The University of Manitoba

FLUIDIZED BED DEHYDRATION OF MANITOBA ONIONS

by

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ABSTRACT

FLUIDIZED BED DEHYDRATION OF MANITOBA ONIONS

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Physical appearance, cleanliness and pungency are the three main criteria for judging the quality of dehydrated onions. Preservation of the best quality is essential for the onion processing industry. Quality characteristics such as color, total solid content, microbial population and flavor are highly dependent on the conditions of processing. Proper dehydration and storage conditions are necessary to ensure good quality dehydrated products. This study was designed to evaluate optimum dehydration technique for Manitoba onion varieties and optimum storage conditions for the processed product. A preliminary dehydration study of white onion varieties grown for this project by the Department of Plant Science was also carried out.

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CHAPTER 1

INTRODUCTION

Allium cepa L., the common onion, is a vegetable facing rapidly increasing demands. In 1967 Canada produced 224,627,000 pounds of onions but still had to import 86,508,000 pounds of onions from the United States and other European and African countries. A tariff of 1.5% per pound of imported onions was imposed by the Canadian Government for 44 weeks of the 52 week year [11]. Increased costs in the shipping and storage of fresh onions are essentially responsible for Canadian buyers switching to importation of dehydrated vegetables. From April to June, 1972, Canada had imported a total of 1,502,835 pounds of dehydrated vegetables totalling $722,246 and dehydrated onions accounted for 734,158 pounds or $311,504 [20]. The current market price of imported dehydrated onions ranges between 60 to 70 cents per pound for American imports and around 40 cents per pound for African, Asian and European imports, which are of inferior quality [20].

Considered as a spice, onions can be added to many food items to enhance or contribute a particular flavor. Beside domestic uses, packing industries, institutional food supplies and convenience food products all utilize onions in both fresh and dehydrated forms [63].

Canada produces over two hundred million pounds of fresh onions annually. Little or none of these are dehydrated. Ontario and Quebec are the largest onion producers in the country. Together they account for 90% of the annual production. Table 1 lists the Canadian onion production figures from 1969 to 1971.

Manitoba averaged 3532.5 acres of land for vegetable production from 1968 to 1971 annually and an average of 805 acres were used for onion production [37]. Table 2 demonstrates the farm values of Manitoba vegetable from 1968 to 1971.

Judging from the production statistics, Manitoba is capable of supporting a vegetable dehydration industry. However, the quality of the dehydrated product remains the major uncertainty. The purpose of this study was to evaluate the potential of Manitoba onions in the dehydration industry. The main areas of concern studied were:

1. The establishment of an optimum dehydration technique for Manitoba onions.
2. The effect of storage conditions upon the quality of dehydrated Manitoba onions.
3. Comparison of yellow versus white onion varieties.
4. Preliminary investigation of three white onion varieties grown in Manitoba by the Department of

Table 1

Production of Onions in Canada 1969-1971 [57,58]

Year	Canadian Production	Quebec Production	Ontario Production	Manitoba Production
	. . . In '000 pounds . . .			
1969	226,060	70,670	126,941	11,592
1970	254,952	105,154	121,511	9,782
1971	234,717	132,506	72,163	13,392

Table 2

Fresh Vegetable Production and Farm Values
in Manitoba 1968-1971 [34,35,36,37]

Year	Total Acreage	Acreage on Onions	Total Value	Onion Value
			in '000 dollars	
1968	3,655	990	1,662	492
1969	3,605	840	1,996	522
1970	3,440	670	2,023	342
1971	3,430	720	2,757	549

Plant Science, University of Manitoba in 1972.

CHAPTER 2

REVIEW OF LITERATURE

There are more than 250 members of the family *Allium* The two most commonly known are *Allium sativum* and *Allium cepa* -- the garlic and the cooking onion. The earliest record of onion dehydration was unavailable but believed to be in the late 19th Century. One of the pioneer processors in North America was W.A. Peck of Waesonville, California. It was recorded that samples of dehydrated onions produced in 1909 still retained their pungency when tested in 1959 [63].

The popularity of dehydrated onions did not increase until 1923 when more processors started new dehydration plants in California. In 1960 the total farm tonnage for onion in the U.S. was 1,312,000 tons and 112,000 tons were dehydrated [63].

The demand for dehydrated onions is continuing to mount and now in 1973 the world is facing a shortage in the supply of dehydrated onions. It is hard to explain why a common commodity like onion should attract so much attention in processing techniques and variety modifications. Fresh onions are cheap and readily available in almost any part of the world.

Why are onions dehydrated?

Ease of processing and low transportation costs are the main factors. Dehydrated onions at 1/8 of the original weight will not only reduce shipping costs but also cut down storage costs. The advance of dehydration technology had also allowed the processing costs to be greatly reduced.

2.1 Tunnel Drying of Onion

The oldest commercial method of onion dehydration involved the use of tunnel driers [17]. Chopped or diced onions were spread evenly on wooden trays, 1¼ pounds per square foot. Hot air between 160° to 190°F was blown on the onion in the first stage of drying for three to four hours. Cooler air at 120°F was used at the later stage to remove moisture from the onions. When the onions were dried to between 5 to 7% moisture they were transferred to bins and dried in hot air until the desired moisture level of 3 to 4% was attained [63,39].

Drying on wooden trays was effective and cheap except for one major problem. Partially dehydrated onions are highly adhesive and they tend to adhere to the wooden trays. If not properly removed, these adhered particles would char and burn under prolonged exposure to the constant heat. The only means of removal was by scraping, scrubbing and washing. Sometimes loses due to mechanical injury and burning could go up to as high as 10%. Furthermore, wooden trays had a much shorter life span than expected due to scrubbings and washings [61,63].

The introduction of stainless steel conveyor belts eliminated most of the damages caused by adhesion. It also provided a means of continuous processing. A sanitary and efficient dehydration process is now available to the industry [16].

Modern dehydration techniques recommended low temperature operation. High dehydration temperatures above 190°F were blamed for unnecessary browning, denaturation and aroma loss. It was believed by lowering processing temperature many of these problems could be eliminated [25]. Low processing temperatures, however, would prolong the processing time, thus exposing the food items to undesirable enzymatic reactions and denaturations. A processor must therefore be justified in the application of a particular process. This coincides with King's "relative temperature dependency" findings [25]. He measured the effects of decreasing temperature on browning versus moisture removal. By lowering processing temperature from 40°C to 10°C, the rate of water removal was reduced by a factor of 5.6 whereas the rate of browning was reduced by a factor of 176. This indicated that the decrease in browning is far more pronounced than the slowing down of the process [25].

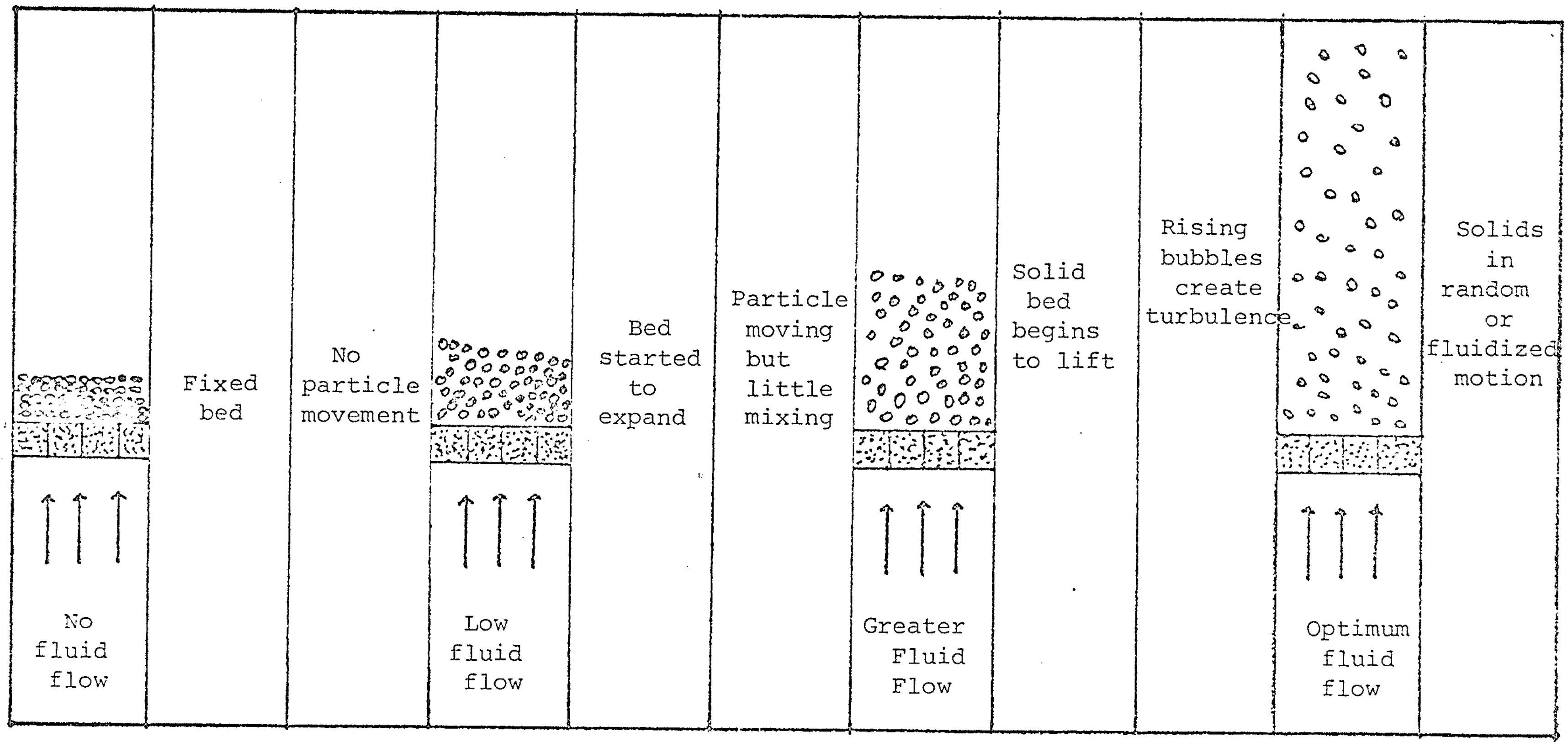
2.2 Fluidized Bed Dehydration Technique

The conventional tunnel drying mechanism represents "fixed bed" dehydration; in a "fixed bed", particles are motionless and support each other. More recent developments in the dehydration industry include the "moving bed", in which particles are suspended by either a liquid or a gaseous fluid [54]. Moisture removal in an air convection drier involves the displacement of water particles from the solid mass into the gaseous system [54]. In a "fixed bed" drier only one surface of the contents is exposed to the air current and moisture removal remains confined to this single surface. By altering the direction of air flow from a horizontal motion to an upright motion through a perforated plate, increased air velocity will transform a "fixed bed" into a "moving bed". Figure 1 demonstrates the transformation [61].

The fluidized technique has long been used in the chemical industry. In 1942 the petroleum industry utilized the fluidized bed to break down heavy petroleum fractions in order to increase gasoline production [9]. Since then fluidized bed has become common for coating fabricated metal parts, processing minerals ores, drying, roasting and freezing of food products [20]. The fluidized bed system has many advantages over other dehydration systems. It has a higher heat transfer coefficient and a more uniform heat transfer. The upward air movement suspends particles in the

Figure 1

Transformation of a Fixed Bed to a Moving Bed



"fluid" thus reducing abrasive action on particles and allowing more uniform heat exposure. Continuous processing is also possible by feeding moist material in from one end and removing it from the opposite end without the aid of conveyors as designed by U.S.D.A. and illustrated in Figure 2 [17]. These characteristics result in several advantageous factors. For the same amount of heat, a fluidized bed drier will remove more moisture from the system; less mechanical damage will take place due to the lack of mechanical contact; and rapid sensitive temperature control is also possible. Most of these factors result in lower operating costs and higher yields. However, limitations do exist. Fluidized bed driers will not work for fibrous or needle-like materials and particle size must be fairly uniform. Items that have high adhesive properties are also difficult to dry in fluidized bed driers [30,61].

Ridgway (1965) reported that a continuous fluidized bed drier does not ensure uniform dehydration. Some materials are dried or burnt while other matierals remain moist and unaffected [49]. To improve the system, Omae and Furukawa proposed the tapered bed driers [40]. These driers have a narrower base and a wider upper opening

According to Levey *et al.*, the pressure difference in a fluidized bed drier is responsible for fluidization. Gas expands as it rises through the bed. It is therefore safe to assume that the upward gas velocity near the top is greater

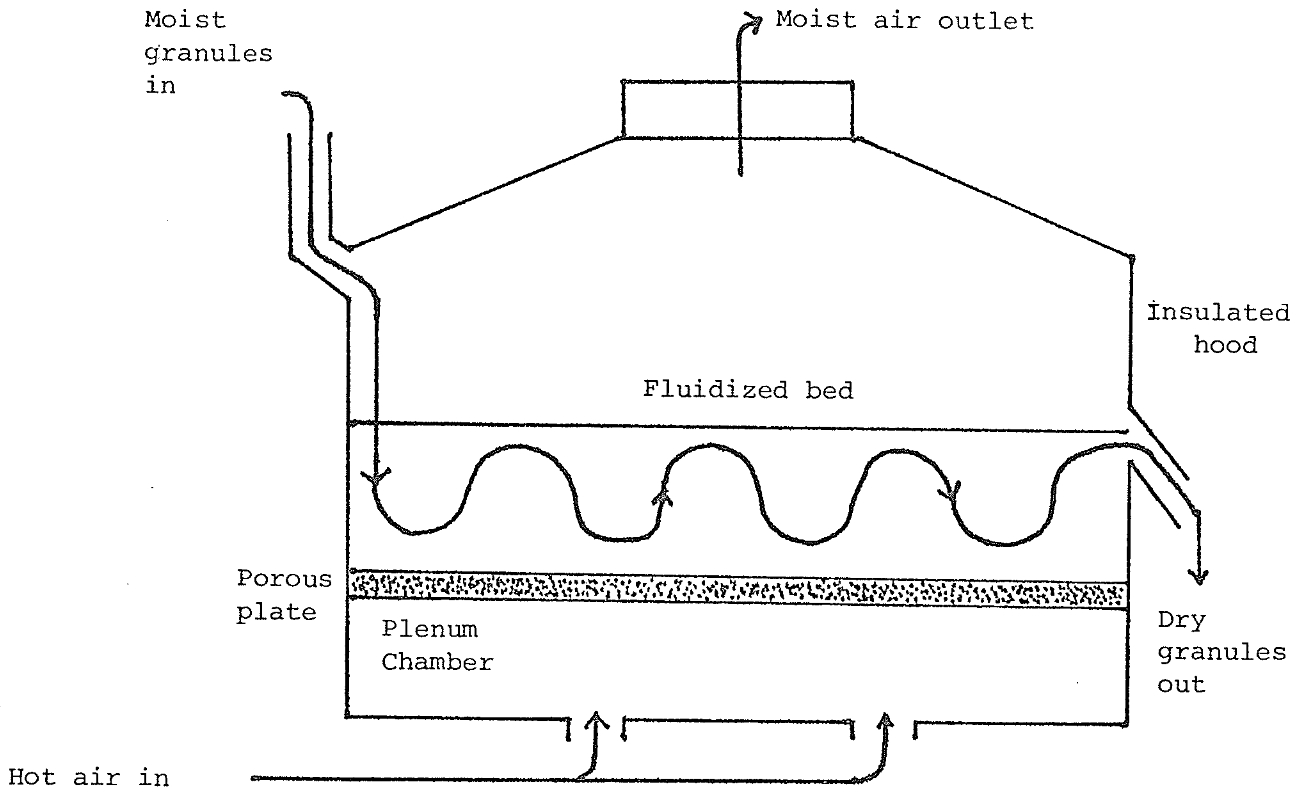


Figure 2

Fluidized bed drier developed by USDA

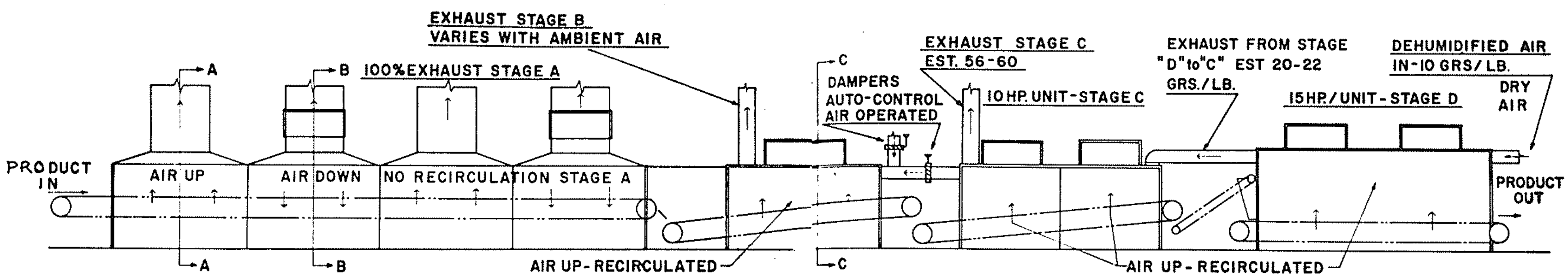
than that near the bottom. If gas velocity is made sufficient to give normal fluidization conditions in the upper regions of the bed, the base is completely static. If the gas velocity is increased to create fluidization at the bottom of the bed, then the top is violently agitated. A transport of material without proper drying is then observed It was reported by Levey *et al.* that this problem does not exist in tapered fluidized bed driers. Smoother fluidization, more uniform mixing and better drying are achieved [29,49].

Brown *et al.* (1972) suggested a further modification of the fluidized bed. They reported that centrifugal fluidized bed still was more efficient than other fluidized beds. By incorporating the centrifugal device the fluidized bed could not only dry particles of irregular shapes and sizes but could also give smoother fluidization at all desired air velocities [5]. Regardless of modifications and adjustments, simple standard batch fluidized bed driers are the more commonly used. A cross section of a pilot-batch fluidized bed drier is shown in Figure 5 in Chapter 3.

Fleming and Doole (1969) proposed a four-stage fluidized bed drying system for onion dehydration. A full graphic demonstration of the model is shown in Figure 3. They claimed at optimum operating conditions, the multistage set could produce 1,100 pounds of onions per hour containing 3.5% moisture from a wet basis of 86%. The system, according to Fleming and Doole, is efficient, has guaranteed uniformity

Figure 3

Fleming and Doole's Multistage Fluidized Bed Drier



of production and is sanitary [12].

2.3 Problems Associated with Onion Dehydration

The value of dehydrated onion relies greatly on its pungency. Only a dried clean product with acceptable color and flavor would be accepted by consumers. The thermo-dehydration process, however, fails to preserve these desirable qualities. Onions may turn brown or pink during dehydration, may lose most of their pungency and may acquire microbial contamination from dirty equipment. It is important that processors are aware of these problems and capable of solving them.

2.3.1 Pinking of Onion in Dehydration

A very common phenomenon observed in white onion dehydration is the development of pink pigments. Onion flakes or slices with pink pigmentation are considered to be of inferior quality and are often rejected by processors. Several researchers have studied the reactions involving pinking but conclusive identification of the major cause is still unavailable.

Pinking of onion during dehydration was believed to be caused by microbial infestation. The fungus *Pyrenochaeta terrestris* was reported by Walker in 1952 to be the cause of pink root in onions [67]. It was subsequently blamed by many processors to be the cause of pinking in dehydrated onions.

Lukes (1958) reported pinking was not related to the growth of microorganisms. He described the formation of pink pigments in two steps. First, there was an enzymatic reaction providing a color precursor. This color precursor then reacted non-enzymatically to form the pink pigment in dehydrated onions [32].

Joslyn and Peterson (1958) reported that pinking occurs initially in the juice portion of the onions. Southport white globe is particularly susceptable to this change. High temperature, low moisture and pH around 5.0 greatly enhances pinking [23]. Joslyn and Peterson (1960) furthermore reported that a carbonyl compound (or a mixture of several such compounds) naturally occurring in onion, resembling the structure of formaldehyde, may react enzymatically with the color precursors to form pink pigments [24].

Yamaguchi *et al.* (1964) and Joslyn and Peterson (1960) both reported on the existance of color precursors in onion tissues [71,24]. It was Shannon *et al.* (1967) who made the suggestion that pinking was a three stage process [56].

$$\text{unknown precursor} \xrightarrow[\text{very fast reaction}]{\text{enzyme}} \text{color developer (colorless, ether-soluble)} \qquad (1)$$

$$\text{color developer + amino acid} \xrightarrow[\text{slow}]{} \text{pigment precursor (colorless, ether-insoluble)} \qquad (2)$$

$$\text{color precursors + formaldehyde or naturally occurring carbonyls} \xrightarrow[\text{fast}]{} \text{pink pigment} \qquad (3)$$

The color developer has not been identified but reaction of the compound with Ehrlich's reagents reveals the compound to have a pyrrole nucleus [56]. More work has yet to be completed before a positive identification of the compound can be drawn.

2.3.2 Browning of Dehydrated Onion Flakes

Browning of spanish white onions after dehydration was reported by Reimers[48] and Yamaguchi (1954) [72]. The formation of a dark colored product was associated with the storage temperature prior to dehydration. Storage at 0°, 2.5° and 30°C was reported by Yamaguchi to produce the best sound onion bulbs. However, at subsequent storage after dehydration, bulbs previously stored at low temperatures had a greater tendency to darken. Analytical works by Yamaguchi indicated the content of reducing sugars was lower at high storage temperatures and that of non-reducing sugars was considerably higher [71]. At the same temperatures Reimers was able to identify the soluble sugars in onion to be glucose, fructose and sucrose [48]. A lighter-colored dehydrated product was produced if the relative concentration of diasaccharide in onions was higher than monosaccharide [48].

It is ironical that Reimers' diasaccharide and Yamaguchi's non-reducing sugar have the same effect on onions upon dehydration. The reducing sugars and monosaccharides appear then to be responsible for browning in dehydrated onion flakes. Although results were again inconclusive, nevertheless the mystery concerning browning does have an explanation.

2.3.3 Bitterness in Dehydrated Onions

Although not a major problem in the onion dehydration industry, occasional traces of bitter substance can be detected in dried onion flakes. Very little work has been completed in this area of study. Onions exposed to prolonged heat treatment are particularly susceptible to the formation of bitter substances. Schwimmer (1967) reported that the development of bitterness could have arisen from enzymatic conversion of endogenous precursors when the onion cells were ruptured [53]. Since bitterness was not affected by prolonged exposure to heat, the precursor or the actual substance appeared to be non-volatile. Laland and Havrevold (1933) reported the bitter substance was not removed by several anion and cation exchange resins but could be removed by activated carbon [28]. It appeared that the bitter substance was non-ionic in nature.

Neither quercetin nor its glycoside quercetrin is bitter in nature. The yellow pigment in onions has been long associated with the cause of bitterness. Very little is known about this bitter substance in onions. A non-volatile component coupled with enzymatic reaction is believed to contribute to the objectionable taste [53].

2.4 Microbiology of Dehydrated Onions

Bacteria are the major group of microorganisms in dehydrated vegetables. Molds exist in lesser amounts and yeasts are rarely discovered. Most of the bacteria isolated from dried vegetables were common to soil and water, such as *Bacillus species* and *Pseudomonas species* [46]. Bacteria causing human infections and food poisonings such as *Salmonella species* and *Clostridium botulinum* were not isolated from dehydrated vegetables although special attempts made to do so [46].

Lovell (1937) reported that the vapor and juice of fresh onions to have a germicidal effect on several bacteria [31]. Vaughn (1951) reported sterilized onion juice could kill cultures of *Bacillus subtilus*, *Escherichia coli*, *Saccharomyces cerevisiae* but have no effect on *Lactobacillus plantarum*, *Lactobacillus brevis* or *Aerobacter aerogenes*. As a result *Lactobacillus species* and *Aerobacter species* were the predominant species found in onions [66].

Johnson and Vaughn (1969) reported resting cells of *Salmonella typhimurium* and *Escherichia coli* are highly susceptible to garlic and onion juices [21]. n-propyl allyl and di-n-propyl disulfide at 0.1% kill resting cells of the two species but only have bacteriostatic effect on growing cells.

Onions for dehydration were unblanched to retain most of their volatile components. The bacterial population as a result was expected to be quite high. But little do consumers know that the species of bacteria associated with dried onions are harmless in nature. Such high standards for dehydrated onions are set by consumers that the processors find it difficult to comply [65].

2.5 Flavor of Onions

The compound essential for the characteristic odor of onion was long under investigation by researchers. Semmler (1892) reported the major volatile odorous components in onion to be allyl n-propyl disulfide [55]. Kohman found propionaldehyde was essential for the odor in 1947 [26]. Challenger and Greenwood revealed the presence of n-propyl mercaptan in 1949. A major discovery was made by Stoll *et al.* in 1951 that the characteristic volatiles are absent in intact tissues. They are only produced enzymatically when injury occurred to the tissues [60]. Niegish and Stahl (1956) identified n-propyl thiol and n-propyl disulfide from the onion volatiles but no trace of allyl disulfide was identified [38]. Carson and Wong (1961) concluded that the most important compounds for flavor formation were the sulfur-containing compounds [6]. Later works of Schwimmer and Guadagni (1964) and Carson (1967) showed that a major enzymatic reaction within comminuted tissues is responsible for the odor development [7,15]. Alliinase or L-cysteine sulfoxidelyase hydrolyzed the naturally occurring S-allyl (methyl and propyl) and S-alkenyl-derivatives of L-cysteine sulfoxides to their corresponding alkyl and alkenyl sulfenic acids, ammonia and pyruvic acid.

$$RSCH_2CHNH_2COOH + H_2O \xrightarrow[\text{allinase}]{} (R\text{-}SOH) + NH_3 + \underset{\text{pyruvate}}{CH_3COCOOH}$$

R = methyl and propyl groups

(RSOH) the unstable hydrocarbonyl sulfenic acid continues to interact and decomposes to form hydrocarbonyl thiosulfinate and thiosulfonates (R-S-SO-R and R-S-SOO-R) the odorous compounds. Since pyruvate is a product of the reaction, the determination of pyruvic acid content in onion became a reliable index of the overall odor intensity of the onion [52,53].

Many of the flavor volatiles in onions are lost in early stages of dehydration. A major loss of volatiles takes place during slicing or chopping operations in preparation for dehydration [59]. More volatiles are released in the early stages of dehydration. Bernhard (1968) measured the loss of volatiles in onion due to dehydration to average at 98% and loss of disulfides to be greater than 89% [4]. This seems to be a substantial loss of pungency in forms of volatiles. Fortunately even with the high percentage loss in volatile flavor components, dehydrated onions still retain sufficient flavor to be widely accepted.

Several flavor recovering methods were found successful in recovering volatile flavor components from vegetable products. There is very little work completed on onion flavor recovery. While the recovery process is elaborate and expensive, processors believe the residual flavor content in dehydrated onions is sufficient for its world wide acceptance.

2.6 Quality Standards of Dehydrated Onions

The American dehydrated onion and garlic association was first formed in 1956 by the major processors in the United States. The association called for standardized quality and uniform nomenclature for the dehydrated onion and garlic products. It was engaged in research work to improve plant varieties, processing, packaging and quality analysis. Official standards and methods were published in 1957, 1960 and 1969 [2].

2.6.1 Particle Size of Dehydrated Onions

Particle sizes of dehydrated onions are a main concern for processors. Foster (1968) of Gentry Corporation described ten sizes of dehydrated onion particles and their uses [13].

1. Powdered onions: fine sizes used when large particle size was not desirable.
2. Agglomerated onions: a mixture of fine and large

particles but not as dusty as the powdered onions. Used in foods when small particle sizes were required.

3. Granulated onion: larger in particle size, particularly suitable for use in sauce and gravy, readily absorbs liquid.

4. Ground onion: coarser in size than any of the previous mentioned. Used when texture and mouth feel were desired.

5. Minced onion: the smallest piece size onion flakes. Favorite size for stews and foods containing liquid.

6. Chopped onion: particle size between U.S. screen No. 8 and 12, considerably larger pieces.

7. Large chopped onion: uniform large pieces

8. Sliced onion: Mainly used in stew, soups and Chinese specialty dishes.

9. Toasted onion: golden brown product produced from gently toasting the dried onions. It appeared in different sizes similar to the previous eight categories. Consumed mainly for the specific toasted flavor.

10. French-fried onion: a deep fat-fried flavor was incorporated into the dried onion. It appeared in all particle sizes and was consumed for the characteristic flavor.

A photographic representation of the ten categories is demonstrated in Appendix 1.

2.6.2 Moisture Content of Dehydrated Onions

A good dehydrated onion product should not contain more than 4.25% moisture [2]. Ponting *et al.* (1964) reported that a critical moisture level was essential for dried product stability [45]. Off-flavor and off-color precursors were in high concentration and were closely associated in partially dried products. A very small amount of free moisture could activate these compounds and cause unnecessary irreversible damage [48]. Caking of onion powder could also be reduced by lowering the moisture content. Peleg and Mannheim (1969) suggested when the moisture level of dehydrated onions was beyond 7%, further addition of anti-caking agent was futile [43]. When moisture content became too low unnecessary browning could also occur. Greater losses of volatile components and damage to tissue structures could ruin the quality of the product [63].

2.6.3 Color of Dehydrated Onions

Only white onion products are universally accepted. Dehydrated white onions should not have an optical index reading above 105 as measured by a spectrophotometer at 420 mμ (2,3) the color of onion is a good indicator for quality. Inferior color could be related to improper storage of onion bulbs, excessive heat in dehydration, excessive moisture content, undesirable enzymatic reaction during or after dehydration and other factors such as temperature and relative humidity of storage, and the length of storage [72, 24,71].

It is against Federal law to apply color additives to cover up defective products. Colors of food products should always reflect the quality of the products [33].

2.7 Methods of Color Measurements

The 1922 report of the Colorimetry Committee of the Optical Society of America defined color as follows:

> "Color is the general name for all sensations arising from the activity of the retina of the eye and its attached nervous mechanisms, this activity being, in nearly every case in the normal individual, a specific response to radiant energy of certain wavelengths and intensities" [42].

A better definition was given by the same society in 1944.

> "The characteristics of light .... being that aspect of radiant energy which a human observer is aware through the visual sensations which arise from the stimulation of the retina of the eye" [41].

Hue, intensity and saturation are the three attributes of color. They can be defined as:

Hue: the attribute of a color perception denoted by green, yellow, red and purple, etc.

Intensity (value): the lightness scale from white to black.

Saturation (chroma, purity): the strength of the color [27,1,70].

Spectrophotometers are the most widely used instruments for color measurement. They measure color differences in terms of reflectance or absorbance at particular wavelengths [69]. Large scale modifications of the spectrophotometers allow the instrument to be useful in wide ranges of color measurements.

Colorimeters are less sophisticated comparatively, they analyze color in three dimensions. The Hunterlab color difference meter is an example. It measures color in terms of *L*, a*L* and b*L* values.

The *L* value measures the intensity of a color. At 99.9, the *L* value indicates total light reflection or total whiteness. At 0.00, the *L* value indicates total light absorption or complete blackness. The a*L* value measures the degree of green versus redness. A positive a*L* value indicates the appearance of reddish components whereas a negative a value indicates the appearance of green colorations. The b*L* value reflects blue and yellow components. A negative b*L* value indicates blue components whereas a positive b*L* value means the existance of a yellow component [44]. A diagrammatic representation of the correlations between a*L*, b*L*, and *L* values is given in Appendix 2.

The hue and saturation of any object can be computed from the simple expressions:

$$\text{Hue} = \frac{aL}{bL}$$

$$\text{Saturation} = \sqrt{aL^2 + bL^2}$$

These three measurements are very helpful in the mathematical description of colors [19,14,33].

The American Dehydrated Onion and Garlic Association (ADOGA) had specified spectrophotometers as the official color measuring instruments and color characteristics were to be communicated in terms of optical index [2].

The above review reveals the past and present technology in onion dehydration industries, problems encountered and possible solutions. As the popularity of dehydrated onions increases, processors would like to see the improvement in the dehydration system and more solutions to overcoming the problem of the factors leading to quality damage.

CHAPTER 3

METHODS AND MATERIALS

3.1 Experimental Design

3.1.1 Introduction

Mr. W. Kroecker of Kroecker and Son Limited, Winkler, Manitoba provided the Department with 5,000 pounds of yellow globe onions in the spring of 1972 for preliminary studies on dehydration and storage characteristics. Between 2,000 to 3,000 pounds of spanish white onions were also grown by Mr. G. Luther of the Department of Plant Science which were harvested in late August, 1972 for detailed dehydration studies. Most of the onions were dried between April and August 1972 and November and May 1972-1973.

An Aeromatic batch fluidized bed drier, manufactured in Switzerland, was used as the machine for dehydration. Diced onions were dried from 87% moisture to below 5% in a period of 20 to 25 hours. They were then tested for quality and subsequently stored for a period of six to twelve months. Experiments on factors such as color, optical index, moisture and ash contents, hot water insolubles, pungency and bacterial counts were carried out throughout the entire length of the research program.

Quality of onions is judged by three main factors; color, pungency and cleanliness. Good dehydrated onions should be white in color, pungent and low in microbiological content and free of coliform organisms. These three factors are easily affected by the processing techniques and subsequent storage conditions. It is therefore essential for the processors to be able to control processing conditions and to use the proper varieties in order to produce high quality products.

Six varieties of *Allium cepa L* were used in the experiment. A description of these varieties is given in Table 3.

All onions produced by the growers were harvested, sun dried, graded, cleaned and bagged into 50 pound lots. Temperature of storage prior to dehydration was set at 10° C.

The studies were intended to fulfill the following objectives:

1. To dehydrate onions at the most desirable temperature in order to produce good quality products by utilizing a pilot plant batch type fluidized bed drier.
2. To study the quality changes in storage after the dehydration process.
3. To compare yellow and white dehydrated onion products.

Table 3

Description of the Onion Varieties Used in the Dehydration and Storage Experiments

Variety	Production Location	Variety Description	Studies
Autumn Spice	Winkler*	Yellow globe	Storage
Autumn Pride	Winkler	Yellow globe	Storage
Spartan Era	Winkler	Yellow globe	Storage
Southport white globe	U. of M.†	White globe	Dehydration/storage
Seco	U. of M.	White globe	Dehydration/storage
XPW 156	U. of M.	White globe	Dehydration

* Produced by Kroecker and Sons Limited, Winkler, Manitoba

† Produced by Plant Science Department, Fort Garry, Manitoba

4. To evaluate three white onion varieties grown in Manitoba for dehydration.

3.1.2 Design of the Dehydration Study

Three varieties of yellow globe onions harvested in fall, 1971 were made available to the University in the spring of 1972. These were used primarily for preliminary dehydration studies. While there was little available information on fluidized bed dehydration of onions and no standard whatsoever for yellow globe onions, qualities of the onions were judged mainly by color and taste. Samples of dehydrated yellow onions were sent to several food processors for quality evaluation. Relatively successful dehydration temperature settings were achieved by this trial and error study with yellow globe onions.

In September 1972 three varieties of Manitoba grown white onions were harvested by the Department of Plant Science and made available for the dehydration studies. Two sets of temperature controls were employed.

1. Set I: initial temperature at 70°C and gradually reduced to 20°C at a rate of 10°C per hour.
2. Set II: initial temperature at 60°C and gradually reduced to 20°C at a rate of 10°C per hour.

At the end of each hour two samples of onions were removed and measured for color changes and moisture removal. This continued for nine consecutive hours, after which samples were removed every two hours and tested. Between 15 to 20 hours of dehydration produced onion flakes with moisture level between 5 to 10%.

An STS 5 Batch type fluidized bed drier produced by Aeromatic Limited, Muttenz-Basle, Switzerland was employeed as the drying unit. The maximum capacity of the drier was 5 kilograms. An additional fan was attached to the air flow system increasing the capacity of the fan from 212 cubic feet per minute to 1476 cubic feet per minute. Figure 4 describes the exterior of the drier and Figure 5 gives a cross section diagram of the drier. The air capacity of the drier with the additional fan is described in Appendix 3.

3.1.3 Design of the Storage Study

The prime objective of the storage study was to establish a correlation between storage temperatures and product quality as affected by storage. Storage temperatures of 10° and 25°C were used. Five varieties of onions were used in this storage study. Variety XPW 156 was not used due to the low quantity of supply. All onion samples were dried to a moisture level of less than 5% prior to storage. Dark brown plastic bottles with air tight screw-on caps were used as the storage containers.

3.1.3.1 Storage study of yellow globe onions

Three varieties of dried yellow globe onions were tested for qualities such as color, moisture, ash

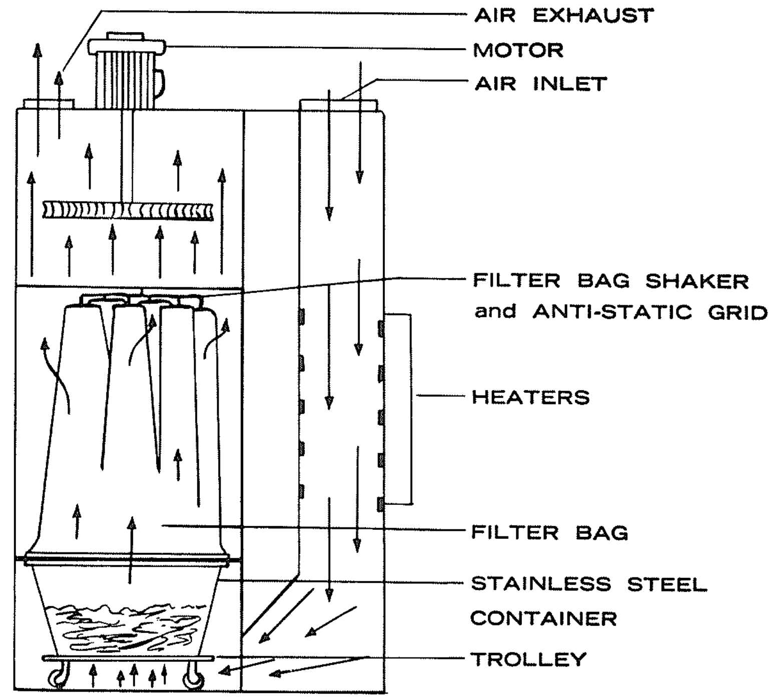
Photograph of a STS 5 Batch type fluidized bed drier

Figure 5

Cross-section of a STS 5 Batch Type Fluidized Bed Drier

OPERATING SEQUENCE

Moist granules are dumped into the conical container. A powerful stream of hot air is drawn upwards through the bottom of the container so that the granules are lifted and float freely in the dry air. Air leaves the drier saturated with moisture, assuring complete utilization of heat energy and ultra-rapid drying in 30 minutes per batch.



SPECIFICATIONS

CAPACITY	Motor Horse Power	Peak Power Consumption of Heaters	Peak Steam Consumption in Lbs. of Steam/Hr.	Heat Consumed For a Batch 10% Humidity		Heat Consumed For a Batch 20% Humidity		Cubic Feet per Minute Fan
		KW/Hr.		KW/Hrs.	Lbs.	KW/Hr.	Lbs.	
5 kg.	1	6	21	2	7	3	10	212
15 kg.	3	18	64	5	18	8	28	530
30 kg.	5	36	128	9	32	16	57	1060
60 kg.	15	72	255	18	64	30	106	2120
100 kg.	20	108	382	30	106	52	184	3540
200 kg.	40	216	765	60	206	104	370	7080

Actual Power Consumption is subject to the physical properties and character of the granule and air inlet temperature.

content, hot water insoluble solids and bacterial counts. After initial analyses were performed on a uniform mixture of each variety, equal amounts of the varieties were stored in plastic containers at 10°C and 25°C for 360 days. Additional amounts of Autumn Spice were stored at 35°C for 90 days. At the end of each period of storage at 30, 60, 90 and 360 day intervals, samples were removed and identical tests were performed.

3.1.3.2 Storage study of white globe onions

Essentially identical to section 3.1.3.1. Two varieties of white onions were studied; Southport white globe and Seco. The third variety of white onion XPW 156 was not used in the storage study due to the insufficient supply of fresh bulbs. The bacterial study was eliminated and replaced by taste study. Samples were studied at zero time, 30, 60, 90, 120, 150 and 180 day intervals. The storage studies were scheduled as presented in Table 4.

3.2 Laboratory Procedures

This section deals with the appropriate experimental procedures in each of the studies conducted.

3.2.1 Sample Preparation for Dehydration

An average of 5,000 grams (11 pounds) of onions were removed from storage and prepared for each trial of the

Table 4

The Frequency of Testing, Conditions of Storage and Analytical Tests for White and Yellow Dehydrated Onions

	Study A (White onions)	Study B (Yellow onions)
Varieties	Southport white globe Seco	Autumn Pride Autumn Spice Spartan Era
Frequency of Testing	0, 30, 60, 90 120, 150, 180 days	0, 30, 60, 90, 360 days
Storage Conditions	25°C and 10°C	25°C, 10°C. 35°C for Autumn Spice for 90 days.
Tests performed	Moisture percentage Ash content Hot water insoluble solids Optical index Hunterlab colorimetric measurements Flavor	Moisture percentage Ash content Hot water insoluble solids Optical index Hunterlab colorimetric measurements Microbial count Food processor survey

dehydration process. Onion bulbs were soaked in hot water then in cold water to loosen the peel. They were then peeled, cored, trimmed and diced. Dicing was achieved by putting the onion bulbs through an Hobart A-200F mixer with modified power dicer. All onions were diced into 3/8 inch cubes. No blanching of any type was applied to the diced onions. Diced onions were spread evenly on the bottom of the cylindrical fluidized bed drier.

3.2.2 Drying Conditions

Temperature, air velocity and bed load were carefully controlled throughout the drying process. Van Arsdel *et al.* (1964) reported the traditional tunnel dehydration of onion involved initial temperatures of 160° to 190°F [63], but experimental results from preliminary studies revealed 190°F was too high for fluidized-bed operation. The temperature for dehydration did not exceed 160°F throughout the whole length of dehydration. The air velocity in the fluidized-bed drier was also carefully controlled. When the moisture content of the diced onions was high, high air velocity would disrupt the uniformity of the bed, create "channels" in the bed and produce uneven drying. Air flow was maintained at a low rate until onion flakes became drier. The bed thickness (or drying load) was also kept at optimum. By exceeding the 5 kilogram capacity of the drier, prolonged and uneven drying was expected.

Two initial temperatures were employed in the dehydration process; 70°C (158°F) for Set I and 60°C (140°F) for Set II. The temperature was lowered at the rate of 10°C per hour until it reached 20°C. Table 5 lists the drying conditions.

3.2.3 Determination of Dry Matter

Dry matter was determined prior to dehydration for each trial. A Blue M power-o-matic 70 mechanical convection oven was used for dry matter and moisture determination. At each stage of experimentation, in dehydration processes and storage studies, samples were collected for moisture determination.

Porcelain crucibles were placed in a convection oven to remove adhered moisture. Dried crucibles were cooled to room temperature in vacuum desiccators containing calcium chloride. A Sartorius 2462 analytical balance was used to determine all weights in grams. Samples between five to ten grams were added to the crucibles and they were reweighed. Onion samples were dried in the convection oven at 70°C to constant weight. Dry matter percentage was determined by calculations given in Appendix 4. Moisture content could also be determined by subtracting the dry matter content from 100%.

3.2.4 Measurement of Color

Color was measured by two instruments; the Hunter

Table 5

Dehydration Conditions for the Two Varieties of White Onions

Hours	Temperature °C Set I	Set II	Air Velocity cu.ft./min.
0 - 1	70	60	700
1 - 2	60	50	700
2 - 3	50	40	700
3 - 4	40	30	700
4 - 5	30	20	700
5 - 25	20	20	1500

color difference meter and the spectronic 20 spectrophotometer. The Hunterlab color difference meter Model D25 was used for color determination throughout the first fifteen hours of dehydration when the change of color was most prominent. Both Hunterlab color difference meter and a Bauch and Lomb spectronic 20 were used for color determinations in the storage studies. The Hunterlab color difference meter measured color in *L*, a*L* and b*L* values whereas the spectronic 20 interpreted color in terms of optical index.

3.2.4.1 Color measurement by Hunterlab color difference meter

Samples of onions were measured for intensity (*L*), a*L* and b*L* values. The color difference meter was standardized to a white reference with *L* = 93.8, a*L* = -1.1 and b*L* = 2.3. The operating procedures for the Hunterlab color difference meter are as follows.

1. Set the dials to the color values assigned at the standard and cover the color orifice with the standard. For white color standard values are *L* = 93.8, a*L* = -1.1, b*L* = 2.3.
2. Zero the galvanometer.
3. Calibrate the cTc value by using b = -4.7 as reference.
4. Standardize the *L*, a*L* and b*L* value according to the standard value.
5. Test samples, restandardizing when necessary.

3.2.4.2 Determination of optical index

A Bausch and Lomb spectronic 20 spectrophotometer was used to measure the optical index of the onion samples. The procedures used are as follows:

1. Prepare a 10% sodium chloride solution with distilled water.

2. Mix 2 grams of onion powder and 1/2 teaspoonful of filter aid with 100 millilitres of 10% sodium chloride solution; allow to stand for 15 minutes with occasional stirring.

3. Set the wavelength of the Spectronic 20 at 420 mμ and standardize at 100% transmission with 10% sodium chloride solution.

4. Filter the solution of onion and sodium chloride through Whatman #1 filter paper until crystal clear.

5. Place samples in 1/2 inch Bausch and Lomb cuvettes.

6. Determine the percent transmission of filtrate with the Spectronic 20.

7. Calculate the optical index with the following formula

$$OI = \log \frac{100}{\%T} \times c \times 1,000 \times \frac{1}{\text{sample weight (gms)}}$$

where

$$c = \text{constant} = \frac{50 \text{ mm}}{\text{cuvette diameter (mm)}}$$

T = percentage transmittancy

3.2.5 Determination of Ash Content

The ash content was determined from the loss in weight that occurred during incineration of the samples at a temperature high enough to allow all organic matter to be burnt off without allowing appreciable decomposition of the ash constituents or loss by volatilization [22]. Ash content of the test varieties was determined at zero time and subsequent 30 day periods. (In yellow varieties it was 0, 30, 60, 90 and 360 days.) The total ash content of dried onion samples was determined by the following technique.

Apparatus: Muffle furnace, porcelain crucible, vacuum desiccator with calcium chloride.

Method: Porcelain crucibles were dried in a convection oven. Weights were recorded after the crucibles were cooled in a vacuum desiccator Between 5 to 10 grams of dried onions were weighed into the dried porcelain crucibles. The crucibles with onions were put onto open flame or hot plates allowing the onions to char. Excessive flaming and spattering during charring was avoided to reduce unnecessary losses. Charred onions then entered the muffle furnace at 525°C. When white ash was obtained crucibles were once again cooled in the vacuum desiccator. A small amount of water was added to moisten the white ash, followed by drying off on hot plates. The crucible then reentered the furnace and was heated until constant weight was attained. The calculation for ash content resembled the total solid determination based on weight loss.

3.2.6 Measurements of Hot Water Insolubles

The content of hot water insolubles was significant in determining the acceptability of the products. The

American Dehydrated Onion and Garlic Association (ADOGA) official standards allowed not more than 30% hot water insolubles in standard powdered onions and 20% in all other products [2]. Excessive amounts of hot water insolubles were considered as non-edible onion fractions or contaminants [22]. The content of hot water insolubles was determined for both white and yellow varieties at 30 day intervals.

Apparatus: Hot plates, convection drier operating at 105°C, analytical balance, vacuum system and suction flasks, Gooch crucibles, Whatman #540 filter paper and vacuum desiccator.

Method:

1. Dry and cool clean Gooch crucibles containing a disc of Whatman #540 filter paper each.
2. Mix 1.5 grams of powdered onion and 1.5 grams of dried filter aid into 200 millilitres of hot distilled water.
3. Boil for five minutes.
4. Filter the solution through a tared Gooch crucible with the suction and vacuum system.
5. Dry the contents of the Gooch crucible in the convection oven at 105°C for five hours to constant weight. Determine the weight of the cooled crucible.
6. Repeat the experiment with 1.5 grams of filter aid and determine the correction factor.
7. Calculate the percentage of hot water insolubles based on the weight difference with the following formula:

$$\%\ HWI = \frac{\text{"difference" corrected for filter} \times 100}{\text{sample weight}}$$

where

"difference" = weight of dried hot water insolubles, and filter aid − weight of dried filter aid (the correction factor).

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3.2.7 Flavor Changes in Storage

Prolonged storage might reduce the pungency of dehydrated products mainly due to the loss of volatile flavor components. The effects of temperature during storage on the flavor of dried products are relatively unknown. Peleg *et al.* (1970) concluded that low temperature storage had a distinct advantage on flavor retention [44].

Samples of dehydrated Southport white globe and Seco were collected at 9 time, 90 days and 180 days. They were frozen immediately. At the end of the storage period, a panel of judges consisting of 5 male and 15 female members were asked to evaluate the onion flavor in terms of preference. The panelists were untrained and between 18 and 55 years of age. Varieties were compared at each stage of storage and under each temperature of storage. A description of the testing schedule is given in Appendix 38. Onions were prepared as a soup containing 4% dehydrated onion, 0.5% salt and 95.5% water. The water was first brought to a boil and the salt and dehydrated onions were added, the contents were subsequently simmered for 10 minutes and served to the panelists at 60°C. All tests were performed under red fluorescent lights in individual booths in a round and odor controlled sensory evaluation chamber. A 9-point Hedonic scale (like extremely = 9, dislike extremely = 1) was used to measure the preferences (Appendix 39).

Instead of a study on flavor changes the dehydrated yellow onion varieties were evaluated by the food processing industry for acceptance. A full description of the survey is given in Section 3.2.9.

3.2.8 Microbial Assay of Dehydrated Yellow Globe Onions

Three varieties of yellow onions were studied for microbial population for 90 days of storage. Three tests were performed at 30 day intervals. The procedures were recorded from the Methods of Analysis set by the Gilroy Foods Incorporation [16].

1.0 Standard plate count: determination of total bacterial population, mesophilic aerobic count.

1.1 Sample collection: collect 50 grams of random sample aseptically.

1.2 Apparatus and culture media.

1. Incubator at 35°C.
2. Standard Methods Media BBL 01-632 or Difco B2.
3. Distilled water.

1.3 Sample preparation: aseptically prepare serial dilution of onion samples to 10^{-6} dilutions.

1.4 Standard plate count: using pour plate method plate out 10^{-4}, 10^{-5} and 10^{-6} dilutions and incubate for 48 hours at 35°C. Record the dilution containing between 30-300 colonies if possible but if a plate cannot be found in this range record the dilution counted and the colonies found. Report as the standard plate count per gram.

2.0 Yeast and mold count.

2.1 Sample collection: refer to 1.1

2.2 Apparatus and media:

1. Incubator at 30°C
2. Potato dextrose agar
3. Sterilized 10% tartaric acid

2.3 Plate count on mold and yeast

1. Prepare 10^{-1} to 10^{-4} dilution and plate out using pour plate method
2. Incubate at room temperature for 5 days and count colonies on plates that permit enumeration. Record as count per gram.

3.0 Enumeration of coliform - most probable number procedure

3.1 Apparatus and media

1. Dilution blanks
2. Incubator - 35°C
3. Lauryl sulfate broth
4. Brilliant green bile broth (BGB) 2%.

3.2 Procedure:

1. Prepare four decimal dilutions
2. Transfer aseptically one millilitre of each of the decimal dilutions of the sample to each of three tubes lauryl sulfate broth and 10 millilitres of 10^{-1} to 3 tubes of double strength lauryl sulfate broth.
3. Incubate inoculated tubes at 35°C for 24 and 48 hours.

4. Select all lauryl sulfate tubes evidencing gas production as presumptive positive tubes.
5. Inoculate a loopful of growth from each positive tube to a tube of BGB broth.
6. Incubate the inoculated tubes at 35°C, for 24 and 48 hours.
7. Record as "positive" all tubes evidencing gas production at the end of either incubation period.
8. Select the highest dilution at which all three tubes are positive and the next two higher dilutions. Record beside each dilution the number of tubes in that set of three that are positive.
9. Refer to the MPN table (Table 6) to find the MPN or grams per 100 millilitres.
10. Calculate MPN per gram.

$$\text{MPN/gram} = \frac{\text{MPN org.}}{\text{100 mls}} \times \text{median dilution}$$

where median dilution is the dilution representing the 2nd of the three decimal dilutions.

11. Report MPN of coliforms per gram of dehydrated onion.

Table 6

MPN TABLE*

Most Probable Numbers per 100 ml of Sample, Planting

Three Portions in Each of 3 Dilutions in Geometric Series

Number of Positive Tubes			MPN	Number of Positive Tubes			MPN	Number of Positive Tubes			MPN	Number of Positive Tubes			MPN
10 ml	1 ml	0.1 ml		10 ml	1 ml	0.1 ml		10 ml	1 ml	0.1 ml		10 ml	1 ml	0.1 ml	
0	0	0		1	0	0	3.6	2	0	0	9.1	3	0	0	23
0	0	1	3.0	1	0	1	7.2	2	0	1	14	3	0	1	39
0	0	2	6.0	1	0	2	11	2	0	2	20	3	0	2	64
0	0	3	9.0	1	0	3	15	2	0	3	26	3	0	3	95
0	1	0	3.0	1	1	0	7.3	2	1	0	15	3	1	0	43
0	1	1	6.1	1	1	1	11	2	1	1	20	3	1	1	75
0	1	2	9.2	1	1	2	15	2	1	2	27	3	1	2	120
0	1	3	12	1	1	3	19	2	1	3	34	3	1	3	160
0	2	0	6.2	1	2	0	11	2	2	0	21	3	2	0	93
0	2	1	9.3	1	2	1	15	2	2	1	28	3	2	1	150
0	2	2	12	1	2	2	20	2	2	2	35	3	2	2	210
0	2	3	16	1	2	3	24	2	2	3	42	3	2	3	290
0	3	0	9.4	1	3	0	16	2	3	0	29	3	3	0	240
0	3	1	13	1	3	1	20	2	3	1	36	3	3	1	460
0	3	2	16	1	3	2	24	2	3	2	44	3	3	2	1100
0	3	3	19	1	3	3	29	2	3	3	53				

* Table taken from Gilroy Foods, Incorporated [16].

3.2.9 Food Processor Survey

In the summer of 1972 samples of dehydrated yellow onions were sent to food companies all over Canada. All three tested samples were shipped as a mixture. The main aim for the study was to obtain consumer judgment on the laboratory produced samples. Companies were asked the following questions:

1. Is the color of the product satisfactory?
2. If not, why not?
3. How would you rate the flavor of the products?
4. Would you buy this product if it was available commercially?

There were other questions concerning the price, quantity and varieties of dehydrated vegetables desired. A copy of the questionnaire is given in Appendix 5. Replies were received the same summer.

CHAPTER 4

RESULTS AND DISCUSSION

This study of onion dehydration was carried out between April, 1972 and September, 1973 with the following objectives.

1. To establish an optimum dehydration process for Manitoba onions.
2. To evaluate the effect of storage conditions upon the quality of dehydrated Manitoba onions.
3. To compare the quality characteristics of yellow versus white onion varieties.
4. To do a preliminary investigation of three white onion varieties grown in Manitoba.

A total of 5000 pounds of yellow onions grown by Kroecker's Limited at Winkler in 1971 and 2000 pounds of white onions grown in 1972 by the Plant Science Department was processed. The drier used in the study was an Aeromatic STS 5 Batch fluidized bed drier and all dehydration processes were done between May, 1972 to May, 1973. Dehydrated yellow onions were stored at 10°, 25° and 35°C between August, 1972 to August, 1973. Dehydrated white onions were stored at 10° and 25°C from March, 1973 to September, 1973.

*Autumn Spice was stored at 35°C from August to November, 1972.

Summaries of the data for moisture removed from white onions and the corresponding color changes are given in Appendices 6a, 6b, 7a, 7b.

4.1 Dehydration Studies

The average time of dehydration with the fluidized bed drier was 25 hours. Ninety percent of the moisture was removed in the first 15 hours of dehydration (Appendix 8). Drying curves for the three white varieities are shown in Figure 6. The time for moisture removal was comparable to the time required by tunnel driers as reported by Van Arsdel [63].

Several researchers [30,5,7,23,50,51,64] suggested that fluidized bed driers were not suitable for dehydrating viscous or adhesive substances. Agglomeration of adhesive substances would prevent uniform dehydration. After limited exposure to heat, diced onions became extremely adhesive and tended to form clumps. If left unattended, the surface of these clumps would continue to dehydrate and harden. Further dehydration would produce dried out clumps with moist interiors.

4.1.1 Optimum Dehydration Requirements

Three factors, air velocity, capacity of the drying system, and drying temperature were considered essential for a smooth and even dehydration process; optimum dehydration

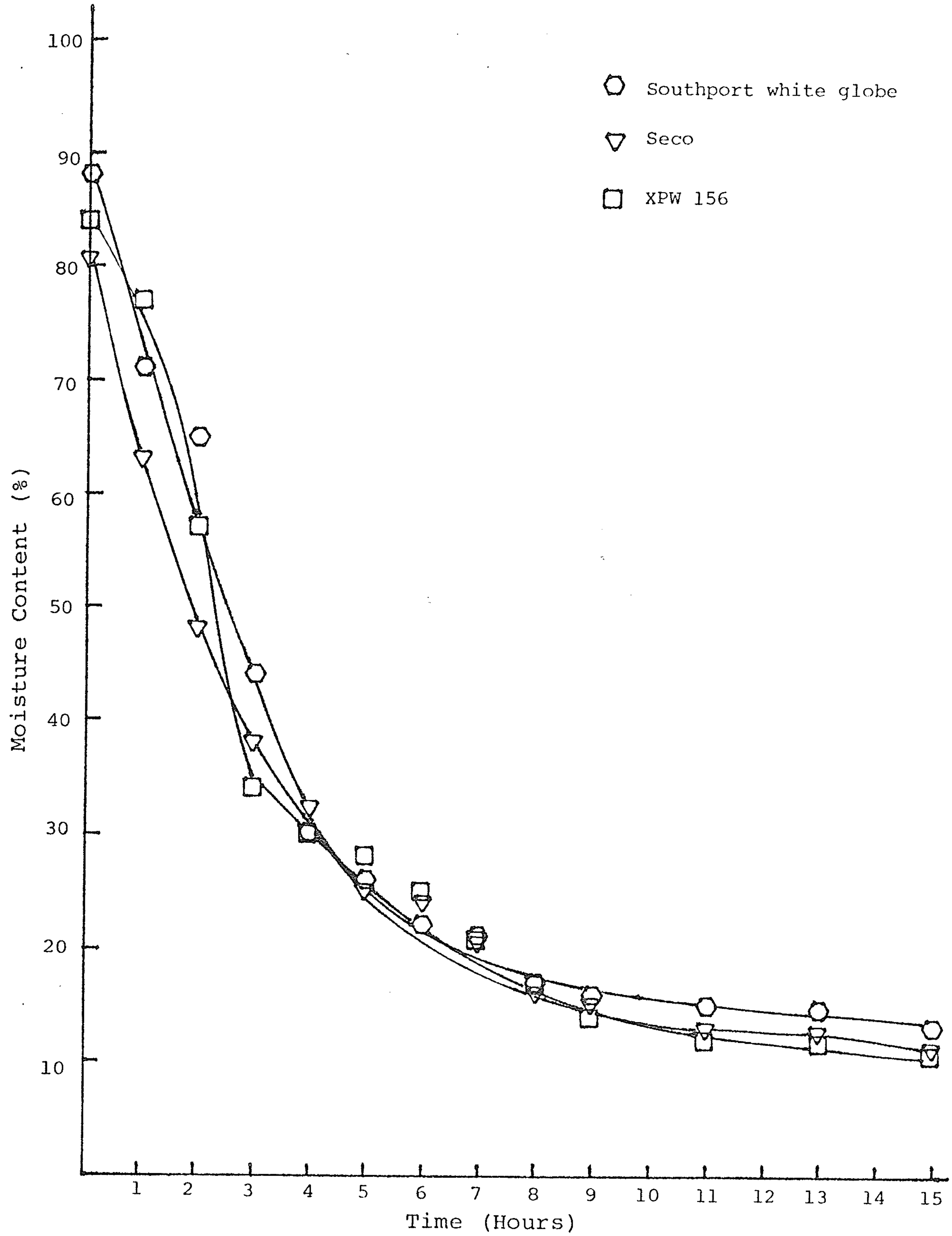

Figure 6. Dehydration curves of three varieties of white onions in the first 15 hours of dehydration

conditions could be achieved by harmonizing these three factors.

4.1.1.1 Optimum air velocity for dehydration

Diced onions were highly adhesive at intermediate moisture levels. High velocity air flow would create "channels" in the bed rather than successfully lifting the bed materials. When "channels" were formed water removal would centre around the "channels" and prevent uniform dehydration. To solve this problem, an initially low velocity of air was applied. Operating at half of the capacity of the air inlet, approximately 700 cubic feet per minute (Appendix 3), moisture was removed without significant fluidization of the bed. When the moisture level was lowered to below 20% the maximum air velocity could be applied without fear of producing "channels" within the bed.

A conclusion can be drawn from this observation: total fluidization at initial stages of onion dehydration is often risky. Instead of smooth fluidization as expected, diced onions would resist any changes in bed motion, and as a result non-uniform dehydration often resulted.

4.1.1.2 Maximum capacity of the drying system

The STS 5 Batch fluidized bed drier has a maximum capacity of five kilograms per drying load. Unaware of the capacity, the drier was frequently overloaded in the summer of 1972. Uneven drying occurred and rapid browning and pinking of the diced onions took place. Reducing the load to below five kilograms produced vastly superior quality products. The highest quality dehydrated products were produced at between three to four kilograms per drying load.

4.1.1.3 Optimum dehydration temperatures

Van Arsdel (1964) and Noyes (1969) reported optimum dehydrating temperatures for onions to be between 160° to 190°F for both tunnel and fluidized bed dehydrating systems [63,39]. However, experimental results revealed that extensive browning of onions took place after two hours of exposure to 80°C (176°F). After several trial runs at 60° and 70°C (140° and 160°F) combined with gradually reduced temperatures (listed in Table 5), dried onions with superior color were produced. The total dehydration time was approximately 25 hours. Ninety percent of the moisture was removed in the first 15 hours of dehydration. A low temperature was maintained at the latter stages of dehydration to avoid unnecessary browning. A summary of the rate of moisture removal of diced onions at 60°C and 70°C for the first nine hours of dehydration is available in Appendix 6.

4.1.2 Agitation in Fluidized Dehydration

Levey (1960) had pointed out uniform mixing of bed materials was a problem in cylindrical fluidized driers [29]. Brown *et al.* (1972) proposed the incorporation of centrifugal force in fluidized bed driers to ensure uniform mixing [5].

It was pointed out previously that at early drying stages thorough mixing of diced onion was a problem. Although a mechanical agitator was available with the drier, it could not be applied in the initial stages of dehydration. Moist diced onions adhered to the metal agitator and prevented even dehydration. As a result mechanical agitation was replaced by hand mixing at half hour intervals to ensure even exposure of the diced onions to heat and air movement.

Clumping appeared to be inevitable in onion dehydration processes. No available literature described any solutions to clumping in dehydration industry. Care must be taken to minimize clumping during the first stage of dehydration. Some form of agitation could have been incorporated in the commercial operation to break the clumps of onions down to individual pieces.

4.1.3 Color Change During Dehydration

Color change during dehydration was measured by a Hunterlab color difference meter in terms of *L*, a*L* and b*L* values at hourly intervals (for the first nine hours). Color was the best indicator of onion quality during dehydration. Undesirable dehydration conditions usually produced poorly colored products. Changes in a*L* and b*L* readings were clearly identifiable by the color difference meter as dehydration proceeded (Tables 7 and 8). Changes of *L* readings in the early hours were identifiable, but little

Table 7

The Range and Average aL and bL Measurement
For Three Varieties of White Onion Flakes During Dehydration
As Recorded by the Hunterlab Color Difference Meter

Variety		Zero Hours aL	Zero Hours bL	15 Hours aL	15 Hours bL
Southport white globe	Range*	-5.7 to -5.9	11.5 to 12.6	-2.1 to -3.5	19.2 to 21.1
	Average†	-5.8	12.2	-2.8	20.1
Seco	Range	-6.3 to -7.0	15.4 to 16.5	-2.5 to -3.7	20.3 to 21.0
	Average	-6.7	15.6	-3.2	20.6
XPW 156	Range	-5.9 to 6.3	13.0 to 14.3	-3.3 to -3.4	19.3 to 20.1
	Average	-6.1	13.7	-3.3	19.6

* Range - the lower and upper limits of three sample.

† Average - the average reading of the three samples.

Table 8

Changes Observed for a*L* and b*L* Values during Dehydration of White Onion Varieties and Calculated Hue Values at Temperature Set I (see Table 5)

Hour	Southport white globe May 9			Seco April 9			XPW 156 April 12		
	a*L*	b*L*	Hue	a*L*	b*L*	Hue	a*L*	b*L*	Hue
	in Hunterlab colorimetric measurements								
0	-5.9	12.6	-0.4682	-5.3	15.4	-0.40%	-6.2	13.9	-0.4428
1	-6.3	16.0	-0.3875	-5.7	18.2	-0.3131	-5.7	16.6	-0.3433
2	-5.4	18.9	-0.2857	-5.3	19.0	-0.2789	-4.8	18.0	-0.2651
3	-5.0	19.6	-0.2538	-4.0	19.7	-0.2094	-4.4	19.1	-0.2251
4	-4.7	20.2	-0.2326	-3.7	21.2	-0.1698	-4.0	19.5	-0.2051
5	-4.7	20.6	-0.2227	-3.4	21.3	-0.1596	-4.1	19.3	-0.2124
6	-4.5	20.4	-0.2243	-3.2	21.1	-0.1563	-3.8	19.5	-0.1948
7	-4.2	20.7	-0.2023	-2.9	20.1	-0.1442	-3.6	19.2	-0.1822
8	-4.6	20.6	-0.2222	-3.4	21.7	-0.1559	-3.5	19.4	-0.1855
9	-4.3	21.3	-0.2018	-2.8	20.8	-0.1394	-3.4	19.0	-0.1746
11	-4.3	19.0	-0.2263	-3.3	20.5	-0.1658	-3.2	19.4	-0.1752
13	-4.1	19.5	-0.2051	-2.8	20.3	-0.1379	-3.3	19.7	-0.1641
15	-3.5	21.2	-0.1650	-2.5	20.4	-0.1225	-3.3	19.4	-0.1701

change was observed after four hours of dehydration (Table 9). A summary of the color changes in onion dehydration is listed in Appendix 7.

The color of diced onions darkened as dehydration proceeded. Measurable increases in aL and bL values were recorded in all three varieties of onions (Table 8). The calculated hue values also identified the process of darkening as a result of dehydration (Table 8). The aL value for all three white varieties increased an average of 3.0 units after 15 hours of dehydration; whereas the bL value increased by 5.0, 5.9 and 7.9 units respectively (Tables 7 and 8).

Although darkening appears to be inevitable, the degree of darkening depends upon several basic factors; the initial color of fresh white onions, temperature of storage prior to dehydration [72], temperature of dehydration, air velocity of dehydration and the initial bed load in the dehydration system. When these parameters are under control then the final product should be of high quality.

4.1.4 Total Dry Matter of the White Onions

Onion varieties used for commercial dehydration processing should contain over 12% total dry matter [46,63]. The three varieties of white onions that were grown for this study recorded total dry matter levels greater than this minimum (Table 10).

Total dry matter content is a judgement criteria for

Table 9

Changes in Intensities of White Onion Flakes as Measured by Hunterlab Color Difference Meter During Dehydration at Temperature Set I (see Table 5)

	Varieties		
	Southport White Globe	XPW 156	Seco
Hours	May 9	April 12	April 9
	L Value	*L* Value	*L* Value
0	63.1	67.0	67.4
1	65.8	67.6	66.8
2	65.9	67.6	65.0
3	66.2	67.2	66.8
4	66.3	68.5	67.3
5	64.8	70.2	68.8
6	65.6	70.9	67.3
7	67.4	70.9	69.5
8	67.1	70.6	68.5
9	67.4	70.3	69.6
11	66.0	70.3	68.8
13	66.9	70.7	69.9
15	67.5	71.1	70.2

Table 10

Average Total Dry Matter and Moisture Contents of Three Varieties of White Onions

Variety	Average Total Dry Matter Content %	Moisture Content %
Southport white globe	13.5 ± 0.5*	86.5 ± 0.5
Seco	18.0 ± 0.5	81.5 ± 0.5
XPW 156	15.5 ± 0.5	84.5 ± 0.5

* Average variation in observed data

variety selection. Van Arsdel (1962) reported onions with high total dry matter contents were given priority in the dehydration industry. Cross breeding was known to produce pungent onions with high dry matter contents. Among the three varieties or white onions studied, Seco contained the highest total dry matter content.

4.2 Storage Studies

Peleg *et al.* stored dehydrated kibble onions at 15°, 25° and 35° for 39 weeks [44]. The dehydrated onions retained their quality best at 15°C and severe deterioration took place at 35°C [44]. The results of this study agree with most of Peleg's findings (Tables 11 to 22, Figures 7 to 13, Appendices 10 to 31). The variety XPW 156 was not included in these studies due to the limited supply of fresh bulbs.

4.2.1 Moisture Content in Storage

The moisture content of all five varieties of dehydrated onions fluctuated during storage (Tables 11 and 12). Similar fluctuations were recorded by Peleg [44]. The analyses of variance data indicates temperature of storage and length of storage had an effect on the moisture level of white and yellow onions respectively (Appendices 9 and 10). All varieties started out at different moisture contents (Tables 11 and 12). The storage temperature had a significant effect

Table 11

Moisture Changes in Dehydrated White Onion Flakes After 180 Days at Two Temperatures

Time (Days)	Southport white Globe		Seco	
	25°C	10°C	25°C	10°C
	%	%	%	%
0	4.46	4.46	4.34	4.34
30	4.52	4.60	3.89	4.17
60	4.40	4.40	3.70	4.03
90	4.31	4.49	3.73	3.96
120	4.41	4.45	4.02	4.42
150	4.89	4.79	4.01	4.26
180	4.51	4.68	3.79	4.11

Table 12

Moisture Changes in Dehydrated Yellow Onion Flakes After 360 Days of Storage at Two Temperatures

	Spartan Era		Autumn Pride		Autumn Spice	
	25°C	10°C	25°C	10°C	25°C	10°C
	%	%	%	%	%	%
0	3.30	3.30	2.90	2.90	3.12	3.12
30	4.03	3.13	3.04	3.15	2.72	2.91
60	4.20	3.24	4.14	3.10	4.13	3.12
90	3.84	3.87	3.68	3.26	3.78	3.53
360	4.10	4.39	3.86	4.37	3.97	4.20

on the moisture content of the white onion varieties but not the yellow types, while the length of storage had a significant effect on the yellow varieties but not the white varieties. In general, the longer the product is stored the more moisture the product absorbs. Also, the lower temperature of storage (10°C) permitted the dehydrated onions to pick up a greater amount of moisture than the higher temperature level of 25°C.

4.2.2 The Effect of Storage on Ash Content

The ash contents of the five varieties ranged between 3 to 4%. Autumn Spice was the lowest at 3.01% and Autumn Pride was the highest at 3.73%. Watt and Merrill reported that the average ash content for dehydrated onion was 3.9% [68]. Temperatures of storage had no effect on the ash content of either white or yellow dehydrated onions. Prolonged storage appeared to increase the percentage of ash content in dehydrated onions (Tables 13 and 14). Analysis of variance data indicated that length of storage significantly affected the percentage content of ash in the yellow varieties (Appendices 11 and 12). This trend though not significant could also be observed in the white varieties. This increase in percentage ash content could not be explained using existing data since no observable reactions took place that could give a significant change in mineral content.

Table 13

Ash Contents of Two Varieties of Dehydrated White Onions Stored up to 180 Days at Two Temperatures

Time (Days)	Ash Content - %			
	Southport white globe		Seco	
	25°C	10°C	25°C	10°C
0	3.40	3.40	3.04	3.04
30	3.49	3.47	3.16	3.07
60	3.41	3.30	3.15	3.10
90	3.60	3.55	3.27	3.24
120	3.47	3.47	2.96	2.95
150	3.59	3.64	3.19	3.25
180	3.61	3.56	3.33	3.29

Table 14

Ash Contents of Three Varieties of Dehydrated Yellow Onions Stored Up to 360 Days at Two Temperatures

Time (Days)	Ash Content - %					
	Spartan Era		Autumn Pride		Autumn Spice	
	25°C	10°C	25°C	10°C	25°C	10°C
0	3.25	3.25	3.73	3.73	3.01	3.01
30	3.44	3.48	3.85	3.80	3.25	3.31
60	4.04	3.91	4.24	4.31	3.48	3.65
90	4.00	3.99	4.20	4.06	3.82	4.18
360	3.91	4.24	3.77	4.62	4.08	3.79

4.2.3 The Effect of Storage on Hot Water Insolubles

The American Dehydrated Onion and Garlic Association (ADOGA) specified that dehydrated onions should contain no more than 20% hot water insolubles (HWI) [2]. With the exception of Autumn Pride, all fresh dehydrated samples contained less than 20% hot water insolubles. Time and temperature of storage had no prominent effect on the content of HWI (Tables 15 and 16).

Analysis of variance data (Appendices 13, 14) did not report any significant changes during the storage period.

The content of hot water insolubles is a good indicator of the purity of dehydrated onions. Most of the constituents of dehydrated onions are readily soluble in hot water. However, when impurities are present in the products, the HWI content increases. The most common impurities are ground-up insects, filth and wastes. Dried peels (skins) and roots of the plant also contribute to a high HWI measurement. The measurement of hot water insolubles is generally used in estimating the purity of dehydrated onions.

Dehydrated onions produced in this study were clean, free of foreign particles, skins and roots as indicated by the low content of hot water insolubles. In general, the three yellow onion varieties contained more insoluble contents than the white varieties. Of the five varieties tested, Seco contained the lowest percentage of hot water insolubles. Since all onions were treated the same prior to

Table 15

Hot Water Insolubles of Two Varieties of Dehydrated White Onions Stored for 180 Days at Two Temperatures

Time (Days)	Hot Water Insolubles - %			
	Southport white globe		Seco	
	25°C	10°C	25°C	10°C
0	14.55	14.55	12.20	12.20
30	14.62	14.76	13.58	12.44
60	14.23	14.23	11.44	12.40
90	14.78	14.97	12.32	11.42
120	13.11	12.94	12.64	11.59
150	11.91	14.37	11.65	11.66
180	11.68	13.09	12.63	12.47

Table 16

Hot Water Insolubles of Three Varieties of Dehydrated White Onions Stored for 360 Days at Two Temperatures

Time (Days)	Hot Water Insolubles - %					
	Spartan Era		Autumn Pride		Autumn Spice	
	25°C	10°C	25°C	10°C	25°C	10°C
0	18.44	18.44	20.64	20.64	18.71	18.71
30	20.07	17.20	19.71	19.54	15.81	19.18
60	20.62	19.00	19.44	20.04	18.31	20.39
90	17.15	17.56	17.49	18.82	17.52	17.94
360	18.26	17.46	19.59	18.45	16.82	15.70

dehydration, this measured difference in HWI could be due to varietal differences.

4.2.4 Color Changes in Storage

The main color alteration observed during storage was darkening of all samples. Both of the color measuring instruments, the Spectronic 20 spectrophotometer and the Hunterlab color difference meter, reported the darkening phenomenon.

4.2.4.1 Changes of optical index in storage

The ADOGA group specified that all powdered and granulated white onions should have an optical index (OI) not exceeding 105 [2]. No optical index standards were set for yellow globe onions. The yellow pigmentation in these varieties had been the reason for rejection by onion processors.

Freshly dehydrated Seco onions registered an OI value of 20.3 and Southport white globe registered at 21.5 (Table 17). The yellow onions were higher in initial OI values. They registered at 205.19, 280.1 and 255.23 for Spartan Era, Autumn Pride and Autumn Spice respectively (Table 18).

The optical index data (Tables 17 and 18, Figure 7) clearly demonstrated the darkening phenomenon. Maillard browning is the probable cause of this darkening since the majority of the enzymes in onions would be inactivated by

Table 17

Changes in Optical Index of Two Varieties of Dehydrated White Onion Flakes Stored for 180 Days at Two Temperatures Measured in Optical Index units

Time (Days)	Optical Index Units: Seco 25°C	Seco 10°C	Southport white globe 25°C	Southport white globe 10°C
0	20.30	20.30	21.50	21.50
30	29.30	20.35	30.25	20.50
60	117.30	70.90	123.00	96.85
90	122.53	76.04	123.00	89.94
120	74.52	61.81	109.05	71.34
150	109.06	71.46	159.25	83.66
180	106.10	85.24	149.41	62.01

Table 18

Changes in Optical Index of Three Varieties of Dehydrated Yellow Onion Flakes for 360 Days at Two Storage Temperatures Measured in Optical Index Units

Time (Days)	Optical Index Units					
	Spartan Era		Autumn Pride		Autumn Spice	
	25°C	10°C	25°C	10°C	25°C	10°C
0	205.19	205.19	280.10	280.10	255.23	255.23
30	198.03	249.60	249.64	190.75	231.30	223.82
60	331.49	247.63	313.03	288.88	298.73	269.00
90	305.70	243.89	305.71	275.39	317.72	230.90
360	381.42	242.06	388.35	245.91	335.92	290.53

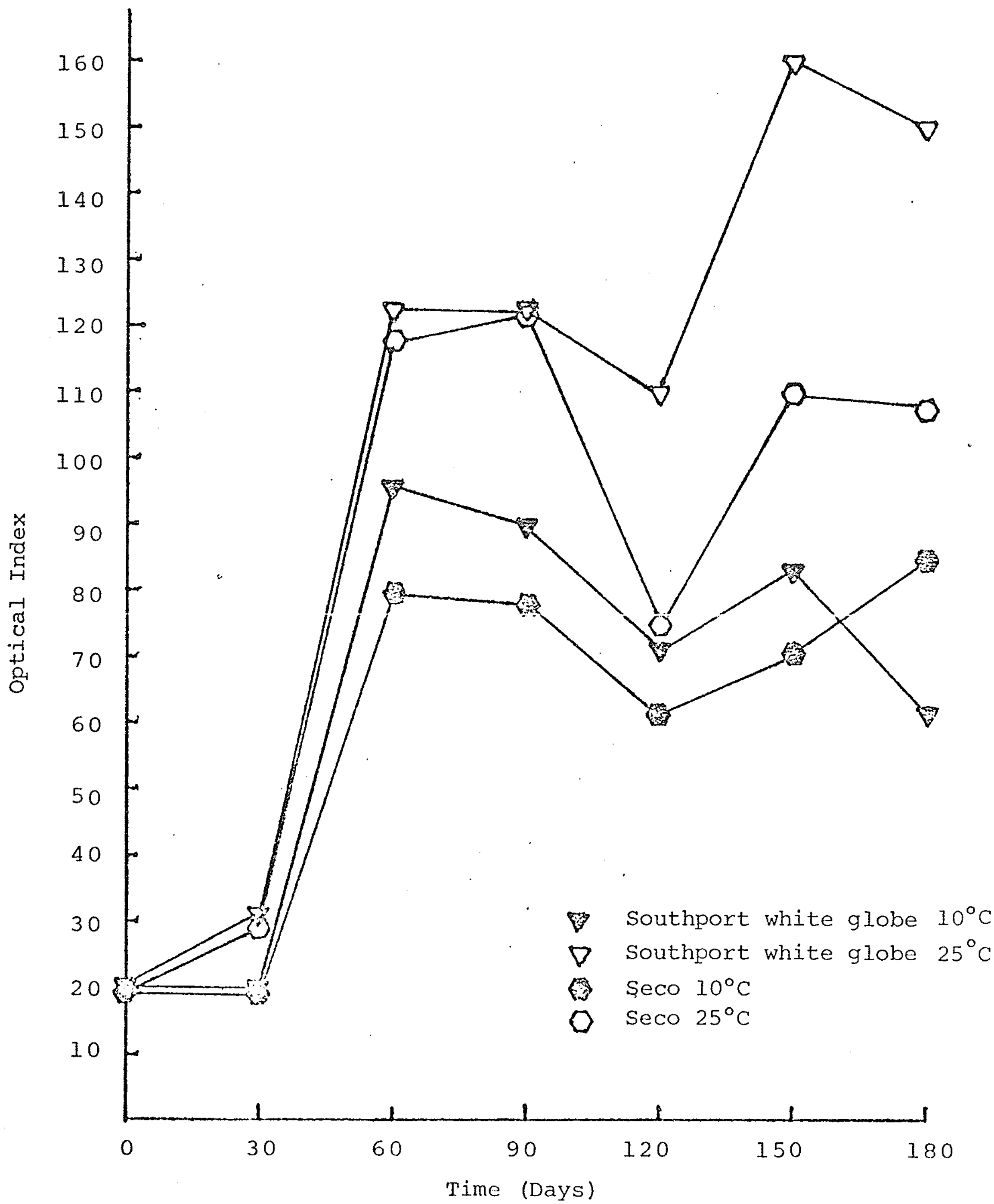

Figure 7

Changes of optical index of two varieties of white onion flakes stored for 180 days at 10°C and 25°C the dehydration process [10,18].

The analysis of variance data indicated that both temperature and length of storage affected the color quality (Appendices 15, 16). The darkening phenomenon increased at a more rapid rate at storage temperatures of 25°C than at 10°C. After 180 days of storage at 25°C the color of dehydrated onions became unacceptable for ADOGA standards. The optical index reading for the Seco variety was 106 and for the Southport white globe variety 149. At 10°C the optical index reading for both varieties was readily acceptable; Seco at 85 and Southport white globe at 62. Even though the yellow globe onions would never meet the ADOGA color standard the 10°C storage temperature was observed to be the superior storage temperature as the OI reading increased much more for all varieties at 25°C.

Limited samples of Autumn Spice were stored at 35°C for 90 days to evaluate color. At the end of the 90 day period, a change of 1730.2 OI units was recorded (Table 19). This tremendous change indicates that 35°C is not desirable for onion storage.

The darkening phenomenon was observed to increase during the entire storage period (Figure 7, Tables 17, 18 and 19). There were some fluctations in the total darkening that occurred within individual varieties. The reasons for these fluctuations are not known at this time but the higher increase of OI values at 25°C indicated dehydrated onions

Table 19

Color Changes of Autumn Spice at 35°C for
90 Days Measured in Optical Index Units
and in Hunterlab Colorimetric Readings

Time (Days)	Optical Index	Hunterlab Colorimetric Reading		
		L	a*L*	b*L*
0	255.23	64.2	-0.2	24.4
30	208.86	57.5	+3.7	24.0
60	660.87	48.1	+8.3	21.9
90	1985.43	47.8	+8.3	21.1

should be stored under cool or refrigeration conditions to retain a color quality that is acceptable to the processing industry.

4.2.4.2 Color changes in storage measured by a Hunterlab color difference meter

A Hunterlab color difference meter was also used for color measurements in this study. No standard for onion color has been set in the language of this instrument. Peleg reported the usefulness of the Hunterlab color difference meter in color measurements of dehydrated onions [44]. Using this instrument, Peleg was able to identify the actual yellowing and reddening of dehydrated onions during storage. A gradual decrease in the *L* value accompanied by an increase in the a*L* and b*L* value was an indication of the continuous darkening process [44]. Results of this study agree with the findings of Peleg (Figures 8, 9, 10, 11, 13 and Appendices 17 to 28).

The Hunterlab color difference meter could detect darkening of the white and yellow dehydrated onion varieties stored at 25°C versus those stored at 10°C (Appendices 17, 18, 19 and 20). The length of storage had little effect on the darkening of white onion flakes, but caused significant darkening in the yellow varieties (Appendices 17, 18, 19 20).

Reddening (a*L* value) of white onions was prominent at 25°C of storage but insignificant at 10°C. Length of storage did not significantly affect the redness of the onion flakes

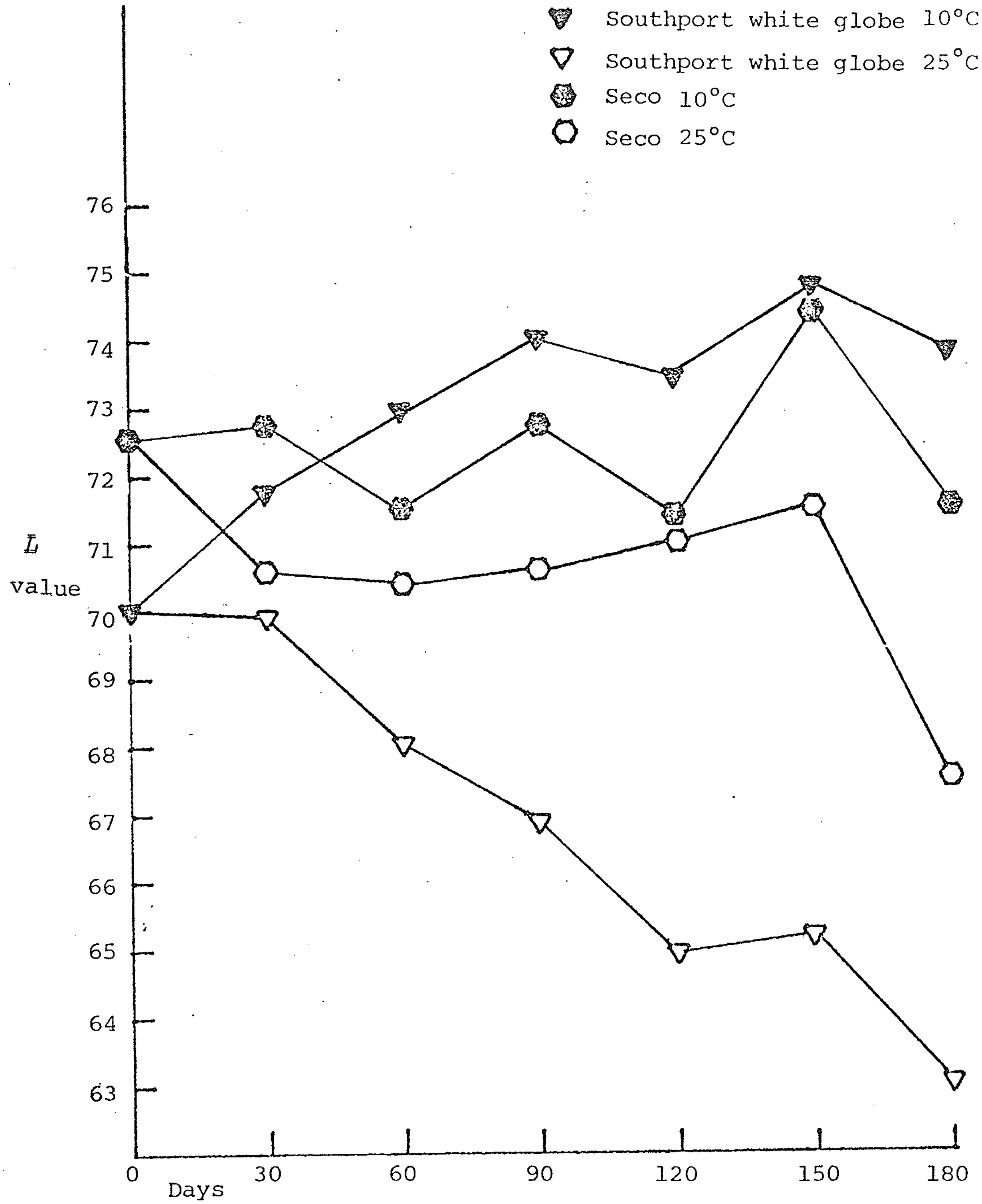

Figure 8

Changes of *L* Value of Two Varieties of White Onion Flakes Stored for 180 Days at 10°C and 25°C Measured by a Hunterlab color difference meter

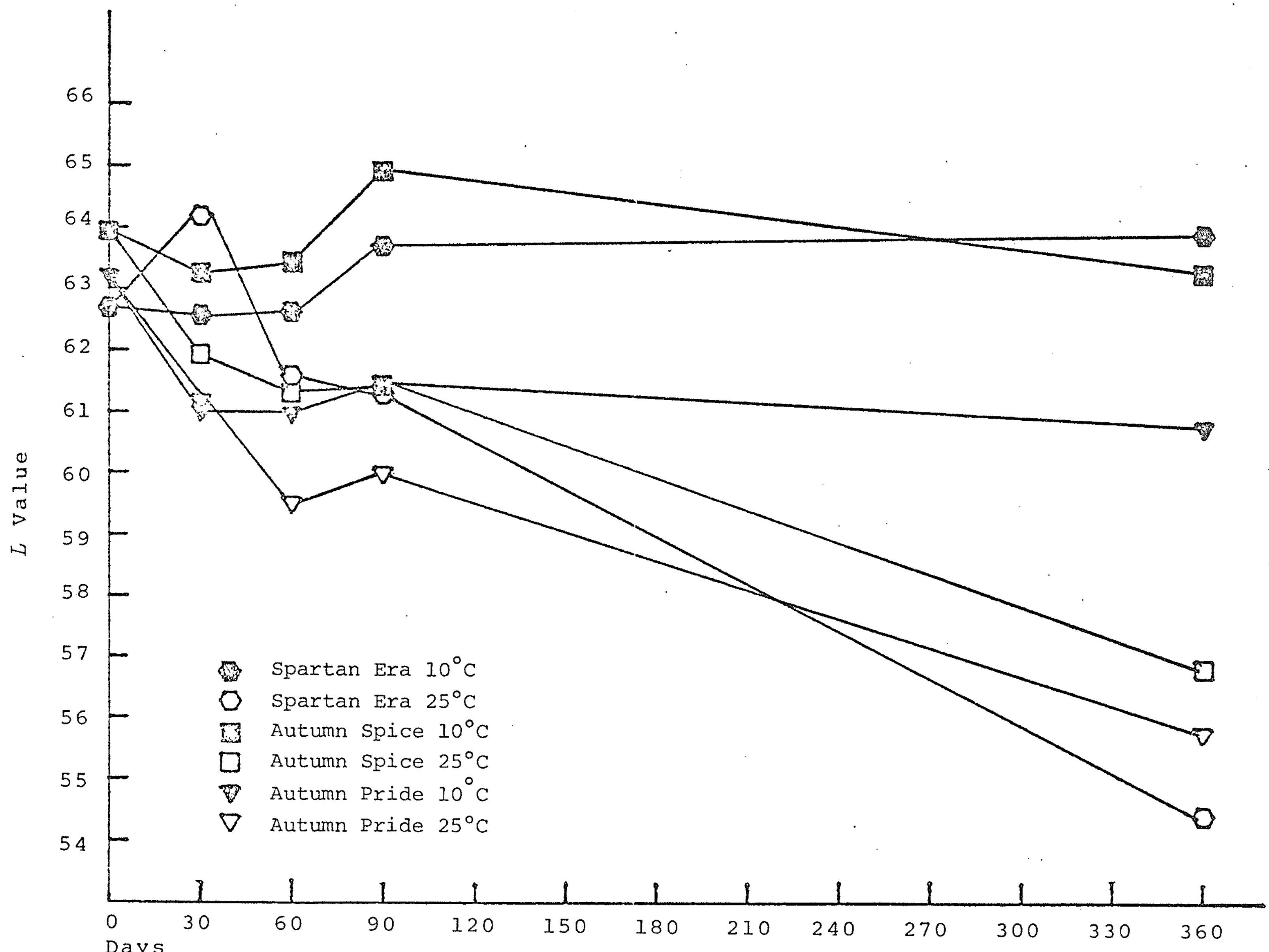

Figure 9

Changes of *L* Value of Three Varieties of Yellow Onion Flakes Stored for Days at 10°C and 25°C Measured by a Hunterlab Color Difference Meter

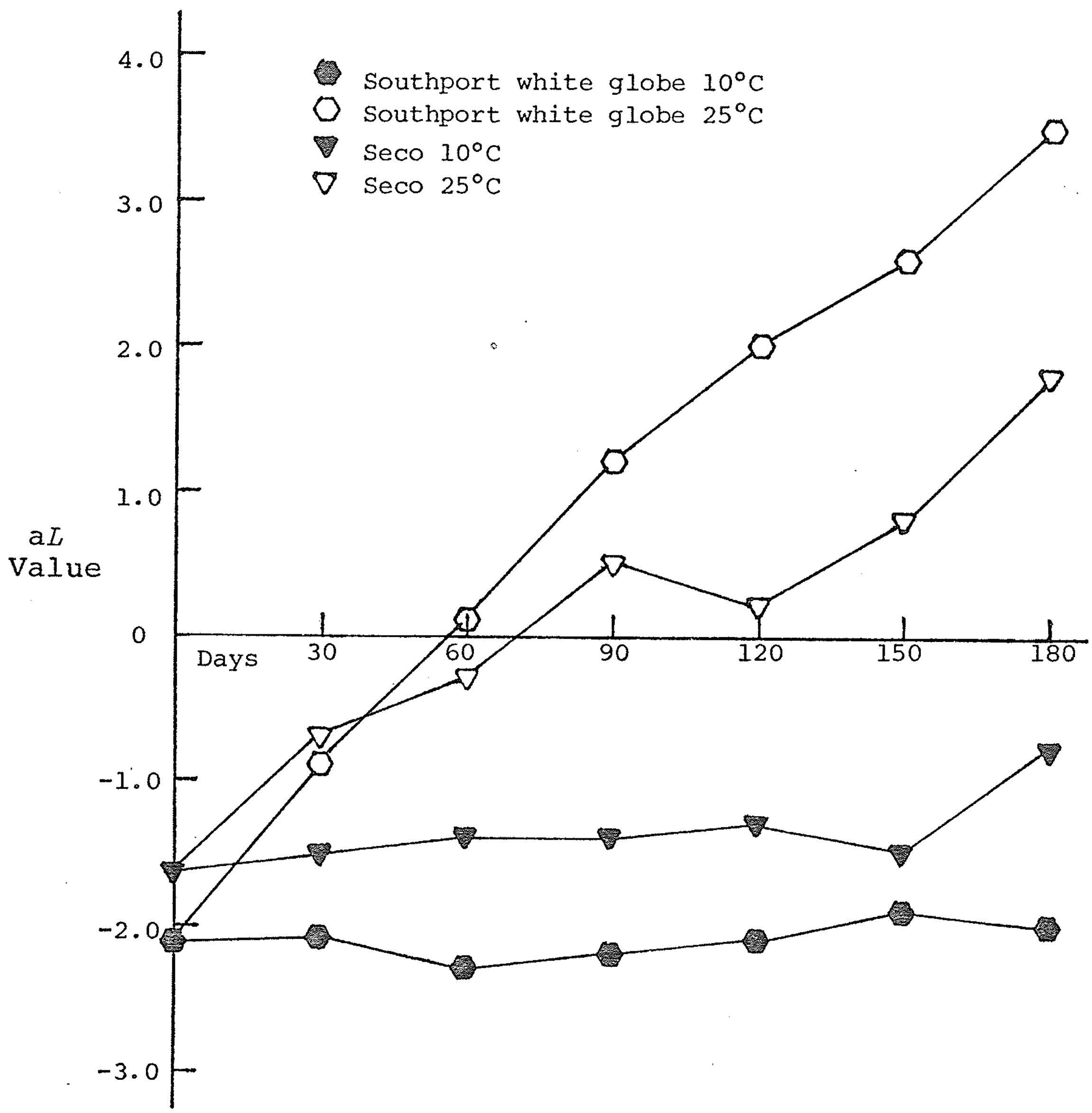

Figure 10

Changes of *aL* Values of Two Varieties of Dehydrated White Onions Stored for 180 Days at 10°C and 25°C

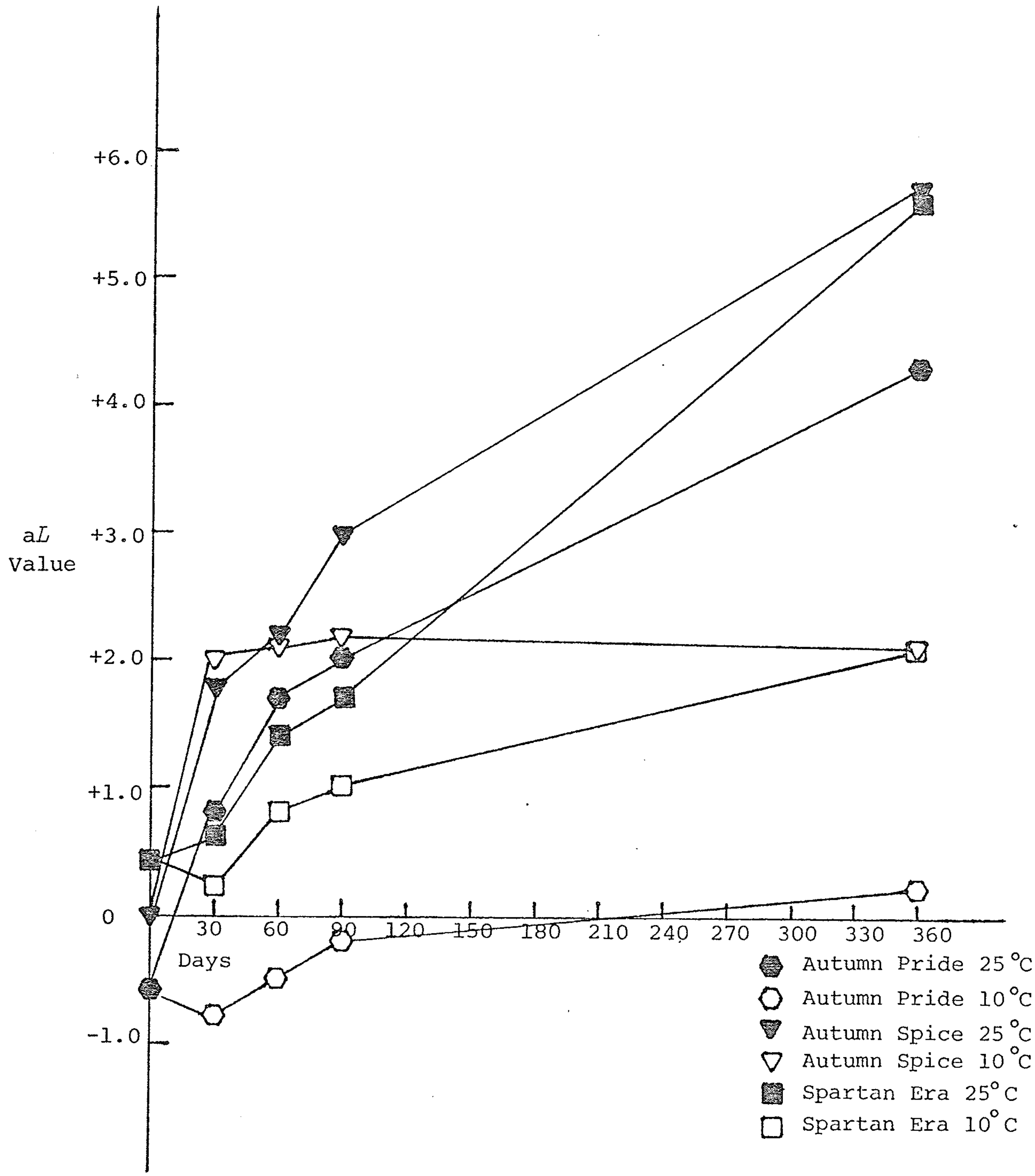

Figure 11

Changes of *aL* Values of Three Varieties of Dehydrated Yellow Onions Stored for 460 Days at 10°C and 25°c

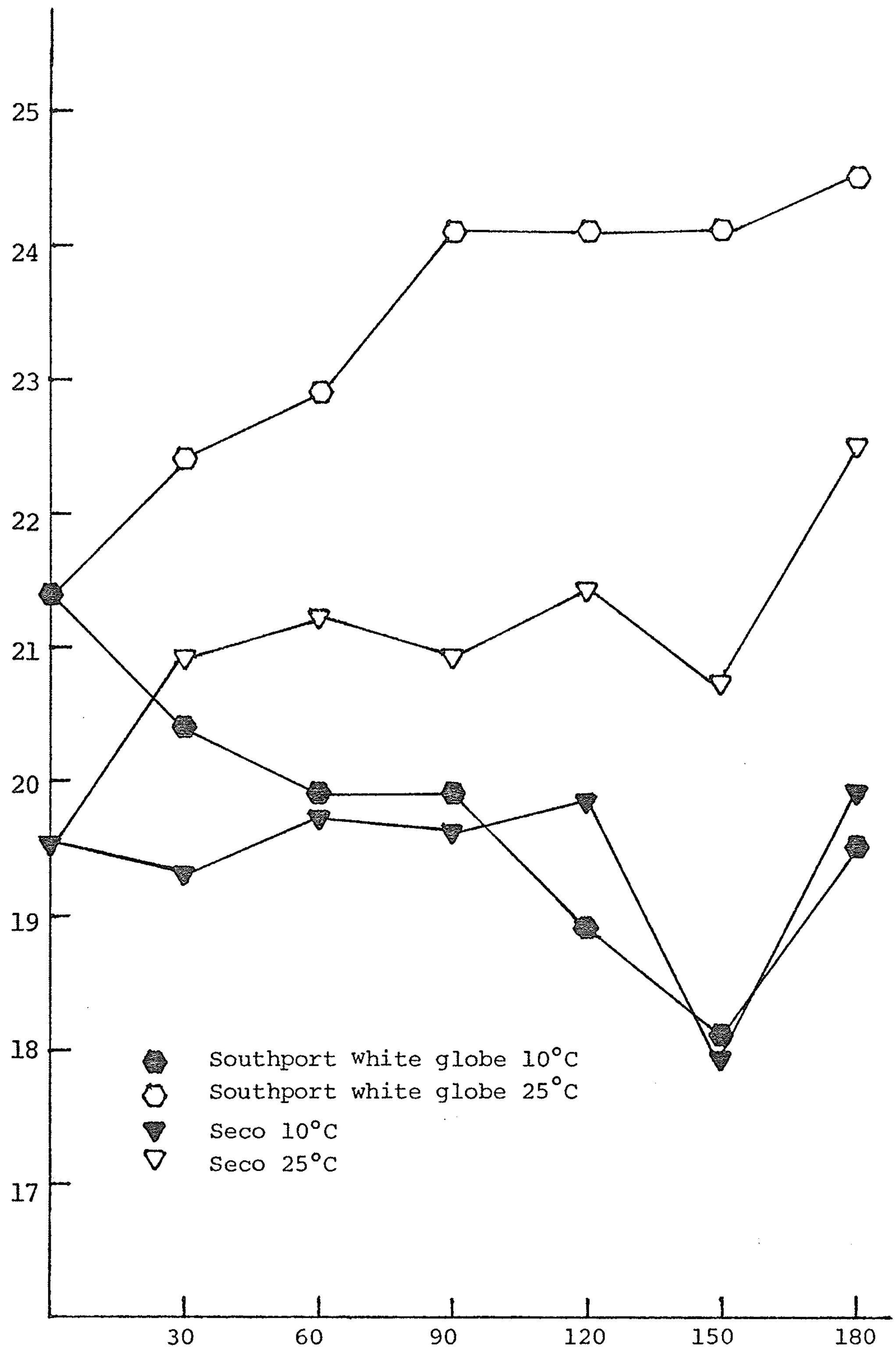

Figure 12

Changes in b*L* Values of Two Varieties of Dehydrated White Onions Stored for 180 Days at 10°C and 25°C

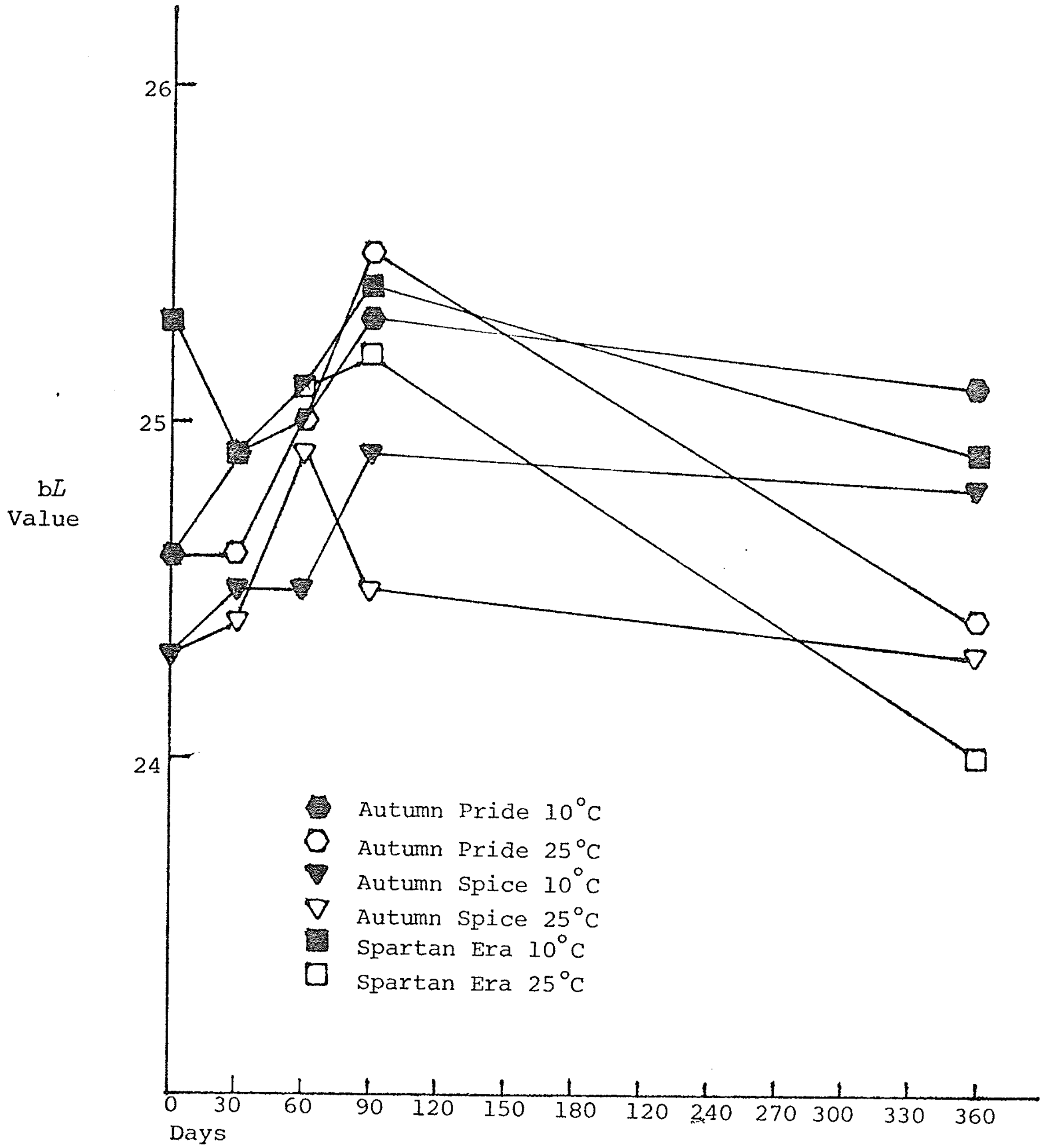

Figure 13

Changes in b*L* Values of Three Varieties of Dehydrated Yellow Onions Stored for 360 Days at 10°C and 25°C

(Appendices 21, 22). Different degrees of redness were registered in the three dehydrated yellow onion varieties. Reddening was significant for all three varieties stored at 25°C and the length of storage increased the degree of redness in all three yellow varieties (Appendices 23, 24).

The two varieties of dehydrated white onions were different in the degree of yellowness (bL value). This yellowness became more prominent when stored at 25°C. Length of storage was not the significant cause for yellowing in either variety (Appendices 25, 26). The three varieties of dehydrated yellow onions also differed in the degree of yellowness; however, temperature and length of storage had little effect on the yellowing process (Appendices 27, 28).

4.2.4.3 Correlations between the Hunterlab colorimetric measurement and the optical index

Both of the color measuring devices were used successfully in color measurements. Optical index values demonstrated color deterioration for onion flakes stored at 25°C and the Hunterlab color difference meter had identified the major change as the reddening of the onion flakes.

4.2.5 <u>Microbiological Content in Onion Storage</u>

Johnson and Vaughn (1969) pointed out that many species of bacteria were inhibited by the volatile components in onions [18]. The microbial counts obtained from the onions dehydrated during this study were astonishingly low (Table 20).

Table 20

Microbial Counts of Three Varieties of Yellow Onion for 90 Days of Storage at Two Temperatures

	25°C			10°C		
Autumn Pride #/gm	SPC	Y & M	Coli	SPC	Y & M	Coli
0	1520	230	0	1520	230	0
30	550	60	0	660	70	0
60	290	10	0	510	250	0
90	140	25	0	310	110	0
Spartan Era						
0	250	130	0	250	130	0
30	180	40	0	55	55	0
60	310	20	0	10	10	0
90	190	15	0	9	10	0
Autumn Spice						
0	60	170	0	60	170	0
30	45	100	36	15	90	0
60	20	30	0	10	20	0
90	15	24	0	12	20	0

SPC - Standard Plate Counts
Y & M - Yeast and Mold Counts
Coli - Coliform Count

Total bacterial, yeast, mould and coliform counts were all lower than expected. The low microbial population could be accredited to proper handling. Equipment in contact with onions were washed and properly dried before and after each use. The dehydrating machine was washed and cleaned frequently. The low number of coliform organisms suggested little contamination of human origin. During the 90 days of storage, microbial growth was further reduced. Reduced moisture content could be the determining factor for low microbial growth.

4.2.6 Flavor Evaluation of Dehydrated Onions

Dehydrated white onion flakes of Southport white globe and Seco were stored at 10° and 25°C for 0 time, 90 and 180 days. They were evaluated for flavor at the end of the storage. A panel consisting of 20 members evaluated the dried onions in forms of onion soup and expressed their likes and dislikes in terms of a nine point Hedonic scale. (The procedure was discussed in Section 3.2.7.)

Peleg reported dehydrated onions retained best flavor at 15°C of storage as compared to 25° and 35°C [44]. No indication was given by the twenty panelists that dehydrated onion retained better flavor at 10°C storage than at 25°C storage (Tables 21 and 22).

The initial flavor of freshly dehydrated onions of the two white varieties was comparable (Appendix 29).

Table 21

Mean Scores of Taste Evaluations of Two Varieties of Dehydrated White Onions at Three Stages of Storage

	Values - Nine Point Hedonic Scale			
	Southport white globe		Seco	
Time (Days)	10°C	25°C	10°C	25°C
0	5.70	5.70	5.10	5.10
90	5.30	5.85	5.20	4.35
180	4.80	5.55	4.80	5.05

Table 22

Mean Scores of Taste Evaluations of Two Varieties of Dehydrated White Onions at Two Storage Temperatures

		Values - Nine Point Hedonic Scale		
Time (days)		0	90	180
Variety	Temp. °C			
Southport white globe	10	5.45	5.55	4.80
Southport white globe	25	5.80	5.40	5.60
Seco	10	5.45	4.85	5.80
Seco	25	5.65	5.65	5.25

Southport white globe were slightly favored by the panelists (Table 21). After 90 days of storage, Southport white globe stored at 25°C was the best liked and Seco stored at 25°C was the least preferred (Table 21). The analysis of variance data confirmed that the difference in variety and temperature of storage was a major factor (Appendix 30). A multiple range test for the mean scores pointed out the difference between the two varieties at 25°C of storage (Appendix 31). After 180 days of storage, panelists again preferred Southport white globe stored at 25°C over the other samples. Both varieties stored at 10°C were least preferred (Table 21). The analysis of variance data indicated there was an significant difference detected on flavor at the two temperatures of storage and there was also a disagreement in the opinion of the judges (Appendix 32). A multiple range test for the mean scores was able to identify the flavor difference as basically between 10°C and 25°C of Southport white globe (Appendix 33). Each variety of dehydrated onion was then tested for its flavor changes at each particular temperature of storage (Table 22). At 25°C of storage flavor changes were detected in both varieties. At 10°C of storage Southport white globe showed a significant change in flavor but the change was less detected in Seco (Table 22, Appendices 34, 35, 36, 37).

It appeared that time and temperature of storage do affect the flavour of dehydrated onions. Fortunately, this change is slight. Dehydrated onions stored at 25°C was more preferred by the panelists (Table 21) which is quite contrary to Peleg's findings. Perhaps the slightly toasted flavor at 25°C was more preferred over the strict onion flavor.

Although the two varieties indicated little flavor difference, Southport white globe was preferred by most of the judges. As the mean scores indicated, Southport white globe has a better flavor at zero time, 90 and 180 days (Tables 21 and 22). At 25°C of storage, the judges rated Southport white globe to possess the best flavor.

4.3 Food Processor Survey

Results of the study are given in Table 23. The quality of dehydrated yellow onions was rated high. Color of the product was the biggest undesirable quality.

Color and flavor of dehydrated onions were agreed upon by the 21 food processors to be the most significant criteria for judging dehydrated onion quality. The yellow varieties produced in this study did not meet the color standard set by the American Dehydrated Onion and Garlic Association. The flavor of the products, however, was praised by many of the processors.

Table 23

Processor Judgements on Three Varieties of Dehydrated Yellow Onions (Based on 21 Observations)

Color		
	Desirable	11
	Undesirable	10
Flavor		
	Desirable	10
	Satisfactory	8
	Undesirable	3
Willingness to Buy		
	Definite	5
	Uncertain	7
	Definitely not	9

Reasoning: preferred white varieties

CHAPTER 5

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary

Six varieties of white and yellow globe onions were dehydrated to below 5% moisture content with a fluidized bed drier. Five of the six varieties were stored at 10° and 25°C for 180 to 360 days. One variety, Autumn Spice was also stored at 35°C for 90 days. The effects of time and temperature of storage on dehydrated onions were measured. Quality characteristics such as moisture, ash, color, hot water insoluble solids, flavor and microbial population were studied at 30 day intervals. Ten degrees centigrade was in general the most preferred storage temperature for dehydrated onion products. The color of dehydrated onions was found to deteriorate in prolonged storage at all three storage temperatures.

5.2 Conclusion

The optimum dehydration temperature for onions should be at 60° or 70°C initially and a temperature over 80°C is considered to be too severe for fluidized bed operations. Gradually reducing the temperature at later stages of dehydration is advantageous in producing high quality products.

Qualities of dehydrated onions at 3 to 5% moisture are best preserved at low temperatures of storage. A storage temperature of 35°C is too severe and will easily damage the onion qualities. Many quality characteristics such as moisture content, ash content, hot water insolubles, and flavor are not damaged at 25°C storage. The greatest change in color occurred at high storage temperatures and this was observed even at 25°C.

Both of the yellow and white Manitoba onions were capable of producing good quality dehydrated products. Color was the major opposing factor for the utilization of yellow globe onions. Quality characteristics were fairly even within the two white globe onions studied in detail. Seco was more preferable in the areas of total dry matter, hot water insolubles and color whereas Southport white globe had the advantage in pungency. Both varieties, however, were of good quality and are suitable for the production of dehydrated onions.

5.3 Recommendations

Most of the problems encountered in onion dehydration were controlled. A fluidization bed system was capable of producing good quality dehydrated onion products. However, caution will still be required in some areas.

The problem of adhesion is still the major problem in the process of dehydration. It appears clumping is inevitable in the early stages of dehydration. An agitation system sufficient to break up the agglomerates without damaging the structure of onions is essential. The first nine hours of dehydration is the most critical period, proper handling of equipment with proper control of air velocity and bed temperature will preserve good quality characteristics of the onions.

The Hunterlab color difference meter is a very useful instrument in color measurement for moist, partially dried and dried onions in forms of powder, dice and slices. Simplicity and quickness of procedures is a big advantage in food industries.

A rapid dehydration process is essential since cut tissues are more susceptible to deteriorations. Dried onions should always be stored in clean, air-tight containers in dry cool storages to prolong storage life.

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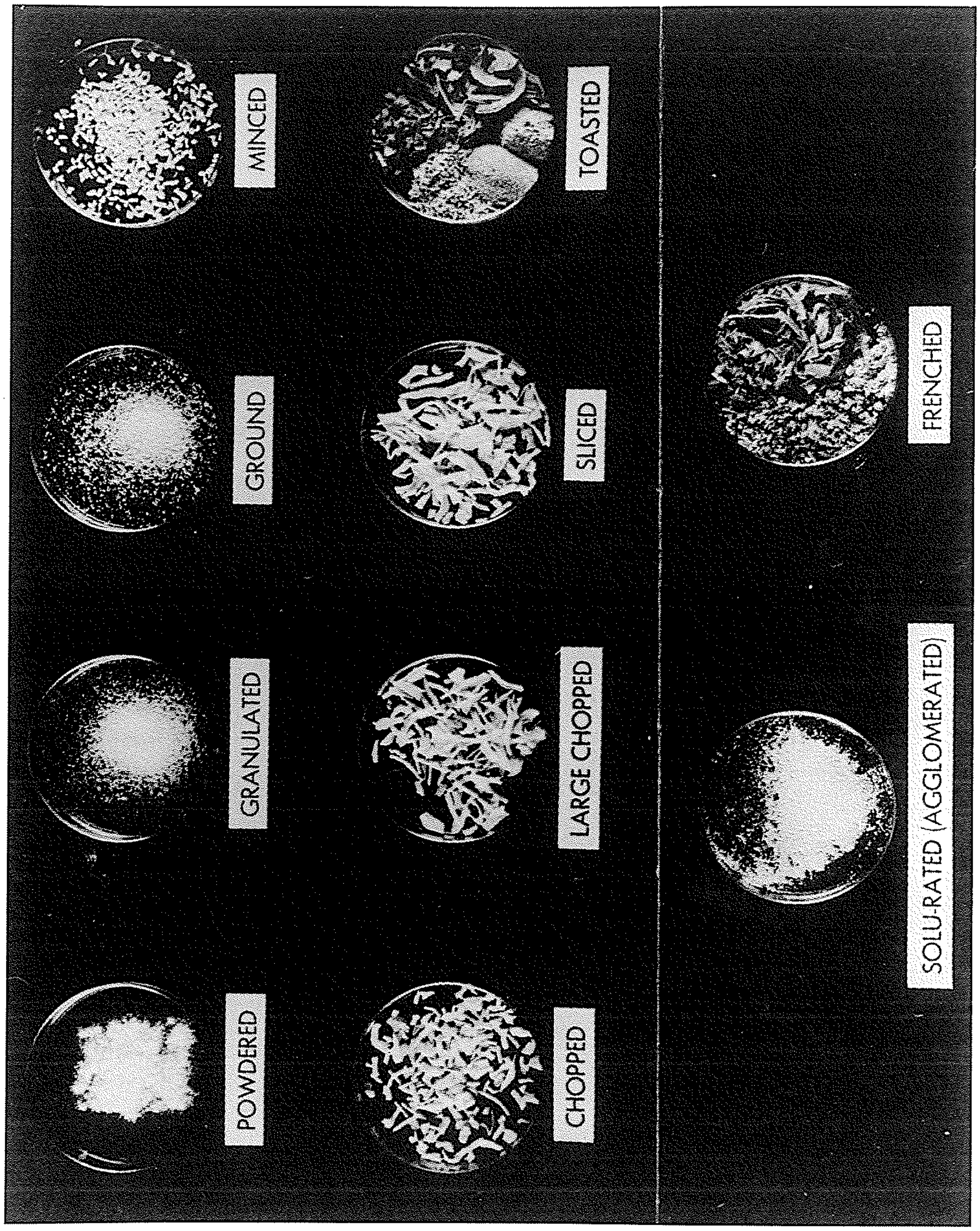
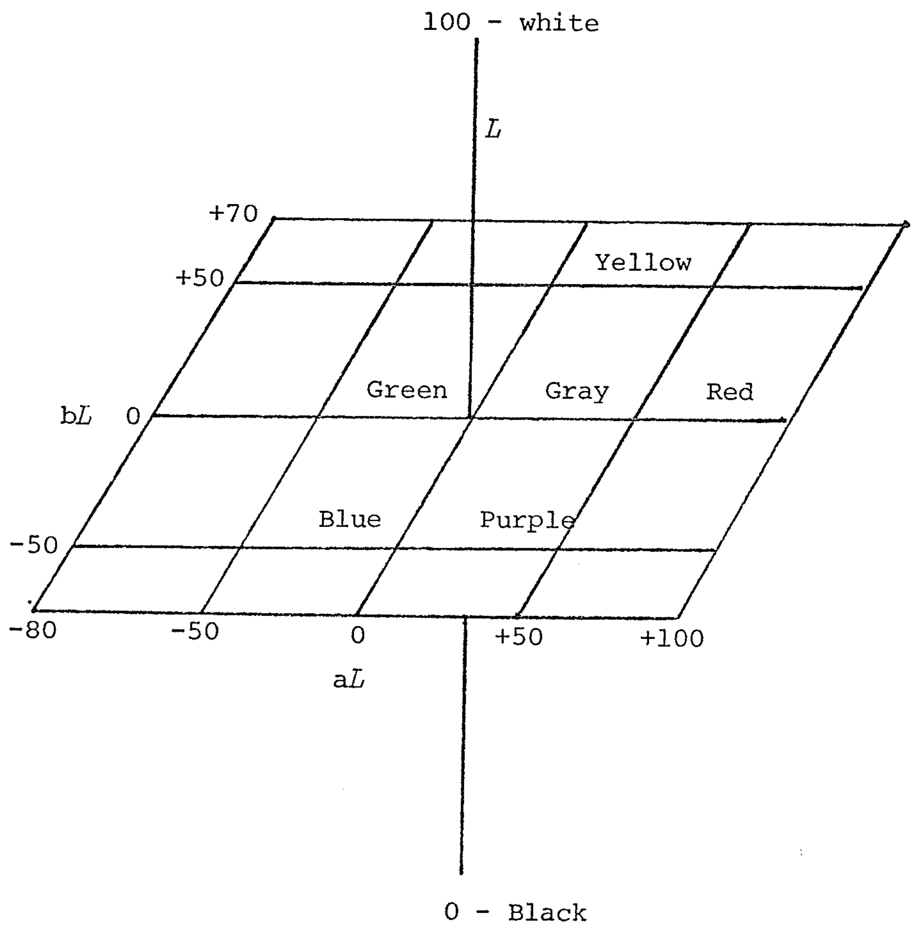
APPENDICES

Appendix 1



Photographic Representation of the Ten
Categories of Dehydrated Onions [13]

Appendix 2. Diagram showing the dimensions of the color and color-difference meter *L*, a*L* and b*L* color solid.



Appendix 3. Air velocity of the STS 5 Batch fluidized bed drier.

Setting on the Drier	Corresponding Air Velocity* cu.ft. per minute
0	358
1	358
2	506
3	716
4	1,012
5	1,240
6	1,339
7	1,432
8	1,476
9	1,476
Full	1,476

* Measured by pitot tubes on air inlets and calculated with the following formulas

$$V_o \text{ (velocity of air in feet per second)} = \sqrt{2 \times 32.174 \times 62.3 \times \frac{\Delta H}{12}}$$

ΔH = pitot reading

Area of the pipe = 2.3562 square feet

Velocity of air in cubic feet per minute =

Vo x Area of the pipe x 60

Appendix 4. Calculation for total dry matter and moisture content of partially and fully dehydrated onions.

W_1 = weight of dried crucible

W_2 = weight of dried crucible + moist samples

W_3 = weight of dried crucible + dried samples

$$\% \text{ Dry Matter} = \frac{W_3 - W_1}{W_2 - W_1} \times 100\%$$

% moisture = 100% - % dry matter

Appendix 5. Questionnaire for consumer evaluation on dehydrated yellow onions.

1. Is the color of the product satisfactory?
2. If not, why not?
3. Is the mesh size suitable for your operation?
4. If not, which mesh size do you prefer?
5. How would you rate the flavor of the product?
6. Would you buy this product if it was available commercially?
7. If you would not buy this product, can you offer suggestions for improvements so that the answer to question 6 could be yes?
8. What price would you be prepared to pay for this product, in relation to other commercial dried onion products that you now purchase?
9. How much onions of this quality product would you buy each year if it was commercially available?
10. What other dried vegetables would you like to see produced in Manitoba? Please estimate possible needs in tons dry per annum and approximate market value.

Appendix 6a. Rate of moisture removal of three varieties of white onions at temperature set number 1*

	0	1	2	3	4	5	6	7	8	9
Southport white globe										
May 15	88.14	80.58	68.49	35.54	22.58	16.84	16.64	16.21	14.77	14.46
May 16	87.35	80.62	68.47	42.85	29.20	22.75	18.45	18.15	17.11	15.58
May 17	86.70	77.87	58.27	37.71	32.08	26.13	25.22	22.69	19.18	18.82
Seco										
April 6	80.86	64.66	31.24	30.38	19.50	17.66	16.27	14.79	9.84	9.64
April 9	80.33	67.07	46.66	28.07	21.66	17.40	16.27	13.64	11.98	11.88
April 10	80.52	70.17	52.20	33.87	23.26	21.42	19.86	18.20	15.23	13.99
XPW 156										
April 18	84.78	72.30	55.23	35.37	27.00	21.81	17.37	17.25	15.21	14.00
April 23	84.04	73.90	55.52	31.55	22.16	18.13	16.31	14.89	12.59	10.96
May 7	84.29	71.93	52.77	35.23	26.03	18.85	18.44	17.22	16.64	14.98

* Refer to Table 5

Appendix 6b. Rate of moisture removal of three varieties of white onions at temperature set number 2*.

	0	1	2	3	4	5	6	7	8	9
Southport white globe										
March 12	86.26	63.34	44.95	28.55	23.16	13.97	13.68	12.84	11.75	11.25
March 13	86.28	68.32	58.76	44.16	32.57	26.34	23.90	18.73	17.55	17.37
March 19	86.21	55.46	32.36	22.02	16.34	12.85	11.28	11.26	9.80	8.85
Seco										
March 20	82.17	69.64	43.53	26.52	24.52	22.64	17.19	16.84	15.38	11.24
April 2	80.75	63.40	35.27	24.75	21.39	18.16	16.92	14.03	13.97	13.31
April 5	80.50	63.45	48.02	38.94	32.41	25.14	24.22	20.08	16.64	15.82
XPW 156										
April 13	83.86	71.24	50.00	31.62	24.19	21.81	18.25	14.25	13.25	12.61
April 16	84.32	77.47	57.09	34.13	30.76	28.44	25.52	21.08	17.18	14.61
April 12	84.55	68.60	42.51	34.14	26.67	19.45	15.00	14.72	14.27	13.77

* Refer to Table 5

Appendix 7a. Color changes of three varieties of white onions during dehydration at temperature set number 1*.

		0	1	2	3	4	5	6	7	8	9
Southport white globe											
May 15	*L*	62.8	64.6	66.0	66.8	66.3	67.0	65.9	67.3	67.5	67.8
	Hue	-0.4640	-0.3806	-0.2983	-0.2307	-0.2211	-0.1853	-0.2000	-0.1918	-0.1875	-0.1818
May 16	Intensity	65.1	63.1	65.5	66.0	66.1	66.3	64.3	67.0	66.4	68.7
	Hue	-0.4960	-0.3653	-0.2972	-0.2526	-0.2205	-0.2326	-0.2100	-0.2009	-0.2097	-0.2077
May 17	Intensity	64.0	65.1	64.5	63.6	65.0	66.6	66.9	67.7	66.6	67.4
	Hue	-0.4064	-0.3371	-0.2512	-0.2698	-0.2653	-0.2178	-0.2200	-0.2150	-0.1674	-0.2125
Seco											
April 6	Intensity	65.2	65.6	64.8	67.2	68.2	68.1	67.6	68.4	68.9	68.9
	Hue	-0.4691	-0.3559	-0.3169	-0.2295	-0.1497	-0.1560	-0.1339	-0.0930	-0.1000	-0.0900
April 9	Intensity	67.3	66.8	65.0	66.8	67.3	68.8	67.3	69.5	68.5	69.6
	Hue	-0.4090	-0.3131	-0.2789	-0.2094	-0.1698	-0.1596	-0.1563	-0.1442	-0.1559	-0.1394
April 10	Intensity	66.9	67.4	67.1	68.9	69.8	69.0	70.7	69.5	69.4	71.1
	Hue	-0.4210	-0.3276	-0.2774	-0.2300	-0.2254	-0.2019	-0.1770	-0.1809	-0.1609	-0.1653
XPW 156											
April 18	Intensity	63.8	65.6	66.3	67.1	67.2	68.2	69.5	68.1	67.0	69.7
	Hue	-0.4744	-0.3734	-0.2756	-0.1884	-0.1940	-0.1756	-0.1717	-0.1818	-0.1917	-0.1492
April 23	Intensity	64.6	67.2	66.5	67.9	67.8	67.3	69.3	68.6	69.8	71.1
	Hue	-0.5238	-0.3772	-0.3389	-0.2642	-0.2164	-0.2142	-0.1791	-0.1868	-0.1979	-0.1796
May 7	Intensity	67.1	65.9	67.8	68.7	66.5	69.1	70.5	68.4	69.4	69.8
	Hue	-0.4468	-0.3563	-0.2588	-0.2029	-0.1379	-0.1641	-0.1435	-0.1456	-0.1490	-0.1563

* Refer to Table 5

Appendix 7b. Color changes of three varieties of white onions during dehydration at temperature set number 2*.

		0	1	2	3	4	5	6	7	8	9
Southport white globe											
March 12	*L*	64.4	64.3	63.4	67.7	68.2	70.3	71.2	70.0	68.7	70.5
	Hue	-0.4956	-0.3722	-0.2721	-0.2440	-0.2705	-0.1881	-0.1789	-0.1947	-0.1562	-0.1494
March 13	Intensity	64.2	64.6	64.0	65.5	63.0	66.2	68.4	67.4	68.5	67.2
	Hue	-0.4214	-0.3647	-0.3333	-0.2864	-0.2755	-0.2450	-0.2167	-0.2128	-0.2211	-0.2097
March 19	Intensity	63.8	65.0	64.5	64.3	67.4	67.2	68.0	67.5	69.7	69.0
	Hue	-0.4960	-0.3259	-0.3015	-0.2410	-0.2408	-0.2526	-0.2040	-0.2288	-0.2081	-0.1941
Seco											
March 20	Intensity	65.5	63.5	66.8	66.3	67.7	67.7	67.0	67.0	68.0	69.9
	Hue	-0.4013	-0.3714	-0.2575	-0.2686	-0.2216	-0.2171	-0.2355	-0.1980	-0.1990	-0.1714
April 2	Intensity	66.6	66.2	65.5	65.6	66.5	67.4	68.8	68.7	69.2	70.5
	Hue	-0.4250	-0.3407	-0.3060	-0.2941	-0.2473	-0.2061	-0.2401	-0.2164	-0.1890	-0.1534
April 5	Intensity	66.0	65.5	65.9	67.3	66.2	67.6	68.4	69.0	68.8	68.6
	Hue	-0.4242	-0.3351	-0.2893	-0.2634	-0.2413	-0.2233	-0.2392	-0.2401	-0.2274	-0.1943
XPW 156											
April 13	Intensity	66.6	64.8	67.1	67.8	67.1	67.1	68.5	68.2	68.6	69.0
	Hue	-0.4883	-0.3647	-0.2460	-0.2105	-0.2164	-0.2263	-0.2124	-0.2091	-0.2083	-0.1822
April 16	Intensity	68.5	66.2	66.1	67.4	67.5	66.7	68.9	68.4	69.4	69.8
	Hue	-0.4154	-0.3975	-0.2786	-0.2606	-0.2195	-0.2221	-0.2019	-0.2077	-0.2118	-0.2083
April 12	Intensity	66.9	67.7	67.6	67.1	68.5	70.1	70.8	70.9	70.6	70.4
	Hue	-0.4428	-0.3433	-0.2651	-0.2251	-0.2051	-0.2124	-0.1948	-0.1822	-0.1855	-0.1746

* Refer to Table 5

Appendix 8. Moisture removal rate for selected samples of three varieties of white onions at temperature set number 2*.

Hours	Southport White Globe May 9th %	Seco April 5th %	XPW 156 April 16th %
0	88.35	80.50	84.32
1	71.96	63.45	77.47
2	65.33	48.02	57.09
3	44.20	38.94	34.13
4	30.52	32.41	30.76
5	26.93	25.14	28.44
6	22.30	24.22	25.52
7	21.31	20.08	21.08
8	17.20	16.64	17.18
9	15.96	15.82	14.61
11	15.22	12.96	12.41
13	14.98	12.56	12.07
15	12.92	11.66	11.71

* Refer to Table 5

Appendix 9. Analysis of variance. The effect of storage on the moisture contents of two varieties of dehydrated white onions stored for 180 days at 10°C and 25°C.

	D.F.	S.S.	M.S.	F.
Total	27	2.5881		
Varieties	1	1.5557	1.5557	67.34**
Storage Temperature	1	0.1697	0.1697	7.34*
Time	6	0.4221	0.0703	3.04
Error	19	0.4406	0.0231	

** significant at 5% level F = 4.12

* significant at 1% level F = 7.85

Appendix 10. Analysis of variance. The effect of storage on the moisture contents of three varieties of dehydrated yellow onions stored for 360 days at 10°C and 25°C.

	D.F.	S.S.	M.S.	F.
Total	29	7.5717		
Variety	1	0.5627	0.5627	6.0701*
Storage Temperature	1	0.3456	0.3456	3.7281
Time	4	4.5294	1.1323	12.2146**
Error	23	2.1340	0.0927	

* significant at 5% level F = 4.95

** significant at 1% level F = 10.67

Appendix 11. Analysis of variance. The effect of storage on the ash contents of two varieties of dehydrated white onions stored for 180 days at 10°C and 25°C.

	D.F.	S.S.	M.S.	F.
Total	27	1.1839		
Variety	1	0.8645	0.8645	51.1538*
Storage Temperature	1	0.0041	0.0041	0.2426
Time	6	0.0030	0.0005	0.0295
Error	9	0.3223	0.0169	

* significant at F(0.05) = 4.12
F(0.10) = 7.85

Appendix 12. Analysis of variance. The effect of storage on the ash contents of three varieties of dehydrated yellow onions stored for 360 days at 10°C and 25°C.

	D.F.	S.S.	M.S.	F
Total	29	4.6824		
Varieties	1	1.1312	1.1312	30.4905*
Storage Temperature	1	0.0213	0.0213	0.5741
Time	4	2.6754	0.6688	18.0269*
Error	23	0.8545	0.0371	

F(0.05) = 4.95

F(0.01) = 10.67

* significant at both levels.

Appendix 13. Analysis of variance. The effect of storage on the hot water insolubles of two varieties of dehydrated white onions stored for 180 days at 10°C and 25°C.

	D.F.	S.S.	M.S.	F
Total	27	45.3946		
Varieties	1	13.6640	13.6640	15.1940**
Storage Temperature	1	0.2880	0.2880	0.3202
Time	6	14.3546	2.3924	0.8993
Error	19	17.0880	0.8993	

F(0.05) = 4.12
F(0.01) = 7.85
**Significant at F(0.01)

Appendix 14. Analysis of variance. The effect of storage on the hot water insolubles of three varieties of dehydrated yellow onions stored for 360 days at 10°C and 25°C.

	D.F.	S.S.	M.S.	F
Total	29	53.3946		
Varieties	2	10.7324	5.3662	5.0358*
Storage Temperature	1	0.0046	0.0046	0.0043
Time	4	18.1479	4.5369	4.2576
Error	23	24.5097	1.0656	

F(0.05) = 4.95

F(0.01) = 10.67

* significant at F(0.05)

Appendix 15. Analysis of variance. The effect of storage on the optical index of two varieties of dehydrated white onions stored for 180 days at 10°C and 25°C.

	D.F.	S.S.	M.S.	F
Total	27	47595.4837		
Varieties	1	1008.60	1008.60	3.6942
Storage Temperature	1	6685.7617	6685.7617	24.4879*
Time	6	34713.6972	5786.6162	21.1910*
Error	19	5187.4248	273.0223	

F(0.05) = 4.12

F(0.01) = 7.85

* significant at both levels

Appendix 16. Analysis of variance. The effect of storage on the optical index of three varieties of dehydrated yellow onions stored for 360 days at 10°C and 25°C.

	D.F.	S.S.	M.S.	F
Total	29	71364.6695		
Varieties	1	2199.3211	2199.3211	1.9805
Storage Temperature	1	15350.1941	15350.1941	13.8234**
Time	4	29274.9443	7318.7360	6.5908*
Error	23	25540.21	1110.4439	

F(0.05) = 4.95

F(0.01) = 10.67

** significant at both levels

* significant at (0.05)

Appendix 17. Changes in *L* reading of two varieties of dehydrated white onion at 10° and 25°C for 180 days.

Time (Days)	Southport White Globe		Seco	
	25°C	10°C	25°C	10°C
		L Values		
0	70.50	70.5	72.26	72.26
30	69.90	71.7	70.60	72.70
60	68.00	72.9	70.40	71.50
90	68.85	74.0	70.60	72.70
120	64.90	73.4	71.10	71.30
150	65.20	74.8	71.50	74.30
180	63.00	73.7	67.50	71.50

Appendix 18. Changes in *L* readings of three varieties of dehydrated yellow onions at 10°C and 25°C for 360 days.

Time (Days)	Spartan Era		Autumn Pride		Autumn Spice	
	25°C	10°C	25°C	10°C	25°C	10°C
			L Values			
0	62.7	62.7	63.9	63.9	64.2	64.2
30	64.2	62.6	61.9	63.2	61.1	61.0
60	61.6	62.6	61.3	63.4	59.5	61.0
90	61.3	63.7	61.4	64.9	60.0	62.4
360	54.4	63.9	56.8	63.3	55.8	60.8

Appendix 19. Analysis of variance. The effect of storage on the *L* value of two varieties of white onions stored at 10°C and 25°C for 180 days.

	D.F.	S.S.	M.S.	F
Total	27	234.3891		
Varieties	1	15.4068	15.4068	3.2069
Storage Temperature	1	108.2322	108.2322	22.5286**
Time	6	19.4696	3.2449	0.6754
Error	19	91.2805	4.8042	

** significant at F(0.05) = 4.12
and F(0.01) = 7.85

Appendix 20. Analysis of variance. The effect of storage on the *L* value of three varieties of yellow onions at 10°C and 25°C for 360 days.

	D.F.	S.S.	M.S.	F
Total	29	181.5270		
Varieties	1	10.2860	10.2860	3.4112
Storage Temperature	1	37.4083	37.4083	12.4061**
Time	4	64.4786	16.1196	5.3459*
Error	23	69.3541	3.0153	

** significant at F(0.01) = 10.67

* significant at F(0.05) = 4.95

Appendix 21. a*L* values of two varieties of dehydrated white onions stored at 10°C and 25°C for 180 days.

	a*L* (Redness or Greenness) Values			
	Southport White Globe		Seco	
Time (Days)	25°C	10°C	25°C	10°C
0	-2.1	-2.1	-1.7	-1.7
30	-0.9	-2.1	-0.7	-1.5
60	+0.1	-2.3	-0.3	-1.4
90	+1.2	-2.2	+0.5	-1.4
120	+2.0	-2.1	+0.2	-1.3
150	+2.6	-1.9	+0.7	-1.5
180	+3.5	-2.0	+1.8	-0.8

Appendix 22. Analysis of variance. The effect of storage on the a*L* value of two varieties of white onions stored at 10°C and 25°C for 180 days.

	D.F.	S.S.	M.S.	F
Total	27	70.9672		
Varieties	1	0.0229	0.0229	0.0227
Storage Temperature	1	34.7657	34.7657	34.4761**
Time	6	17.0172	2.8362	2.8125
Error	19	19.1614	1.0084	

** significant at F(0.01) = 7.85
F(0.05) = 4.12

Appendix 23. *aL* values of three varieties of dehydrated yellow onions stored at 10°C and 25°C for 350 days.

Time (Days)	Spartan Era 25°C	Spartan Era 10°C	Autumn Pride 25°C	Autumn Pride 10°C	Autumn Spice 25°C	Autumn Spice 10°C
	aL (Redness or Greenness) Values					
0	+0.4	+0.4	-0.6	-0.6	0.0	0.0
30	+0.6	+0.2	+0.8	-0.8	+1.8	+2.0
60	+1.4	+0.8	+1.7	-0.5	+2.2	+2.1
90	+1.7	+1.0	+2.0	-0.2	+3.0	+2.2
360	+5.6	+2.1	+4.3	+0.2	+5.7	+2.1

Appendix 24. Analysis of variance. The effect of storage on the aL values of three varieties of yellow onions at 10°C and 25°C for 360 days.

	D.F.	S.S.	M.S.	F
Total	29	79.7470		
Varieties	1	11.1140	11.1140	15.5223**
Storage Temperature	1	12.6750	12.6750	17.7025**
Time	4	38.4886	9.6221	13.4386**
Error	23	16.4694	0.7160	

** significant at both F(0.05) = 4.95
and F(0.01) = 10.67

Appendix 25. b*L* values of two varieties of dehydrated white onions stored at 10°C and 25°C for 180 days.

Time (Days)	b*L* (Yellowness) Values: Southport White Globe 25°C	Southport White Globe 10°C	Seco 25°C	Seco 10°C
0	21.4	21.4	19.5	19.5
30	22.4	20.4	20.9	19.3
60	22.9	19.9	21.2	19.7
90	24.1	19.9	20.9	19.6
120	24.1	18.9	21.4	19.8
150	24.1	17.1	20.7	17.9
180	24.5	19.5	22.5	19.9

Appendix 26. Analysis of variance. The effect of storage on the bL values of two varieties of white onions stored at 10°C and 25°C for 180 days.

	D.F.	S.S.	M.S.	F
Total	27	96.7243		
Varieties	1	11.3157	11.3157	7.7536**
Storage Temperature	1	51.03	51.03	34.9664**
Time	6	6.6493	1.1082	0.7593
Error	19	27.7293	1.4594	

** significant at both F(0.01) = 7.85
F(0.05) = 4.12

Appendix 27. b*L* values of three varieties of dehydrated yellow onions stored at 10°C and 25°C for 360 days.

Time (Days)	bL (Yellowness) Values					
	Spartan Era		Autumn Pride		Autumn Spice	
	25°C	10°C	25°C	10°C	25°C	10°C
0	25.3	25.3	24.6	24.6	24.3	24.3
30	24.9	24.9	24.6	24.9	24.4	24.5
60	25.1	25.1	25.0	25.0	24.9	24.5
90	25.2	25.4	25.5	25.3	24.5	24.9
360	24.0	24.9	24.4	25.1	24.3	24.8

Appendix 28. Analysis of variance. The effect of storage on the b*L* values of three varieties of yellow onions stored at 10°C and 25°C for 360 days.

	D.F.	S.S.	M.S.	F
Total	29	5.2617		
Varieties	1	1.2087	1.2087	9.8108*
Storage Temperature	1	0.2083	0.2083	1.6907
Time	4	1.1333	0.2833	2.2995
Error	22	2.7114	0.1232	

* significant at F(0.05) = 4.95
F(0.01) = 10.67

Appendix 29. Analysis of variance. Flavor evaluation of two varieties of dehydrated white onions at zero time of storage.

	D.F.	S.S.	M.S.	F
Total	79	205.55		
Variety	1	6.05	6.05	1.7430
Temperature	1	0.05	0.05	0.0144
Judge	19	75.55	3.9763	1.1455
Var. x Temp.	1	4.05	4.05	1.1668
Var. x Judge	19	48.95	2.5763	0.7376
Temp. Judge	19	4.95	0.2605	0.0750
Error	19	75.95	3.4710	

F(0.05) = 2.87
F(0.01) = 4.43

Appendix 30. Analysis of variance. Flavor evaluation of two varieties of dehydrated white onions stored at 10°C and 25°C for 90 days.

	D.F.	S.S.	M.S.	F
Total	79	305.55		
Variety	1	12.80	12.80	4.7497**
Temperature	1	0.45	0.45	0.1669
Judges	19	99.55	5.2394	1.9441
Var. x Temp.	1	9.80	9.80	3.6364*
Var. x Judges	19	92.20	4.8526	1.8006
Judges x Temp.	19	39.55	2.0815	0.7723
Error	19	51.20	2.6949	

*significant F(0.05) = 2.87

**significant F(0.01) = 4.43

Appendix 31. Multiple Range test for the mean scores of the taste panel on the two varieties of white onions stored at 10°C and 25°C for 90 days.

Variety	Storage Temperature °C	Hedonic Scale Rating
Seco	10	5.20 ab*
	25	4.35 b
Southport white globe	10	5.30 ab
	25	5.85 a

* Duncan Multiple Range, means with the same caption are not significantly different. Means with different caption are significantly different.

Appendix 32. Analysis of variance. Flavor evaluation of two varieties of white onions stored for 180 days at 10°C and 25°C.

	D.F.	S.S.	M.S.	F
Total	79	247.80		
Variety	1	1.25	1.25	1.0440
Temperature	1	5.0	5.0	4.1760*
Judge	19	96.8	5.0947	4.2551*
Var. x Temp.	1	1.25	1.25	1.0440
Var. x Judge	19	16.75	0.8815	0.7362
Temp. x Judge	19	104.0	5.4736	4.5716**
Error	19	22.75	1.1973	

* significant at F(0.05) = 2.87

**significant at F(0.01) = 4.43

Appendix 33. Multiple range test for the mean scores of the taste panel on the two varieties of white onion stored at 10° and 25°C for 180 days.

Variety	Storage Temperature °C	Hedonic Scale Rating
Seco	10	4.80
	25	5.05
Southport white globe	10	4.80
	25	5.55

Duncan Multiple range test significant differences between 2 means is 0.73; 3 means is 0.76; and 4 means is 0.78.

Appendix 34. Analysis of variance. Flavor evaluation of Southport white globe stored at 10° C for 0, 90 and 180 days.

	D.F.	S.S.	M.S.	F
Total	59	174.7334		
Time	2	6.6334	3.3167	1.2474
Judge	19	67.0667	3.5298	1.3276
Error	38	101.0333	2.6587	

F(0.05) = 3.10

F(0.01) = 4.94

Appendix 35. Analysis of variance. Flavor evaluation of Southport white globe stored at 25°C for 0, 90 and 180 days.

	D.F.	S.S.	M.S.	F
Total	59	226.40		
Time	2	1.60	0.80	0.2165
Judge	19	84.40	4.4421	1.2022
Error	38	140.40	3.6947	

F(0.05) = 3.10

F(0.01) = 4.94

Appendix 36. Analysis of variance. Flavor evaulation of Seco stored at 10°C for 0, 90 and 180 days.

	D.F.	S.S.	M.S.	F
Total	59	191.9334		
Time	2	9.2334	4.6167	2.5026
Judge	19	112.6000	5.9263	3.2126*
Error	38	70.10	1.8447	

F(0.05) = 3.10

* significant at F(0.01) = 4.94

Appendix 37. Analysis of variance. Flavor evaluation of Seco stored at 25°C for 0, 90 and 180 days.

	D.F.	S.S.	M.S.	F
Total	59	168.9834		
Time	2	2.1334	1.0667	0.4170
Judge	19	69.65	3.6657	1.4331
Error	38	97.20	2.5578	

F(0.05) = 3.10

F(0.01) = 4.94

Appendix 38. Schedule of the flavor evaluation of two varieties of dehydrated white onions

At 4% concentration, dehydrated onion samples in form of soup were still strong in odor. The distinguishing power of panelists was greatly reduced due to the strong odor and after taste. Not more than four samples in form of soup was evaluated at each test to avoid adaptation effects. The evaluation schedule is as follows:

Test	Variety	Number of Samples	Sample Description
1	Southport white globe and Seco	2	One sample of each variety at zero time of storage
2	Southport white globe and Seco	4	One sample of each variety at each temperature after 90 days of storage
3	Southport white globe and Seco	4	One sample of each variety at each temperature after 180 days of storage
4	Southport white globe	3	One sample of each at 10°C of storage for 0, 90 and 180 days
5	Southport white globe	3	One sample of each at 25°C of storage for 0, 90 and 180 days
6	Seco	3	One sample of each at 10°C of storage for 0, 90 and 180 days
7	Seco	3	One sample of each at 25°C of storage for 0, 90 and 180 days

Each sample of onion soup was assigned a random code number and panelists were unaware of the true identity of the samples. Panelists' preferences were recorded on evaluation sheets presented in Appendix 39.

Name ________

Date ________

Appendix 39. 9 - Point Hedonic

Please taste from left to right.

PREFERENCE

Code ____	Code ____	Code ____	Code ____
____ Like Extremely	____ Like Extremely	____ Like Extremely	____ Like Extremely
____ Like Very much	____ Like Very much	____ Like Very much	____ Like Very Much
____ Like Moderately	____ Like Moderately	____ Like Moderately	____ Like Moderately
____ Like Slightly	____ Like Slightly	____ Like Slightly	____ Like Slightly
____ Neither like Nor dislike	____ Neither like Nor dislike	____ Neither like Nor Dislike	____ Neither like Nor dislike
____ Dislike Slightly	____ Dislike Slightly	____ Dislike Slightly	____ Dislike Slightly
____ Dislike Moderately	____ Dislike Moderately	____ Dislike Moderately	____ Dislike Moderately
____ Dislike Very much	____ Dislike Very much	____ Dislike Very much	____ Dislike Very Much
____ Dislike Extremely	____ Dislike Extremely	____ Dislike Extremely	____ Dislike Extremely
COMMENTS	COMMENTS	COMMENTS	COMMENTS