warm Storage of Prepackaged Boysenberries Packed Cold



10 days at 33°F, plus 1 and 2 at 80°F

16 days at 33°F, plus 1 and 2 days at 80°F

24 days at 33°F, plus 1 and 2 days at 80°F

(3) Quality.

(a) Cold Storage.

The quality of boysenberries held in cold storage was, in general, like that described for strawberries and raspberries, with one important difference. Boysenberries withstood storage for a longer time. Samples wrapped in acetate were of commercial quality after one month in storage. See Table 36. All samples were scored dessert quality at the six day evaluation while CH was still dessert quality at the 24 day observation. Samples CA, CP, and CX were poor quality after 24 days in cold storage. The main causes of quality deterioration were off flavor for berries in the tighter films, mold for berries in the acetates, and mold plus shriveling of berries in the unwrapped controls.

It was the acetate wrapped samples that maintained better quality than the controls throughout storage. The pliofilm samples were good for short periods of time but provided no real advantage over the unwrapped samples.

TABLE 36

Quality of Pre-packaged Boysenberries in Cold Storage

Grade	Time of Evaluation									
	6 days		10 days		16 days	24 days		30 days	
Dessert	CU CA CP	CH CX	CU CP	CH	CU CH	CH			
Commercial			CA CX		CP	CU		CH CU	
Poor					CA CX	CA CP	CX	CA CP	CX

(b) Warm Storage.

In Table 37 it is shown that boysenberries also tolerated warm storage better than strawberries and raspberries did with reference to quality. For at 10 + 1 the acetate wrapped boysenberry samples still rated dessert quality although at 16 + 1 they were slightly worse. However, after two days in warm storage the quality was alike for both the 10 day and 16 day interval. Again the acetate wrapped samples were better than the controls which had very moldy and shriveled berries. Such tight films as pliofilm were not satisfactory for boysenberries in warm storage.

TABLE 37

Quality of Pre-packaged Boysenberries in Warm Storage

Grade	Storage in Days					
	10 + 0	10 + 1	10 + 2	16 + 0	16 + 1	16 + 2
Dessert	CH CP CU	CH CU		CU CH		
Commercial	CX CA	CP	CU	CP	CU CH	CU
Poor		CX CA	CH CP CX CA	CA CX	CP CX CA	CH CP CX CA

(4) Graph Relationships.

(a) Weight Loss versus Wilting.

Boysenberries did not show shriveling until they had lost approximately 7½% moisture while for raspberries and strawberries only 5% change was necessary to be obvious.

(b) Flavor versus Per Cent Carbon Dioxide: Boysenberries were able to withstand high carbon dioxide or low oxygen concentrations for short periods of time. But after the longer intervals they behaved more nearly like the raspberries and strawberries.

(c) Films versus Mold.

Films such as pliofilm and

polyethylene inhibited mold growth on boysenberries because of relatively high carbon dioxide content in the package but at the expense of off flavor development of the product.

(d) Washing versus Mold.

Due to the poor results obtained with other berries no water treatments were included in the study of boysenberries.

e. Blackberries:

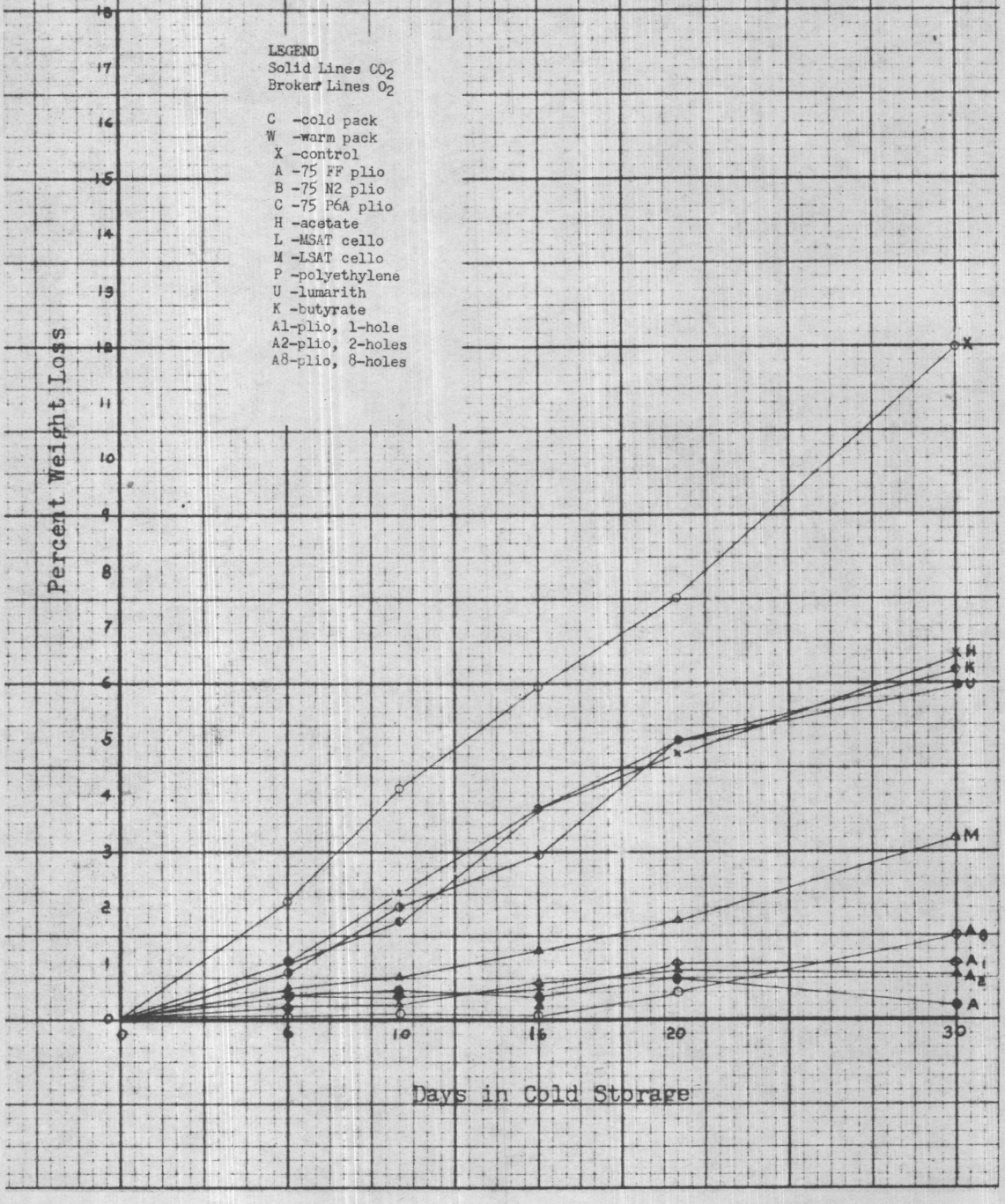
Exploratory tests with boysenberries indicated that the presence of holes punctured in a film such as pliofilm might be beneficial toward quality of the fruit in warm storage. On that basis this variation was included in the systematic investigation of blackberries. A second variable which was not included in the other berry studies was the addition of Kodapak acetate butyrate film which was not available until the time the blackberries were packed.

(1) Transpiration.

(a) Cold Storage.

Figure 59 reports the weight losses of blackberries which occurred in cold storage. It shows that the butyrate film allowed berry weight losses in the same range as the Lumarith and DuPont acetates. In addition the position of the punctured A samples with respect to the sealed samples were not very different from

Figure 59: Weight Changes in Cold Storage for Prepackaged Blackberries



each other. The moisture loss varied between 1.50% for berries in the sealed A to 0.25% for the samples of eight one-millimeter diameter punctures (A8). The losses for berries wrapped in acetate and controls were approximately the same for both boysenberries and blackberries.

(2) Respiration.

(a) Cold Storage.

In the gas analyses of blackberries only the carbon dioxide values were determined. The samples wrapped in pliofilm accumulated carbon dioxide steadily until at 10 days there was 18% present. After that time the amount stayed in that range. Film M produced the same type of curve but at the intermediate level of 7% CO_2. The butyrate and acetate wrapped samples had similar CO_2 accumulations. An important difference was observed for the punctured series which retarded CO_2 accumulation less like the sealed samples of A and more like the treatment CH. The one-hole puncture sample retained more carbon dioxide than the eight-puncture sample. This reaction was quite different from the results obtained for weight losses.

(b) Warm Storage.

The accumulation of carbon dioxide in warm storage was limited to two days after intervals of 6 and 20 days in cold storage. See figure 61. This afforded a comparison of the acetate, sealed pliofilm, and punctured pliofilm samples and established the position of the punctured variation with reference to carbon dioxide

Figure 60: Accumulation of Carbon Dioxide in Cold Storage for Prepackaged Blackberries

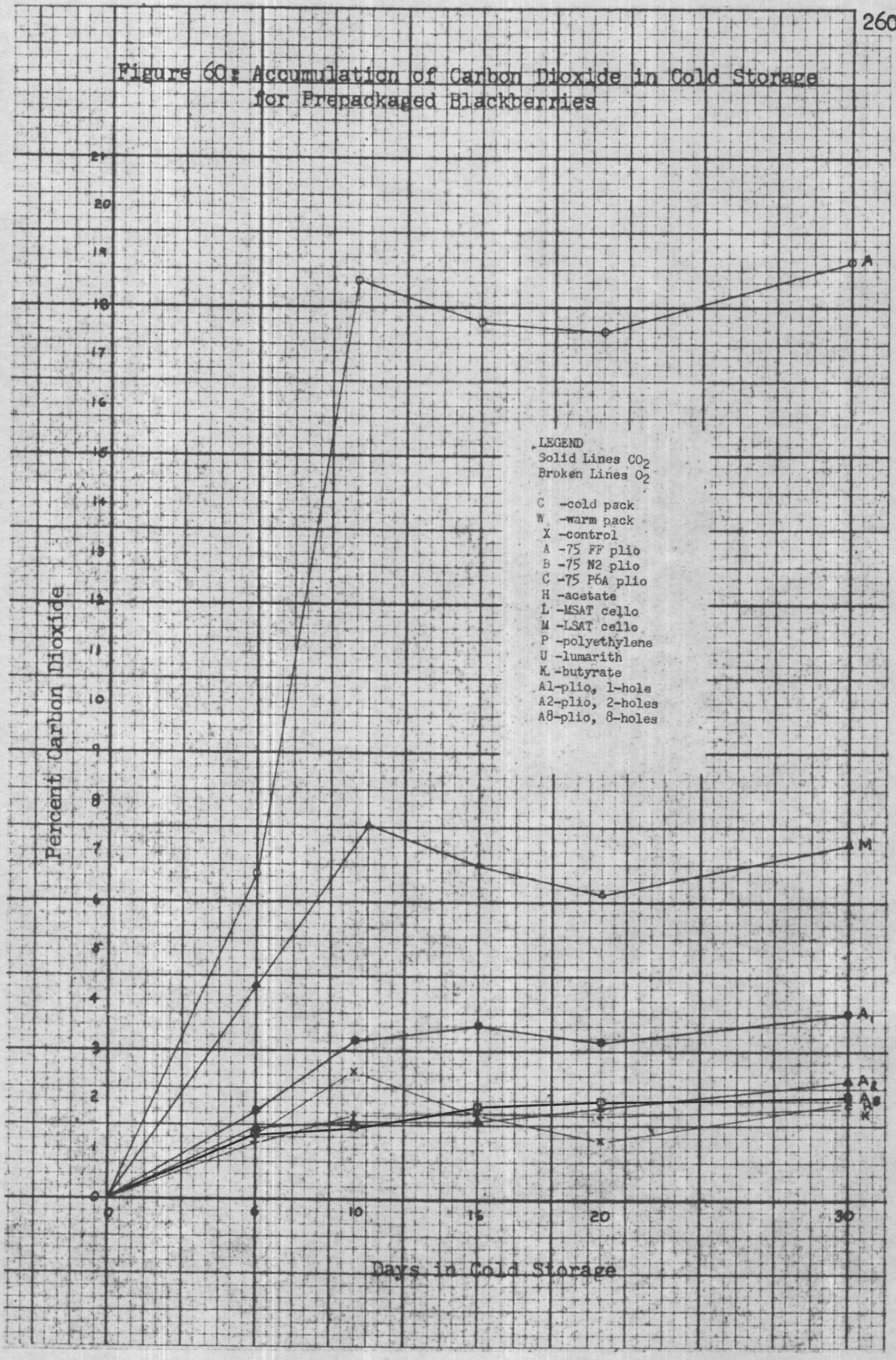
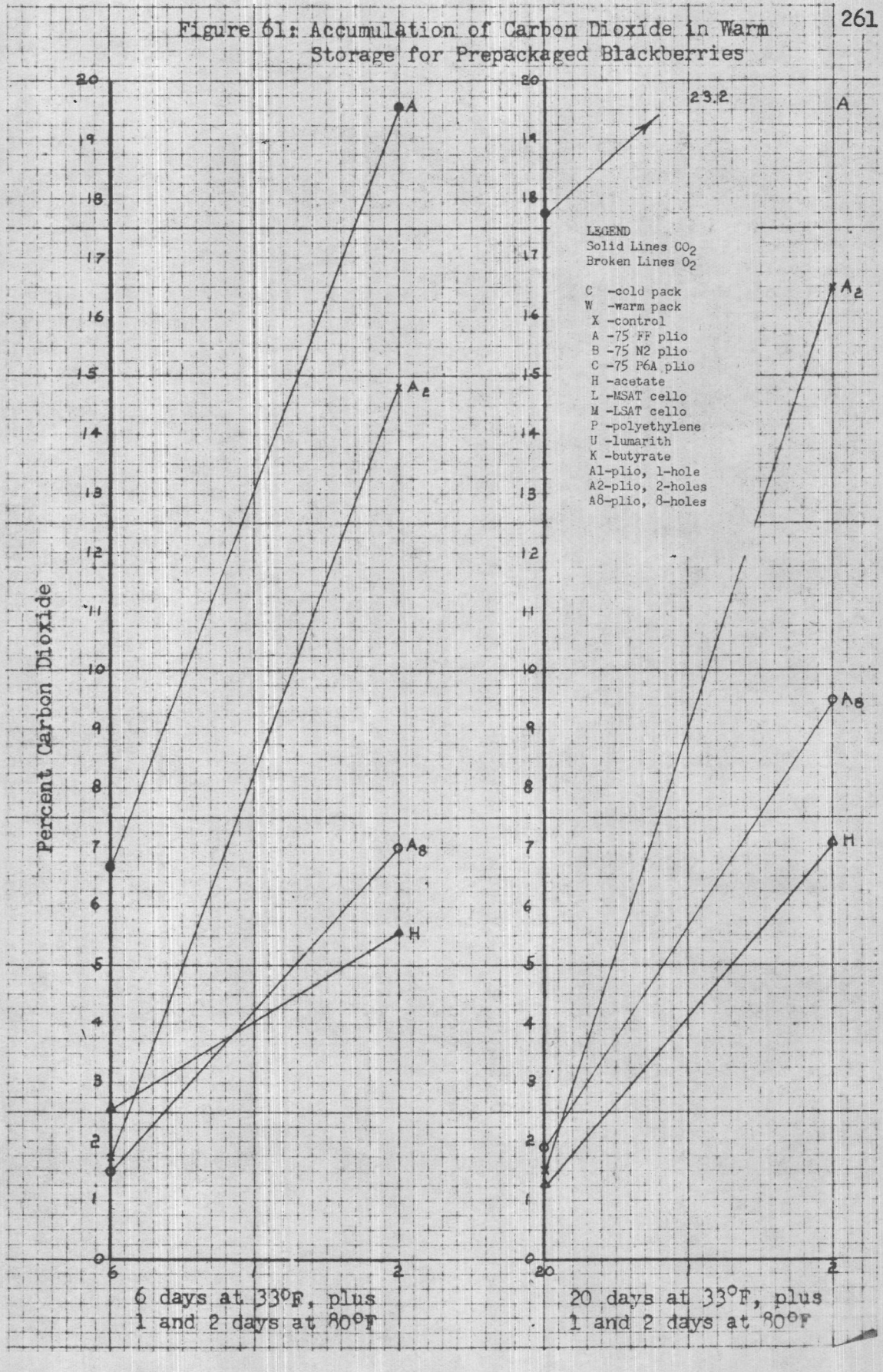


Figure 61: Accumulation of Carbon Dioxide in Warm Storage for Prepackaged Blackberries



accumulation.

A rapid rise in carbon dioxide content was observed for both test periods. The increase was greater for sample A than for A2 and greater for A8 than for H. Furthermore, the increase at the 20 + 2 period was greater than for the 6 + 2 interval. All samples had relatively low carbon dioxide values immediately after removal from cold storage.

It is important to note that in cold storage the punctured samples allowed sufficient escape of carbon dioxide to rate them at approximately the same level as the acetate sample. But in warm storage the differences were much more pronounced so that sample A2 more closely approached sample A than H while A8 was intermediate.

(3) Quality.

(a) Cold Storage.

Since the quality of blackberries was similar to that described for boysenberries, only the K film and punctured variations are discussed here. The quality of berries packed in butyrate was not different from those packed in acetate and, like them, was better than the controls. This was to be expected on the basis of the results of the weight loss and carbon dioxide values.

The samples in punctured pliofilm as well as in the sealed film all scored dessert quality after six days at

33° F. This was to be expected since little carbon dioxide had accumulated by that time. But by 10 days the CA sample was slightly off flavored and was scored commercial while the berries in punctured A's maintained top quality. At 16 days the fruit in A and A1 had become unsalable, A2 was commercial, and the 8-hole samples together with the acetates were still dessert quality. At 20 days all the pliofilm wrapped samples of berries were poor, except A8 was commercial while after one month the CU, CH, and CK samples were all that remained acceptable. The control deteriorated at about the same rate as the CA samples but for different reasons. To summarize, the berries in punctured film were better than in the corresponding sealed film but the puncture variation presented no advantage over the acetate type films since other factors of deterioration rather than weight losses appeared to be the controlling factors in quality breakdown of berries.

TABLE 38

Quality of Pre-packaged Blackberries in Cold Storage

Grade	Days in Storage									
	6		10		16		20		30	
Dessert	CA CA1 CA2 CA8	CU CH CK CX CM	CA1 CA2 CA8	CU CH CK	CA8	CU CH CK	CH CU			
Commercial			CA CX CM		CA2		CA8 CK		CK CH CU	
Poor					CA CA1	CX CM	CA CA1 CA2	CM CX	CA CA1 CA2	CM CX CA8

(b) Warm Storage.

The quality of blackberries was tested at the 6 + 1 + 2 and the 20 + 1 + 2 day intervals as shown in table 39. The rate of deterioration was found to be very much the same as that for boysenberries. The butyrate film and the acetate wraps permitted the samples to deteriorate in about the same manner and at the same speed. While in cold storage the pliofilm treatment with holes were definitely better than the tightly sealed packages, in warm storage the picture was not the same. Due to the larger amounts of carbon dioxide which accumulated a

rapid decrease in quality of flavor resulted so that the treatment more nearly resembled the sealed pliofilm than the acetate and butyrate wrapped samples.

Since weight losses did not present a problem in berries as they did for vegetables the advantage of punctures was not of much value in berries.

TABLE 39

Quality of Pre-packaged Blackberries in Warm Storage

	Days in Storage					
Grade	6 + 0	6 + 1	6 + 2	20 + 0	20 + 1	20 + 2
Dessert	CH CA8	CH		CH CA8		
Commercial	CX CA	CA8	CH	CA2	CH	CH
Poor		CA2 CA CX	CA2 CA8 CA CX	CA CX	CX CA8 CA2	CX CA8 CA2

4. Other Fruits: Grapes.

In order to facilitate comparison of results with those shown by "unwrapped" disinfection treatments, a table has been prepared showing the relative rank of all the treatments used in the pilot plant study.

TABLE 41

Results of Pilot-Plant Mold Inhibition Study on Emperor Grapes With and Without the Aid of Pre-Packaging

(Total Storage Time = 14 wks at 33° F)

Treatment					% Salable	
Compound	Conc.	Wrap	Code	Rank	Weight	Condition
$K_2S_2O_5$ cushion	5 g/crate	75FF pliofilm	J	1	66.7	Excellent.
$K_2S_2O_5$ pellets	5 g/crate	"	K	2	38.3	Good.
Dowicide C (pH = 8)	1000 ppm	None	C	3	29.0	Fair; some brown stems, no bloom.
Roccal	2%	75FF pliofilm	F	4	19.5	Fair - poor; some fruit soft, no bloom.
Roccal	2%	None	A	5	17.4	Fair - poor; some brown & dry stems. Slight bloom.
Phygon	100 ppm	None	D	6	16.3	Fair - poor; some brown & dry stems. No bloom.
Roccal	1%	None	E	7	7.8	Poor; mostly brown & dry stems. Trace of bloom.
Sodium Propionate	1%	None	B	8	1.3	Very poor; brown & dry stems, soft fruit.
Sodium Propionate	1%	75FF pliofilm	G	10.5	0.0	Very poor.
None	--	"	M	10.5	0.0	Very poor.
$K_2S_2O_5$ cushion	5 g/crate	None	U	10.5	0.0	Very poor.
None	--	None	X	10.5	0.0	Very poor.

An inspection of table 41 reveals:

1. Both wrapped and unwrapped treatments are generally better than the controls.

2. Wrapping alone did not reduce deterioration due to mold.

3. Overwrapping coupled with the maintenance of a very low partial pressure of SO_2 within the package gave promising results.

4. Solid potassium metabisulphite was satisfactory for the maintenance of such an atmosphere.

5. The same bisulphite treatment without the overwrap showed no significant improvement over untreated controls.

6. Since the latter represents commercial practice overwrapping merits considerable further investigation.

7. Among the aqueous dips Dowicide C was superior.

8. The effectiveness of aqueous dips was not improved by overwrapping, indicating that the disinfected treatments used were unable to inhibit the growth of mold even if storage contamination was eliminated.

9. The pilot-plant study showed sufficient promise especially with treatments J, K, and C to warrant a large scale field test similar to the one described for celery.

The distribution of "heavy, light and no-mold" in single crates of treatment J ($K_2S_2O_5$ cushion plus overwrap)

Plate XVII

Typical Bunch of Emperor Grapes of the Best Pilot Plant Treatment After 14 Weeks of Cold Storage

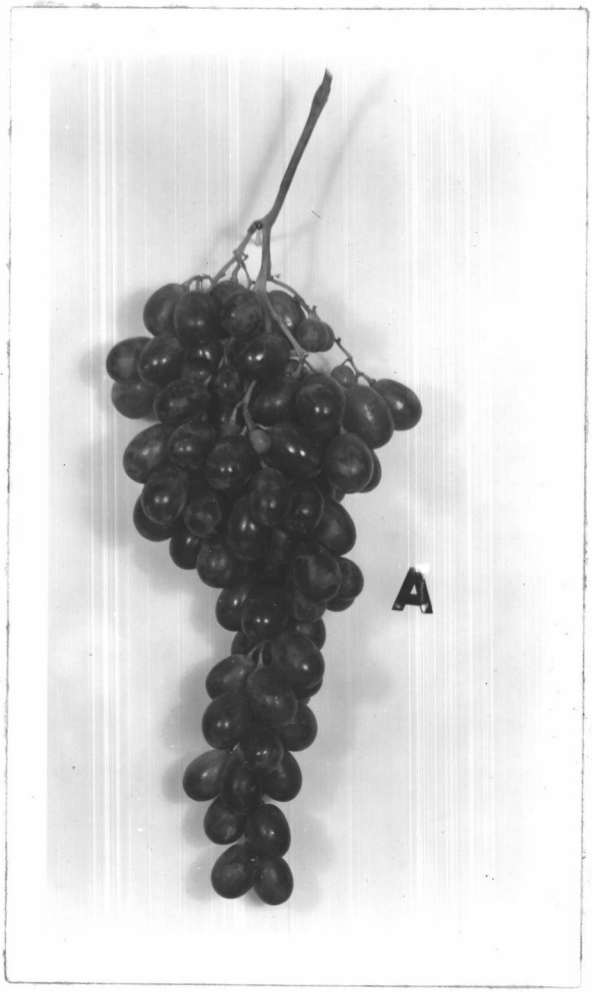
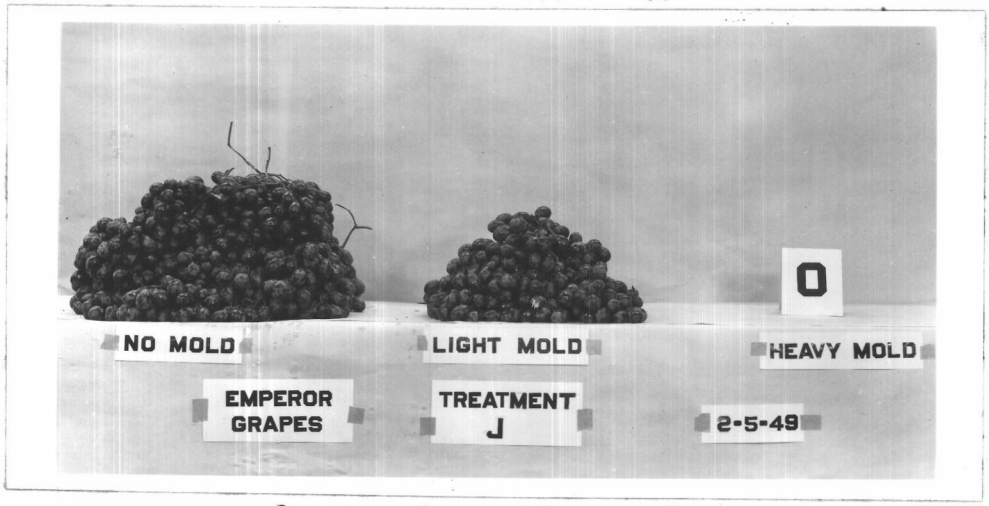
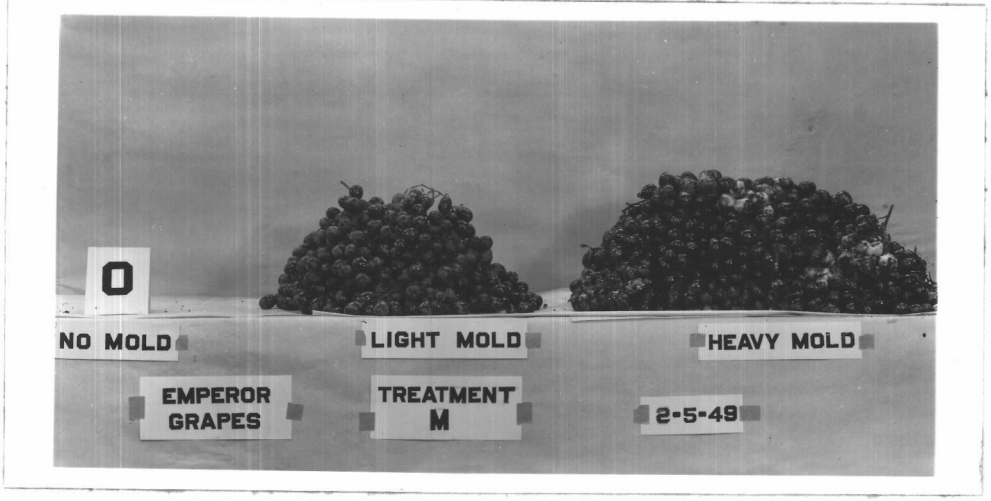


Plate XVIII

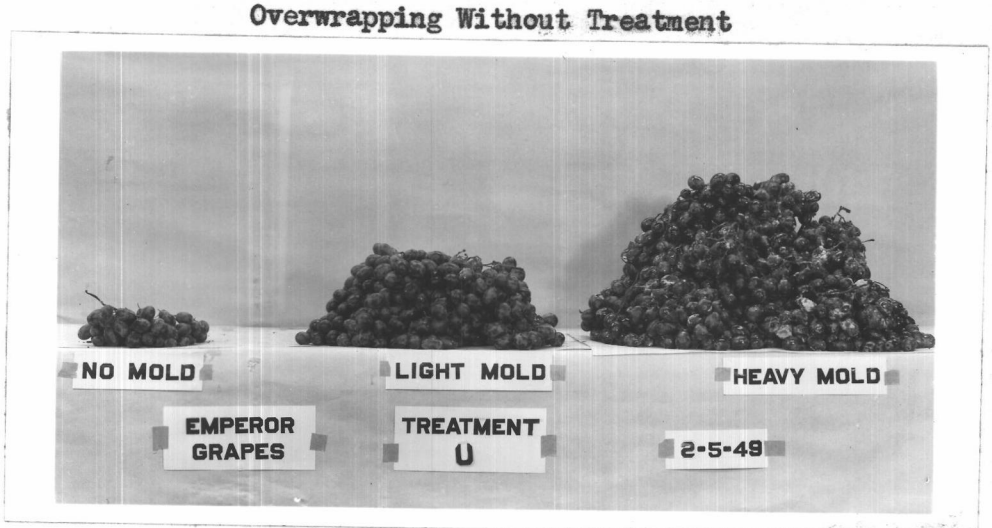
Distribution of Mold in Single Crates of Emperor Grapes Stored 14 Weeks at 33° F.



Overwrapping and Treatment



Overwrapping Without Treatment



Treatment Without Overwrapping

together with treatment M (overwrap without treatment) as well as treatment U ($K_2S_2O_5$ cushion without overwrap) are shown in Plate XVIII to illustrate some of the points discussed above. Plate XVII shows a typical bunch of Emperor grapes after 14 weeks of storage using treatment J.

D. Discussion of Section II.

An inspection of the results of pre-packaged vegetables and berries shows that for all products one or more treatments received quality ratings better than untreated samples. In general, a relationship was evident between carbon dioxide accumulation within the package and the flavor of the product; while a second relationship was observed between the weight loss and the extent of wilting. A third relationship was sometimes observed between the disinfection treatments and decay. Additional relationships between treatments and quality factors were observed but cannot be generalized since they appeared to be inherent characteristics of the particular produce tested. A comparison of the behavior of the seven vegetables and four fruits with respect to the various treatments will be discussed in the following pages on the basis of the three above-mentioned relationships.

1. Carbon Dioxide.

a. Accumulation.

(1) Cold Storage.

The two distinct groups of

carbon dioxide accumulations have been mentioned previously. They are general for most products and can be divided into those films in which the accumulation was 3% CO_2 or less and to those with considerable amounts of the gas—as much as 50% in a few cases.

The group of treatments having a low concentration consisted of the butyrate, polyethylene and acetate films as well as the 1, 2, 4, and 8 punctured MSAT samples and the tent flap closures. The low concentration of gas does not imply the curtailment of carbon dioxide production by these wraps. Instead these films permit a gaseous exchange equal to or greater than the respiration activity of the product while in cold storage.

The second group of treatments presented a greater barrier toward the passage of gases across the films and hence the carbon dioxide accumulated to a much greater extent. Since the degree of retention varied considerably among the several films it becomes necessary to limit the discussion to a single film. Thus a comparison of various products was made with reference to a particular film.

The first characteristic, common to all products, was the observation that after the first few days in cold storage the concentration of carbon dioxide attained a relatively constant level. This was true for all products. But it was also true that for the individual vegetables and berries the absolute values of carbon dioxide present

TABLE 40

Effect of Respiration Rate & Air-pack Volume on CO_2 Accumulation for Pre-packaged Vegetables and Fruits

Produce	CO_2 Accumulation in MSAT Bags			Avg Air Volume (cc) per gram Produce*	Avg Wt of Samples, grams
	Rank	Percent	Respiration Rate[x]		
Strawberries	1	20	20[xx]	0.50 ± 0.00	380.0**
Carrots	2	15	6	0.60 ± 0.20	294.1
Spinach	3	14	15	5.02 ± 0.50	58.2
Salad Mix	4	12	2	1.37 ± 0.17	73.5
Cauliflower	5	9	--	1.64 ± 0.24	60.6
Celery	6	7	3	2.41 ± 0.40	409.2
Tomatoes	7	6	5	0.94 ± 0.26	221.6
Lettuce	8	4	10	1.75 ± 0.25	342.4

[x] Mg CO_2/Kg/hr @ 0° C; ref (31).

* 10 samples of each vegetable weighed at 80 ± 0 storage interval and their volume determined by displacement.

[xx] Ref (12).

** Avg of 10 samples reported except strawberries where 3 samples were used.

varied widely from about 4% for lettuce to 20% for berries.

At first it would appear that the level of carbon dioxide within the package was principally a function of the respiration rate of the product. Table 40 lists the pre-packaged products studied and their rank according to the carbon dioxide accumulation together with the corresponding respiration rate of each in cold storage. Inspection of this table shows no direct relationship existing between these two factors alone. Next, the possibility of the volume of air included within the package at the time of sealing was considered. Therefore, in the table is also included the volume of air per unit weight of product in the package. Since no direct relationship is apparent, it was concluded that the original volume of air is not alone responsible for the accumulation of gas within the package.

Apparently other factors such as changes in respiration rate or respiratory quotient with storage time affect the equilibrium carbon dioxide concentration within the package.

The effect of respiration rate on the carbon dioxide accumulation within the package can be illustrated further by the results with the warm and cold packed berry experiments. The gas analysis after six days in cold storage showed much higher carbon dioxide accumulations

for the berries packed as received from the fields than for those which were chilled before packaging. Since the only variable in these tests was the temperature of the fruit at the time of packaging, it can be assumed that the higher respiration rate of the warmer product caused the difference in the carbon dioxide level. But the temperature at which the product was packed did not appear to alter the ultimate level of carbon dioxide attained in the package. For after 10 days in cold storage, the concentration of both variables was essentially the same. Thus the critical period for this particular factor existed for less than the first ten days of storage.

Aside from the three factors just discussed, namely the respiration rate, the air volume to weight ratio and the temperature of the produce when packed, there are unquestionably other factors involved in the attainment of carbon dioxide equilibrium of each product. Probably among these factors are changes in the respiration rate and in the respiratory quotient caused by the quantities of carbon dioxide and oxygen present in the product atmosphere.

(2) Warm Storage.

A study of the carbon dioxide accumulations in warm storage is hampered somewhat by the differences in the post-harvest life of the

various products. Because of this it was necessary to evaluate tomatoes, for example, within one and two days and carrots not until one and two weeks after removal from cold storage. Therefore, comparisons of the various products are limited.

In warm storage the grouping of treatments causing high accumulations and those allowing low concentrations of carbon dioxide in cold storage were widened to include an intermediate group of CO_2 concentration. This group was represented by the punctured films, window bags and stapled MSAT films. A possible explanation may be made on the basis that in cold storage the permeability of these packages was sufficient but in warm storage the increased respiration produced more carbon dioxide than the film would allow to diffuse. Thus in the higher temperature storage these treatments became unlike the acetates. But when a high respiration rate product such as spinach and berries was encountered, then even the acetate films were inadequate and allowed accumulation to occur so that even these treatments were raised to an intermediate CO_2 level.

It is also recognized that in warm storage the accumulation of carbon dioxide may not be a function of respiration alone but may be further enhanced by microbiological activity. Some evidence for this was obtained in cauliflower and salad mix when the disinfected

samples showed lower carbon dioxide values than the corresponding not disinfected samples.

Treatments in the above-mentioned intermediate group usually passed through a maximum point of concentration soon after removal from cold storage which decreased after further holding at room temperature. This was typical of most products and might be explained by one of two phenomena or a combination of both. The first explanation is based on reports in the literature in which it is stated that an abnormal increase in the respiration rate of plant products takes place immediately following removal from cold storage (2). This irregularity is supplanted in time by the normally occurring rate. The second possibility is that the normally increased rate occurring at the higher temperature is retarded by the unusually high amount of carbon dioxide (38). Following this decrease in rate a lowered concentration is obtained by diffusion through the package film. No evidence pertaining to the causes of this maximum point was obtained in these studies.

The effect of the level of carbon dioxide in cold storage on the rate of production in warm storage was not clear. Possibly there is a tendency for an increase in rate after the longer cold storage periods.

b. Off Flavor.

(1) Cold Storage.

For the majority of products packed a positive correlation was found for the carbon dioxide concentration with the formation of pronounced off flavors in the produce. Using the subjective criteria outlined in this report earlier, an off flavor borderline could be drawn on the graphs of carbon dioxide accumulation for most of the vegetables tested. The position and shape of the line varied for each product, depending upon its tolerance for carbon dioxide. For example, carrots were able to stand high amounts of the gas while berries were susceptible to relatively small quantities. The slope of the flavor borderline was usually negative which indicated that with prolonged storage less carbon dioxide can be tolerated.

(2) Warm Storage.

Accumulations of carbon dioxide were generally acceptable with regard to product flavor for only those treatments with low concentrations at the time of removal from cold storage.

c. Mold Development.

Mold growth did not occur on any wrapped product except tomatoes and berries. Unwrapped control samples of all products invariably showed mold

thus pointing to probable storage contamination. This infection was prevented effectively in wrapped produce including stapled and punctured treatments. For tomatoes and berries where mold development was noticeable in wrapped samples, it was found that in treatments which allowed a high carbon dioxide accumulation mold growth was markedly reduced and often completely prevented. However, the levels at which this occurred were undesirable from other points of view.

d. Color.

No generalization is possible with respect to the effect of carbon dioxide on the color of the product. For some produce the presence of carbon dioxide appeared to improve color retention—cauliflower and salad mix for example. For others, such as tomatoes, there was no apparent effect, while for some, such as carrots, it was harmful.

e. Rot.

The term rot, as discussed earlier, was used in the general sense of bacteriological decay as well as natural aging and physiological breakdown. Recognizing this definition, it may be stated that high carbon dioxide concentrations appeared to be conducive to rot. The critical level of carbon dioxide and time of exposure varied with the product. Since this type of

deterioration was not found with the corresponding produce samples with low carbon dioxide it was inferred that this spoilage was not caused by microbiological activity but rather due to physiological breakdown. Furthermore, disinfection treatments showed no improvement in such cases.

2. Weight Loss.

a. Wilting.

(1) Cold Storage.

Although the acetate and butyrate films on one hand and the punctured, stapled and window bags on the other hand exhibited about the same carbon dioxide level, their protection against moisture loss was quite different. The acetates and butyrate films were much less effective in their retention of moisture vapor. At the same time, the effect of moisture loss on wilting varied among the different products. For tomatoes and berries wilting was not pronounced even in the acetate wraps but for carrots the difference between the two film groups was marked. Thus, the overall quality of products in the partially sealed containers was generally higher than in the sealed acetate and butyrate films in cold storage.

(2) Warm Storage.

At the higher storage temperature wilting was also reduced by the open bags more than

by the acetate wraps. But the high humidity present in the former was conducive to greater micro-organism activity than was the case for the corresponding H and K film treatments which appeared relatively dry. Therefore, in many cases in warm storage, the quality of the high transmission wrapped products was above those of the punctured, stapled, and window-bag series. This was contrary to the situation reported for cold storage. For some products this situation could be reversed so that the punctured series rated superior by means of germicidal treatments. For some products, however, disinfection was not successful. This last statement does not preclude the possibility that the particular disinfection treatment was ineffective. In the cases of successful disinfection, the punctured series scored higher than the acetate samples by reducing the degree of wilt, and scored higher than the untreated, punctured series by reducing the off odor and rot formation.

3. Protection against Storage Contamination: Storage contamination was avoided for all pre-packaged samples including the tent flap and punctured wraps. In contrast the unwrapped control samples usually became badly molded whether disinfected prior to storage or not.

4. Quality.

A comparison of the results described for seven vegetables and four berry fruits indicates that no single film nor even treatment can be recommended for all the products tested.

For a produce such as lettuce, punctured or stapled films (treatments 2, 3, and 5) present a real advantage over acetates or butyrate in long-term cold storage by preventing undesirable wilt. Protection against wilt is also afforded by completely sealed treatments corresponding to 2, 3, and 5 but harmful accumulations of carbon dioxide produce injury. In tomatoes or berries, on the other hand, wilting is not an important quality consideration and thus for those products treatments 2, 3, and 5 present no advantage over the high gas transmission acetate films.

For some produce such as cauliflower or chopped salad, quality can best be preserved by sealed low gas transmission treatments since the accumulation of carbon dioxide is desirable for good retention of produce color.

In all cases, the time and temperature of storage are critical due to inherent characteristics of each product for each treatment or group of treatments. Only an examination of the results of the particular produce in question will reveal these relationships.

A very general separation of high and low moisture protection treatments can be made with regard to the type of microbiological decay which is indicated by the formation of rot and off odors. The high humidity present in any partially or tightly sealed low M.V.T. wrap was found to be conducive to bacterial activity, especially in warm storage.

For some products such as cauliflower, tomatoes, or chopped salad decay was effectively reduced by specific germicidal treatments while other products did not respond, ex. carrots, or were questionable, as lettuce and celery. In warm storage, proper disinfection prior to packaging appears to be a requisite for the safe usage of any film other than acetate or butyrate. Since the former treatments present distinct advantages over acetates or butyrates, efforts should be concentrated toward the application of the treatments found promising in this study as well as toward the investigation of additional germicidal treatments especially for such produce where the present disinfection tests were negative.

The use of partially sealed low permeability films cannot, however, be recommended for merchandizing at room temperature of products such as spinach or berries which have very high respiration rates. For these even acetates accumulate dangerous amounts of

carbon dioxide. Since flavor is impaired efforts should be centered on the development of films with gas permeabilities even greater than those shown by acetate and butyrate. The question as to why such commodities should be packaged at all can be answered principally by emphasizing the protective power of any plastic film against microbiological contamination. Assuming that proper disinfection methods can be developed for products such as spinach or berries, these would be of only limited usefulness unless combined with a protective agent such as a proper plastic wrap to preserve the partial sterility attained. Films with gas transmission rates higher than acetates have recently been reported by some of the plastic film manufacturers. Higher gas transmission rates also could be attained by reducing the gauge of the present films. Since the thicknesses used are not great such additional reductions would introduce severe handling problems.

Most of the films and wrapping techniques which were tested in this comparison study represent commercial practice. It must be emphasized again that the results obtained cannot serve as a basis for final commercial choice but merely as a starting point for large-scale studies since only trends can be derived from these experiments.

A number of individual values can be picked out of any of the experimental series which will not corroborate the trends outlined for the products tested. The reason for this discrepancy can be traced first to the relatively small number of samples used and second, to the subjective nature of some of the characteristics scored. Despite all efforts towards uniformity variations within each produce were found to be unavoidable. Additional field tests will be required to confirm some of the results indicated in the present study.

Since the technical evaluation of prepackaging represents a new field it was necessary to run first an exploratory type of study. This will serve as a basis for future detailed investigations on commercial size samples of specific produce using the treatments found best in the present study.

It should be brought out also that the quality characteristics studied are not the only ones to be considered in the final choice of prepackaging since other factors such as film cost, availability, mechanical strength, ease of application and transparency also have to be considered.

While this study did not attempt to evaluate the tensile strength and durability of the various films it was evident that the pliofilms and polyethylene bags were strong and durable during storage. The acetates

were strong but not as pliable. The cellophanes weakened in storage considerably but showed little loss of flexibility. It should be mentioned also that the acetate and butyrate films are not heat sealable and that the polyethylene films are not transparent but merely translucent.

SUMMARY AND CONCLUSIONS

This investigation was concerned with the reduction of waste in raw vegetables and fruits between harvest and consumption. The work has been presented in three phases which were inter-related. The first phase was an evaluation of a number of chemical compounds with respect to their effectiveness in reducing post-harvest spoilage of fresh fruits and vegetables. The second part consisted of an evaluation of several transparent films applied to raw produce as wrappers and their effect on the keeping quality of the plant material until consumed. And finally, a combination of the above two phases namely chemical disinfection and overwrapping was studied for certain fruits and vegetables.

I. Disinfection.

A. Laboratory Studies: A number of chemicals having "in vitro" germicidal power were evaluated for their ability to reduce decay caused by micro-organisms on raw fruits and vegetables between harvest and consumption. Small samples of six vegetables and two fruits were inoculated with mixed cultures typical for each produce and then treated with aqueous solutions of the various chemicals.

Each chemical was studied at three concentrations, the level varying with the reported "in vitro" potency of each compound.

The treatments were evaluated for each produce against untreated controls using duplicate tests with triplicate samples for each chemical and concentration.

Treatments which consistently reduced mold and/or rot development compared to controls were singled out. Among these treatments were a number of chemicals and concentrations which caused physiological damage in specific fruits or vegetables tested. Such treatments had to be rejected. Thus the final selection reduced the number of promising treatments to a few chemicals and concentrations which, in turn, varied with each product.

These were used for pilot plant studies in which commercial crates of produce rather than individual units were tested. No satisfactory disinfectant was found for strawberries.

In addition the information gained in the preliminary experiments served as a basis for disinfection treatments used in conjunction with pre-packaging. For those tests individual sample units or the contents of a crate were sealed into plastic films immediately following disinfection.

B. Pilot Plant Studies:

1. Celery. Germicidal aqueous dips of Onyxide, Decco, and Cetab were found to reduce spoilage of celery during ten weeks in cold storage. These three

treatments produced the most satisfactory results of the ten treatments studied for a lot of 25 crates of Pascal celery.

2. Grapes. Three of five treatments, namely 0.1% solution of Dowicide C, 2% solution of Roccal and 0.01% Phygon, tested on commercial lug boxes of Almeria and Emperor grapes showed sufficient mycostatic power for 14 weeks in cold storage to warrant a field test.

C. Field Test on Celery: Statistical analysis of a large scale 14 weeks' cold storage test, in which three lots, approximately 1000 bunches each, of Pascal celery were treated with one of three chemical disinfectants considered best in the pilot plant study yielded the following information:

(1) On the basis of the eleven characteristics evaluated subjectively for each bunch, the commercial application of 0.1% aqueous solution of Decco at pH = 5.0 can be recommended for the reduction of general rot development in cold storage of Pascal celery.

(2) One-tenth of one per cent Onyxide and 0.1% Cetab considerably reduced the amount of mold development of Pascal celery in cold storage but commercial application cannot be recommended, at least in the concentrations used, since the amount of visible stalk damage was significantly increased over that shown by corresponding untreated or Decco treated celery.

(3) Inspection showed good correlation between total bacterial and mold counts with the subjective evaluations for mold and rot development.

II. Prepackaging.

Several of the commercially available plastic films as well as some experimental types were compared for their merit in prolonging the salable life of raw vegetables and fruits.

Using nine types of films for prepackaging, seven of the major vegetables and five fruits were studied. All of the commercial wrapping techniques such as complete seals, tent-closures, punctures and window bags were compared for their relative merits when applied in conjunction with the various film types.

Harvested produce was packaged both before and after the removal of field heat. Behavior of the prepackaged products in both 33° F storage and 80° F storage was studied. Cold storage was extended as long as 120 days while holding at room temperature varied widely with the produce. Observations were made at regular storage intervals for each product.

1. Comparison of 16 film and wrapping techniques showed variations in overall quality for all seven vegetables and five fruits tested.

2. Individual quality characteristics, such as color, wilt or flavor, were affected to a different extent

by the various treatments.

3. Samples of the same produce scored higher in certain films than the unwrapped control while those in other films scored lower.

4. The relative merits of each treatment varied with each type of produce tested. Certain films and wrapping techniques scored superior for one product and less acceptable for another.

5. Storage temperature and time seriously affected the rating of films and wrapping methods for each vegetable and fruit studied.

6. For most products, the partially sealed, low permeability MSAT containers and the completely sealed Polythene wraps scored highest for overall product quality. These treatments prevented the accumulation of undesirable CO_2 and protected the produce against weight-loss and consequent wilting. For some produce, expecially berries, wilting was not apparent even in high permeability films such as acetates.

7. On the basis of the weight loss and gas analysis data obtained for each produce it was concluded that neither the rate of respiration of the plant at the time of packaging, nore the total volume of air within the package were alone responsible for the rate and amount of carbon dioxide accumulation within each type of container. A direct association between the carbon dioxide concentration

and the critical quality characteristics such as flavor, color, odor, and decay were found to exist and are indicated under the results of each produce studied.

8. The difference in the rate of deterioration between untreated produce and optimum treatment was greater in cold than in warm storage. In warm storage acetate base wraps deteriorated at the lowest rate. For some produce, such as strawberries or spinach, even acetate base treatments accumulated carbon dioxide in warm storage.

9. Storage infection was effectively inhibited by prepackaging even with partially sealed containers.

10. Partially sealing, such as puncture or tent-flap closures, considerably reduced carbon dioxide accumulation of low permeability films, while at the same time showing effective protection against moisture loss, similar to the corresponding completely sealed containers, which on the other hand showed high CO_2 accumulation.

11. For products, such as lettuce or carrots, where wilting is critical, partial seals were ideal for cold storage. In warm storage, however, such containers showed some microbiological spoilage which was probably due to the high relative humidity within such packages.

12. For berries or tomatoes in which wilting is less critical, the partially sealed containers or low gas permeability offered little advantage over acetate base films

in cold storage. In warm storage acetates are preferred again because of significantly lower carbon dioxide accumulation.

13. For some products, sealed low permeability films offer advantages over other treatments in appearance, especially color retention. (ex. cauliflower and chopped salad) But the high incidence of decay limits the commercial application of these films.

14. No significant difference between Lumarith, DuPont acetate and Kodapak acetate-butyrate were found by either the subjective or objective tests. Partially sealed acetates showed no significant difference from the corresponding completely sealed films. No significant difference between produce prepackaged warm or cold into the above film types could be detected regardless of storage temperature.

15. Partially sealed containers of low gas permeability films showed significantly lower carbon dioxide accumulations than corresponding completely sealed films. However, protection against moisture loss was found to be approximately equal to the corresponding tight wraps. This would explain the overall quality rating of the partially sealed wraps being superior to tight closures. This statement is limited to those products where accumulation of carbon dioxide is definitely harmful and where weight losses are generally high.

Variations between types of partial seal were critical only in warm storage where carbon dioxide accumulations were higher for all treatments. In general, the tent-flap closures and single punctures showed equal behavior while four and eight punctures more nearly approached acetates in gas permeability.

16. The polyethylene treatments, in which only tight seals were studied, exhibited subjective and objective characteristics similar to the partially sealed gas transmission treatments, namely: good moisture retention with high gas permeability.

17. Among the low gas transmission treatments, the pliofilms showed the greatest carbon dioxide accumulation, the smallest weight losses and, for most products, the lowest quality scores.

18. Sealed LSAT cellophane wraps behaved differently from all other films in that both the carbon dioxide and oxygen concentration were low.

Since this behavior was consistent for all products tested, it must be considered an inherent characteristic of the film.

19. The removal of field heat prior to packaging was found to be critical only for the first days of cold storage when carbon dioxide accumulation was lower in the samples packed cold so that overall quality, especially flavor, scored higher. After ten days of cold storage,

differences between cold and warm packed samples were not noticeable.

20. The development of rot and mold in prepackaged produce was a function of the carbon dioxide concentration within each type of container, as well as the time and temperature of storage.

III. Disinfection with Prepackaging

The use of a disinfection treatment prior to prepackaging markedly altered the warm storage quality of some products. In this connection film and wrapping methods other than acetate treatments also provided samples with high, sometimes top, quality. For other products disinfection followed by packaging did not reduce the occurrence of decay so that the quality rating was not improved.

1. In the case of Emperor grapes a significant reduction in mold development was accomplished.

2. Among vegetables, disinfection prior to packaging was especially helpful for low moisture-vapor transmission films. For some vegetable disinfection prior to packaging reduced decay sufficiently to give some of the partially sealed low moisture transmission films highest quality ratings.

Since for other products disinfection failed to give any improvements in product quality, a study of additional disinfection treatments is indicated.

IV. General.

On the basis of the pre-packaging studies carried out for seven vegetables and five fruits, it was concluded that no single film or wrapping technique can be recommended for all products tested. Nor can a single method of disinfection for all products or all types of microbiological spoilage be used.

Only after careful inspection has been made of the results detailed under each product can future large-scale tests be carried out with particular fruits or vegetables.

1. Aiken, William H. New plastic films. Modern Packaging 19: No. 9; 141-4; 172, May 1946.

2. Appleman, C. O. and Smith, C. L. Effect of previous cold storage on the respiration of vegetables at higher temperatures. Journal of Agricultural Research 53: 557-580, 1936.

3. Barr, C. Guinn and Slade, M. A. Stericooling packed peaches for the fresh market. Pre-Pack-Age 1: No. 12, 5-8; 32, Aug. 1948.

4. Bartlett, P. G. Disinfectants and sanitizers. Chemical Industries 64: No. 2; 215-217; 318, Feb. 1949.

5. Brooks, Charles, Bratley, C. O. and McColloch, L. P. Transit and storage diseases of fruits and vegetables as affected by initial carbon dioxide treatments. U.S.D.A. Technical Bulletin 519, 1936. 24p.

6. Brooks, Charles, Miller, E. V., Bratley, C. O., Cooley, J. S., Mook, Paul V. and Johnson, Howard B. Effect of solid and gaseous carbon dioxide upon transit diseases of certain fruits and vegetables. U.S.D.A. Technical Bulletin 318, 1932. 59p.

7. Cardinell, H. A. Packaging must have better produce; must have precooling and refrigeration. Pre-Pack-Age 2: No. 2; 5-7; 32, Oct. 1948.

8. Davis, Donald W. Gas Permeability Modern Packaging 19: No. 9; 145-149; 176-178, May 1946.

9. Dow Chemical Company. Dowicides, industrial germicides and fungicides. Midland Mich., Dow Chemical Company, 1941. 44p.

10. Gaylord, F. C., Fawcett, K. I., Doty, D. M., Hivon, K. H., Redfield, G. M., and White, R. V. Packaging fruits and vegetables. Purdue Agric. Expt. Sta. Bulletin 530, 1948. 23p.

11. Gerhart, Fisk and Wright, T. R. Cherry packaging with transparent films. Good Packaging 9: No. 5; 35-39; 40, May 1948.

12. Gore, H. C. Studies on fruit respiration. U.S.D.A. Bureau of Chemistry Bulletin 142, 1911. 40p.

13. Harshbarger, K. E. Report of a study of the toxicity of several food processing agents. Journal of Dairy Science 25: part 1; 169-174, 1942.

14. Hauck, Charles W. Experimental marketing of strawberries and peaches. Ohio Agric. Expt. Sta. Bimonthly Bulletin 21: No. 240; 60-64, May-June 1946.

15. Hauck, Charles W. Shelf-life of fresh fruits and vegetables can be lengthened. Ohio Agric. Expt. Sta. Bimonthly Bulletin 31: No. 241; 100-103, July-Aug. 1946.

16. Hauck, Charles W. and Crawford, John J. Salable life of seven vegetables. Ohio Agric. Expt. Sta. Bimonthly Bulletin 32: 245; 96-101, May-June 1947.

17. Hauck, Charles W. and Lenox, W. L. Tare weights and wastes in marketing fresh fruits and vegetables. Ohio Agric. Expt. Sta. Bimonthly Bulletin 32: No. 245; 71-76, Mar.-Apr. 1947.

18. Hayes, K. M., Fellers, Carl R. and Esselen, W. B., Jr. The keeping quality of pre-packaged fresh cranberries. Proc. Amer. Hort. Soc. 52: 257-262, 1948.

19. Hoffman, Charles, Schweitzer, Robert T. and Dalby, Gaston. Fungistatic properties of the fatty acids and possible biochemical significance. Food Research 4: 539-45, 1939.

20. Hoogerheide, J. C. The germicidal properties of certain quaternary ammonium salts with special reference to cetyl-trimethyl-ammonium bromide. J. Bact. 49; No. 3, 277-289, March 1945.

21. Hucker, G. J., Brooks, R. F., Metcalf, Dorothea and van Eseltine, William P. The activity of certain cationic germicides. N. Y. Agric. Expt. Sta. Technical Bulletin 281, Apr. 1948. 20p.

22. Hucker, G. J., Metcalf, Dorothea and Cook, Carolyn. The rate of germicidal action of the quaternary ammonium compounds. N. Y. Agric. Expt. Sta. Technical Bulletin 280; Apr. 1948. 20p.

23. Ingle, J. D. Some preliminary observations of the effectiveness of propionates as mold inhibitors on dairy products. J. Dairy Sci. 23:509, 1940.

24. Judkins, W. P. The use of pliofilm as a packaging material for peaches. Ohio Agric. Expt. Sta. Bimonthly Bulletin 31:119-122, 1946.

25. Kaloyereas, S. A. Use of dry ice and carbon dioxide for food preservation. Refrigeration Engr. 57: No. 5; 453-457, 498-500, May 1949.

26. Kaufman, J., Friedman, B. A. and H'ruschka, H. W. Prepackaging of Long Island broccoli, brussels sprouts and cauliflower. Pre-Pack-Age 1: No. 11; 10-13, July 1948.

27. Klotz, L. J. Nitrogen trichloride and other gases as fungicides. Hilgardia 10: 27-52, 1936.

28. Lau, Shiu Chi. The potentialities of certain chemical compounds as food preservatives. Ph.D. Thesis Oregon State College, June 1947. 49p.

29. Link, H. L. and Pancoast, H. M. Antiseptic cooling retains top quality of perishables. Food Industries 21:57-61, June 1949.

30. MacIntosh, F. C. The toxicity of diphenyl and ortho-phenyl-phenol. The analyst 70:334-335, 1945.

31. Mehren, G. L., Morris. L. C. and Calhoun, Wendall. Notes on consumer packaging of vegetables. Good Packaging 8: No. 10; 29-39, Oct. 1947.

32. Moulton, James C. The effect of pre-packaging and refrigeration of strawberries on the water loss, spoilage, vitamin C content and sugar-acid ratio of the fruit. Proc. Amer. Soc. of Hort.:263-268, 1947.

33. Nelson, Ray. Storage and transportational diseases of vegetables due to suboxidation. Mich. State College Agric. Exp. Sta. Technical Bulletin 81, 1926. 38p.

34. Pentzer, William T. and Asbury, C. E. Sulfur dioxide as an aid in the preservation of grapes in transit and storage. Blue Anchor 11: No. 8; 2-4; 23, Aug. 1934.

35. Pentzer, William T. and Banger, W. R. A comparison of fungicidal treatments for the control of botrytis rot of grapes in storage. Proceedings of the American Society for Horticultural Science 39:281-284, 1941.

36. Pentzer, William T. Supplementary refrigeration of fruits and vegetables. Refrigeration Engr. 42: 161-164; 239-42, Sept. and Oct. 1941.

37. Platenius, Hans. Effect of temperature on the rate of deterioration of fresh vegetables. Journal of Agric. Research 59: No. 1; 41-58, 1939.

38. Platenius, Hans. Effect of temperature on the respiration rate and respiratory quotient of some vegetables. Plant Physiology 12:179-197, 1942.

39. Platenius, Hans. Effect of oxygen concentration on the respiration of some vegetables. Plant Physiology 18:671-684, 1943.

40. Platenius, Hans and Jones, J. B. Effect of modified atmosphere storage on ascorbic acid of some vegetables. Food Research 9:378-385, 1944.

41. Platenius, Hans. Films for produce Department of Vegetable Crops, Cornell Univ. Paper No. 282, 1946. 6p.

42. Ramsey, Glen B. and Link, G. K. K. Market diseases of fruits and vegetables: tomatoes, peppers, eggplants. U.S.D.A. Misc. Publ. 121, 1932. 44p.

43. Ramsey, Glen B., Wiant, James S. and Link, G. K. K. Market diseases of fruits and vegetables: crucifers and cucurbits. U.S.D.A. Misc. Publ. 292, 1938. 74p.

44. Ramsey, Glen B. and Wiant, James S. Market diseases of fruits and vegetables: asparagus, onions, beans, peas, carrots, celery and related vegetables. U.S.D.A. Misc. Publ. 440, Sept. 1941. 70p.

45. Ramsey, Glen B. and Wiant, James S. Market Diseases of fruits and vegetables: beets, endive, escarole, globe artichokes, lettuce, rhubarb, spinach, Swiss chard and sweet potatoes. U.S.D.A. Misc. Publ. 541, 1944. 40p.

46. Rasmussen, M. P. and Platenius, Hans. Produce pre-packaging. Modern Packaging 19: No. 12; 128-134; 166-170, Aug. 1946.

47. Rudolph, A. S. and Levine, Max. Factors affecting the germicidal effeciency of hypochlorite solutions. Iowa Engr. Expt. Sta. Bulletin 150: July 1941. 48 p.

48. Schmelkes, F. C. and Guiteras, A. F. The comparative action of sodium hypochlorite, chloramine - T and azochloramid on organic substrates. J. Biol. Chem. 107; 235-239, 1934.

49. Scott, L. E. and Tewfik, Salah. Atmospheric conditions in consumer packages of vegetables. Pre-Pack-Age 1: No. 1; 16-18, Sept. 1947. Also Maryland Agric. Expt. Sta. Misc. Publ. 57.

50. Shechmeister, I. L. and Salle, A. J. Germicidal efficiency of synthetic phenolic compounds tested by the improved tissue culture method. Proceedings of Society of Experimental Biology and Medicine 38: Section 9825P:295-6, 1938.

51. Shelanski, H. A. Toxicity of quaternaries. Soap and Sanitary Chemicals 25:125-129,153. Feb. 1949.

52. Stahl, Arthur L. and Vaughan, Paul J. Pliofilm in the preservation of Florida fruits and vegetables. Univ. of Florida Agric. Expt. Sta. Bulletin 369, Feb. 1947. 92p.

53. Stokes, D. R. Millions are lost from spoiled fruits and vegetables. Refrigeration Engr. 54: No. 4; 355-358, Oct. 1947.

54. Stokes, D. R. Pre-packaging conclusions. Modern Packaging 21: No. 11; 104-110, July 1948.

55. Tarr, H. L. A. Chemical disinfection and corrosion prevention. Journal of the Fish Research Board of Canada 7: No. 3; 101-115, 1947.

56. Thornton, Norwood C. The effect of carbon dioxide on fruits and vegetables in storage. Contrib. Boyce Thompson Inst. 3:219-244, 1931.

57. Thornton, Norwood C. The influence of carbon dioxide storage on the oxygen uptake of fruits and vegetables. Contrib. Boyce Thompson Inst. 5: 371-418, 1933.

58. Valley, G. The effect of carbon dioxide on bacteria. Quart. Review Biol. 3:209-224, 1928.

59. van Eseltine, William P. and Hucker, G. J. The effect of organic matter on germicidal activity of the quaternary ammonium compounds. N. Y. Agric. Expt. Sta. Technical Bulletin 282, Apr. 1948. 20p.

60. Weber, George R. and Levine, Max. Factors affecting germicidal efficiency of chlorine and chloramine. Amer. J. Public Health 34:719-728, 1944.

61. Western Grower's Ass'n. Research Inst. Produce shippers' test. Modern Packaging 21: No. 6; 128-133, 188-190, Feb. 1948.

62. Wolford, E. R. and Anderson, A. A. Propionates control microbial growth in fruits and vegetables. Food Industries 17:622-24, 726, 728, 730, 732, 734, 1945.

63. Wyss, A. P. and Poe, C. F. Study of the germicidal values of benzoic acids and benzoates. Proc. Inst. of Food Technologists 21-28, 1945.

64. Personal communication with Dr. R. H. Robinson of Agricultural Experiment Station, Oregon State College. 1947.