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Title THE EFFECT OF DROUGHT STRESS ON THE CHEMICAL COMPOSITION DISTRIBUTIONS IN RUSSET BURBANK AND A082260-8 POTATOES

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The effects of early season and late season drought stress on various carbohydrates, calcium and/or nitrogen content at apical, central and basal tuber locations were studied for Russet Burbank and A082260-8 potatoes. Drought stress which occurred early in the stage of tuber development appeared to have more detrimental effect than later season stress. Interactions between treatment and sampling date and variety x position x date were significant during early season stress.

Generally, percent total solids increased during potato development for both varieties. The central portion of tuber had the lowest total solids.

Total reducing sugar content generally decreased during potato development for both varieties with significant ($P<.05$) differences at early season stress due to the interaction effects of treatment x date and variety x position. No significant difference in reducing sugar at later season stress was found regardless of

treatment. Variety difference in reducing sugar content occurred at the apical end. Russet Burbank had more reducing sugars than A082260-8 at this end. The exploration of fructose, glucose and sucrose individually showed the same developing pattern as total reducing sugar. Sucrose made up over 50% of the total sugars with glucose and fructose the next in order of importance. The apical end had more sucrose and glucose than the basal end.

The interaction of variety and position for both nitrogen and dietary fiber may be a result of growth pattern differences in the two treatments. Total dietary fiber content was generally the highest at the basal portion for both varieties. Russet Burbank appeared to have higher total dietary fiber than A082260-8 at this end. The level of calcium in Russet Burbank was significantly higher than that in A082260-8. Basal and apical portions had higher calcium content than the central portion.

# THE EFFECT OF DROUGHT STRESS ON THE CHEMICAL COMPOSITION AND DISTRIBUTION IN RUSSET BURBANK AND A082260-8 POTATOES

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# THE EFFECT OF DROUGHT STRESS ON THE CHEMICAL COMPOSITION AND DISTRIBUTION IN RUSSET BURBANK AND A082260-8 POTATOES

## Chapter 1

## INTRODUCTION

Potato production and processing is a vitally important industry in the Pacific Northwest. Oregon, Washington, and Idaho (Senior, 1986) produced about 80 percent of the country's potatoes in 1985. An increased consumption of processed potato products has led to a great need to understand the factors which influence the production of a desired raw product for processing. A tremendous economic concern has been the presence of carbohydrate defects in potatoes grown in the Northwest. Considerable information is available on the influence of production, storage, and preparation upon potato carbohydrate composition and associated texture and color. Unfortunately, these data are frequently unique for the experimental conditions, with even less information available on the enzymatic mechanisms, their accelerators and activators as related to sugar and starch metabolism, catabolism and transformation. This lack of understanding has seriously affected the solving of carbohydrate-related problems in the Northwest.

This understanding of carbohydrate mechanisms is important because potatoes as a raw material must meet the quality specifications for industry. A better understanding of mechanisms

inherent in sugar and starch synthesis, catabolism or transformation is requisite to development of potato progeny and to better management of the environment during production.

The goal of this study was to evaluate the effects of drought stress during tuber development on sugar and fiber accumulations and relate these to physiological tuber disorders which adversely affect potato quality. This study focused on growing conditions which influenced development of sugar-end potatoes. These potatoes fry dark on the basal end and light on the apical end. This study included the broad objectives to:

1) quantify the relative proportions of various carbohydrates at the apical, central and basal tuber location in normal and stressed Russet Burbank and A082260-8 potatoes.
2) quantify the relative proportions of calcium at the apical, central and basal tuber location in normal and stressed Russet Burbank and A082260-8 potatoes.
3) compare the possible relationship of carbohydrates and the quality characteristics obtained from a related study of these potatoes at the Malheur Agricultural Experiment Station.

# CHAPTER 2

## REVIEW OF THE LITERATURE

The potato is one of the few foods which are capable of nourishing the great populations of the world. As a food the potato ranks second to soybean in amount of protein produced per hectare, and second to sugarcane in carbohydrate production (Johnson and Lay, 1974). The potato is a major staple in the American diet. In 1986 the annual per capita consumption was 79.6 pounds, of which 37 percent was processed potato products (Bailey, et al., 1988). According to 1978 data, frozen potato products were the fastest growing category of processed potatoes, utilizing more than one-half of all potatoes processed, with potato chips utilizing 22 percent (Talburt, 1987). Frozen French fries accounted for about 85 percent of the total pack of frozen potato products in 1981 (Talburt, et al., 1987). The public acceptance of processed potatoes has stimulated the convenience food industry in the United States resulting in the increase of processed potato products. Institutional customers are defining increasingly narrow quality specifications for potato products. This, in conjunction with the potential for an expanded international market and enhanced interest of the convenience food industry in quality control, has changed the way the potato processing plant functions.

Undoubtedly, there are still a lot of problems in potato

processing, especially the need for starting with a high quality raw product to produce an attractive, high quality processed product. Color is the most common important quality control problem in potato processing. A uniform light brown finished product color is desired for both French fried potatoes and potato chips. However, because of some deficiencies in the raw product, a so called "dark-end" or "sugar-end" phenomenon may occur in potato processing. This has dramatically affected acceptability of French fries and potato chips by the customer, resulting in the necessity of changes in the raw potatoes used for processing. The color of processed potato products is determined by the chemical composition of the tubers. Therefore questions arise as to what and how the compositional factors in the tubers influence color development in processed potato products, what factors affect this chemical composition and how to control these factors in order to control the final color quality of the processed potato products. This review will emphasize the chemical composition of tuber correlated with the "sugar-end" problem and selected important cultural conditions during the growing season affecting this composition.

## 2.1 What Is "Sugar-end" And Why Is It Important ?

The term sugar-end or dark-end as used by the potato processing industry refers to potatoes which typically have more sugars in the basal end (also called stem end, which is the part of potato tuber connected to the plant) than in the rest of the potato tuber. When the potato strip or chips are fried, the end with the greater sugars

develops an undesirable dark-brown color. This is quantified by the potato industry using subjective evaluation and the USDA color chart (USDA, 1972). The dark-end fry color has been attributed to nonenzymatic browning reaction, the Maillard reaction (Burton, 1966; Gray and Hughes, 1978) involving reducing sugars and amine groups of amino acids.

Closely associated with and confused with the sugar-end is the "translucent-end". When the high sugar basal end is accompanied by low starch content, it is called translucent-end (Iritani and Weller, 1973a). The translucent end tubers may become soft and eventually develop into "jelly-end" rot (Kunkel and Garder, 1958; Lugt, 1960; Murphy, 1936; Nielson and Sparks, 1953). Weaver and coworkers (1970) reported on a sugar-end development in which the sample had a high starch and reducing sugar content in the basal portion. In addition, samples have been obtained by Iritani and Weller (1973a) which fried dark on the apical end. This type of sugar-end is rare. Generally, the industry has not distinguished between sugar-end associated with translucent-end potatoes and that due to other causes.

In the fall of 1928 an inquiry was received at the Maine Agricultural Experiment Station from a manufacturer of potato chips in regard to the cause of dark color in potato chips (Sweetman, 1930). She stated that frequently in the winters she had difficulty with Northern-grown potatoes, because potato chips made from them were dark colored. It is probably one of the earliest complaints about dark-end problem. Since then, extensive research has been done

to understand the mechanism and details of production and to find the solution for this problem, but, unfortunately, it still is one of the most severe problems for the potato grower and processor in this decade. In 1984 and 1985 sugar-ends took a severe economic toll on producers and processors in southwestern Idaho and other areas in the Northwest (Jones, 1986). In some fields as much as 50 percent of the crop was affected and many fields under contract to processors were rejected. The defect has become so serious that some processors in the western Idaho area say that they will begin going elsewhere for potatoes unless something can be done to bring the sugar-end problem under control. A detailed comprehensive understanding of sugar-end is imperative.

## 2.2 Chemical Composition And Quality Factors

Considerable information is available on quality factors of potatoes. Generally speaking, the quality factors considered in potato production are texture and appearance, including color. The primary components related to these characteristics are reducing sugar content, specific gravity, protein and nitrogenous compounds, and starch (Iritani, 1981). Many researchers have tried to understand how the chemical composition of potato is influenced by variation in growing, harvesting, handling, storing and processing conditions of the potatoes. The mechanisms for synthesis of sugar, starch and other structural carbohydrates are of particular interest to potato growers and processors as they play an important role in

quality problems of the potato. This is particularly pertinent in regard to the focus of this project--the sugar-end problem.

### 2.2.1 Total Solids And Starch

The major component of total solids in potato tuber is starch. The percentage of non-starch solids is relatively constant, with the starch about 65 to 80 percent while the non-starch solids are around 6 percent in the fresh tuber (Schwimmer and Burr, 1967). Dry matter content varies from 16.1 to 29.08 percent, and starch content varies from 10.2 to 19.14 percent according to Goldthwaite (1925) and Heinze, et al. (1955), although Brautlecht and Getchell (1951) reported a variation of starch content from 8 to 28 percent. This starch affects the texture, as well as serving as a source of substrate for sugar conversion. A large quantity of starch grains in the potato cell leads to development of high internal pressure during cooking, as the starch absorbs a great quantity of water during its gelatinization. This results in an open structure that appears dry and mealy in the mouth because the distention causes groups of cells to shear apart from one another. Conversely, a lower quantity of starch grains in the cells allows them to remain together and the texture can be felt and described as "waxy" (Treadway, 1961). Starch has no significant effect on color but gives opaqueness and firmer texture (Heinze, et al., 1955). However, starch in potato tubers is frequently converted to undesirably high concentration of sugars as a result of stress experienced during growth and/or storage.

The starch content of tubers, the major total solids component, increases rapidly during growth (Appleman and Miller, 1926; Snyder, et al., 1977). It usually reaches a maximum when approximately two-thirds of the foliage is dead and decreases slightly during storage (Heinze, et al., 1955). It varies greatly among varieties, growth (Goldthwaite, 1925), season, and locality (Heinze, et al., 1955). Previous study by Weaver, et al. (1978a) indicated that solids content was greatest in basal-end, lower in apical-end and lowest in core tissue in normal growth potatoes. This result has been substantiated by Iritani and Weller (1973a). Amylose/amylopectin ratio was similar in all parts of the tuber.

Specific gravity is a frequently reported indirect method of determining dry matter or starch content in a tuber. Correlation coefficients between the specific gravity and the total dry matter content of tubers range from 0.637 to 0.972 (Heinze, et al., 1955). The same authors found the correlations between specific gravity and starch and between specific gravity and alcohol insoluble solids were almost as good. However, the relationship between specific gravity and solid matter in tubers is not constant; it is affected by factors such as variety, area of production and storage condition (Agle and Woodbury, 1968; Heinze, et al., 1955).

The specific gravity of tubers was recognized as an indication of quality as early as 1847 (Heinze, et al., 1955). High specific gravity has long been considered by potato chippers as a criterion for the suitability of various potato varieties. High specific gravity potatoes return more processed product per unit of raw

product (Kunkel, et al., 1951; Smith, 1955, 1968), have a better texture or mealiness after cooking (Betteleheim and Sterling, 1955a; Le Tourneau, et al., 1962; Reeve, 1967), absorb less fat during frying (Kirkpatrick, et al., 1956; Kunkel, et al., 1951; Smith, 1955; Whiteman and Wright, 1949) and accumulate less reducing sugars in storage (Schwimmer, et al., 1954; Talburt and Smith, 1967; Watada and Kunkel, 1954) than low specific gravity potatoes. It has been found that a relatively high correlation exists between the degree of mealiness and specific gravity (Clark, et al., 1940; Haddoch and Blood, 1939; Kirkpatrick, 1953; Smith and Nash, 1940; Wright, et al., 1936). In general, tubers of low specific gravity (1.05 to 1.06) are soggy when cooked, and tubers of high specific gravity (1.10) are mealy (Brown, 1960b).

### 2.2.2 Sugars

The major sugars found in potato tubers are sucrose, fructose and glucose, with other sugars present in trace amount (Schwimmer, et al., 1954). The amount and kind of sugar in a particular cultivar are inherited characteristics (Cunningham and Stevenson, 1963; Lauer and Shaw, 1970). According to Heinze, et al., (1955), the total sugars and reducing sugars of 6 varieties from 10 localities varied from .03 to 2.64 percent and from .02 to 1.46 percent, respectively.

Of the many chemical constituents affecting the color of processed potato products (Talbert and Smith, 1967), sugars are generally considered the most important group (Clegg and Chapman,

1962a, b; Hoover and Xander, 1961). Legault, et al (1945) indicated that browning of chips is due, in part at least, to a Maillard reaction between reducing sugars and amino acids. Patton and Pyke (1946), Ross (1948), Habib and Brown (1957) also presented evidence to indicate that the Maillard reaction is responsible for the color of potato chips. All sugars do not contribute equally to the production of dark-color during frying. Most researchers indicate that only the reducing sugar contents are related to the rate and extent of darkening in the finished product (Denny and Thornton, 1942; Hoover and Xander, 1961; Schwimmer, et al., 1957; Weaver, et al., 1972); although, Clegg and Chapman (1962b) and Timm, et al. (1968) reported that high concentrations of sucrose enhanced darkening of chips during the frying process. The amount of sugars in raw potatoes which the processing industry can tolerate depends on the type of processed product. Potatoes used for making chips must have a minimum content of reducing sugars while frozen fries and dehydrated mash can withstand slightly larger amounts (Iritani and Weller, 1980). Brown (1960a) indicated a reducing sugar content of 0.2 percent or less was considered essential for production of light-colored chips. High total or high reducing sugars generally produce poorer flavors, less mealiness, less slough and less dryness in processed potato products (Heinze, et al., 1955).

Although sucrose does not participate in the Maillard reaction of processed potato directly, it serves as a source for reducing sugar products via the storage activated enzyme invertase (Pressey, 1969; Pressey and Shaw, 1966; Sowokinos, 1978). Sucrose is the

intermediate product in the formation of reducing sugars from starch. A sucrose concentration of less than 2.8 mg per gram of tuber is considered acceptable for processing as reducing sugars will also be low (Zulu and Pritchard, 1987). Sucrose can impart a sweet taste (Burton, 1969; Smith, 1968), produce off flavors of processed products (Smith, 1968) and influence, to some degree, texture during the cooking process (Burton, 1969; Schwimmer, et al., 1957; Whittenberger, 1951). The sucrose concentration of tubers declines as the crop nears maturity, reaching a minimum near the time of harvest (Sowokinos, 1978). In their research, Iritani and Weller (1977) indicated that the level and availability of sucrose at harvest may be the critical factor determining storage ability. High sucrose in the tuber at harvest time indicates either relative immaturity (Appleman and Miller, 1926; Burton, 1965; Samotus and Schwimmer, 1962; Singh and Mathur, 1938) or that the tuber had undergone a period of stress during growth. Tubers placed in storage with a higher sucrose content generally accumulate more reducing sugars, lose a greater amount of weight and are more susceptible to rot than tubers stored with a low sucrose content.

The sugar content, as well as other components of potato tubers, not only varies in different areas of production and among tubers on the same plant (Goldthwaithe, 1925), but varies in tissues from different parts within each tuber (Baijal and van Vliel, 1966; Iritani and Weller, 1973a; Weaver, et al., 1972, 1978b). Reducing sugar levels are generally higher at the basal end than at the apical end (Kunkel and Gardner, 1958; Fuller and Hughes, 1984). The

study done by Weaver and coworkers (1978b) showed that only sucrose was uniformly distributed among the different parts of the tuber. However, relative sugar concentration between the apical and basal portion was not consistent and appeared to be influenced by variations in growing and storage conditions (Iritani, et al., 1973).

### 2.2.3 Protein And Nitrogenous Compounds

Varietal differences in the protein content of potatoes are well documented. Schwimmer and Burr (1967) summarized protein content in potatoes to range between 3.5 to 23 percent on a dry basis. Kaldy and Markakis (1972) reported a range in protein content of six varieties of 8.1 to 12.3 percent on a dry basis. Fitzpatrick, et al. (1969) reported total nitrogen content in 83 seedling selections originating from Idaho and Maine to range from 8.75 to 17.71 percent on a dry basis (based on a conversion factor of 6.25). Augustin (1975) got 6.25 to 15.0 percent protein on a dry basis in 1975. According to these figures it can be said that potato can produce as much protein per acre as cereal grains and other major agronomic seed crops.

It has been reported (Snyder, et al., 1977) that the proportion of protein and non-protein nitrogen in tuber dry matter decreases rapidly during the initial stages of tuber growth, then the protein stabilizes but non-protein nitrogen increases during the final stage of tuber growth. An inverse relationship between the distribution of starch and nitrogen has been reported (Schwimmer and Burr, 1967).

The same authors found that about 1/3 to 1/2 of the total nitrogen is present as protein. The bulk of the non-protein fraction comprising up to 2/3 of the total nitrogen, is present as free amino acids.

As previously indicated, protein and amino acids play a role in color development. Shallenberger, et al. (1959) found that the effect of nitrogenous substances on the development of color in chips appeared to limit the development of color in the chips as opposed to the catalytic effect nitrogen has on caramelization. There is some disagreement regarding the actual role of the nitrogenous substances in the Maillard reaction. Habib and Brown (1956) concluded that even though reducing sugars are the most important factor determining the color of the chips, their importance in some cases may be limited by the relative amount of free amino nitrogen. They observed that good chipping varieties contained relatively less free amino acids than varieties which produced dark-colored chips. So both reducing sugar and amino acid content must be considered when evaluating any variety for chipping. Research by Hoover and Xander (1961) also found that basic amino acids are, at least, inconsistently correlated with chipping color. Heinze and coworkers reported (1955) that potatoes containing relatively high nitrogen contents had less sloughing, were less dry and less mealy when boiled or baked. Similar results will be important in potato fries or potato chips. The flavor of high nitrogen potatoes was also slightly less acceptable. It is

conceivable that the non-protein nitrogen may in fact be responsible for off-flavor.

### 2.2.4 Total Dietary Fiber

Dietary fiber is a mixture of many complex organic substances. Trowell (1974) initially defined dietary fiber as consisting of "remnants of the plant cells resistant to hydrolysis by the alimentary enzymes of man." This definition was later modified to include hemicelluloses, celluloses, lignins, nondigestable oligosaccharides, pectins, gums, and waxes (Trowell, et al., 1976; van Soest and McQueen, 1973).

Pectic substances are the portion of dietary fiber most investigated in potatoes. Pectic substances have several properties which distinguish them from the other components of dietary fiber. The pectic substances play an important role in potato tissues by their presence in different parts of the cell wall. It has been shown that pectic substances are present in the primary cell wall and in the middle lamella between adjoining cells, where they are assumed to be made up calcium salts of pectic and pectinic acids. They help maintain structural integrity and largely affect the structural properties and firmness of the tissues (Johnston, et al., 1983). Because they can be degraded under food processing conditions, certain properties of the pectic substances should also bear an important relationship to texture problems in potatoes (Schwimmer and Burr, 1967). There have been many attempts to relate potato texture with pectic content (Freeman and Ritchie, 1940;

Whittenberger and Nutting, 1950; Bettelheim and Sterling, 1955b). On the whole, no obvious relation has been found. The pectic substances content of potatoes from cv. Pentland Crown by Johnston, et al. (1983) was 2.98 percent for raw peeled tubers on dry basis.

### 2.2.5 Other Components

A number of other components may have some influence on the quality of the French fries and potato chips. Calcium may be one such component. The importance of calcium in the metabolic cycle is well-established. Calcium may be involved in various fundamental physiological functions of plants that comprise the structure of the cell wall, the membrane, chromatin and enzyme activities (Epstein, 1972; Jones and Lunt, 1967; and Kuiper, et al., 1974). It is well known that calcium plays an important role in maintaining quality of fruits and vegetables (Shear, 1975; Bangerth, 1979; Hopfinger and Poovaiah, 1979; Arteca, et al., 1980; Collier and Tibbitts, 1982; Huber, 1983). Calcium has been shown in varieties of fruits and vegetables to be related to texture quality. Calcium is essential for structure and function of cell walls and membranes (Poovaiah, 1986). Calcium has been shown to occur in the pectin part of the cell wall and can be assumed to occur also in the proteins and nucleic acids in the cytoplasmic membrane (Burstrom, 1968). Calcium was suggested to regulate cell wall mechanical properties (Cooil and Bonner, 1957; Grant, et al., 1973; Masuda, 1961; Tagawa and Bonner, 1957). It is known to specifically inhibit cell elongation (Burstrom, 1968; Nance, 1973; Thimann and Schneider, 1938; Heath and

Clark, 1956; Moll and Jones, 1981), although the exact nature of this inhibition is unknown. Cleland and Rayle (1977) concluded that calcium acts directly in the biochemical process of cell wall loosening. Under calcium-deficient conditions, there is a profound deterioration of membranes (Marinos, 1962). Poovaiah (1986) summarized that calcium deficiency would alter cell wall structure, decrease cell wall rigidity, increase microviscosity of membranes, alter membrane permeability, lose compartmentation, and as the result, increase physiological disorders of plant. Calcium also been reported to activate sucrose synthetase in the sucrose synthesizing direction (Delmer, 1972; Tsai, 1974). These results may have implications for the effect of calcium on the sugar accumulation of drought stressed potato tubers. Calcium is of particular importance for the growth of roots (Burstrom, 1968). Low tuber calcium concentrations have been associated with increased susceptibility to bacterial soft rot (McGuire and Kelman, 1984), internal brown spot, and subapical necrosis of sprouts (Collier, et al., 1978; Dyson and Digby, 1975a, b; Tzeng, et al., 1986).

Enzymatic discoloration of raw potatoes occurs when potatoes are cut or bruised and this makes the potato unappealing to consumers. This type of discoloration has been shown to be positivity correlated ($r=+0.97$) with tuber phenolic content (Mondy, et al., 1979). In addition, phenolic content has also been shown to be positively correlated with off-flavors such as bitterness and astringency (Mondy, et al., 1971) as well as after-cooking blackening (Mulder, 1949; Thomas, 1981).

It has been reported that ascorbic and other organic acids may also be involved in nonenzymatic browning (Brown, 1960a). The role of niacin, thiamin and riboflavin in potato quality is not understood. The function of many other components in the potato, which may be associated with texture and color in process products, has not been extensively determined. More work on all potato components needs to be done.

## 2.3 Growing And Storage History And Quality Of Potato

The ultimate sugar content, as well as other chemical components, is determined not only by inherited characteristics, but also by growing and storage conditions. The most important conditions affecting the final quality of potato include stresses during growth (irrigation, fertilization, etc.), maturity of the tubers at harvest, and post harvest history (time and temperature of storage and/or recondition) (Agle and Woodbury, 1968; Burton, 1965; Denny and Thornton, 1942; Iritani and Weller, 1980; Kissimeyer-Nielsen and Weckel, 1967; Lyman and Mackey, 1961). All can act alone or in combination with other factors to influence ultimate content of chemical components, particularly sugar content, and thus, influence the ultimate quality of potato. The focus of the current work is to investigate how drought stress influence the composition of potatoes during growth with particular attention to determining the factors related to sugar-end problems.

### 2.3.1 Drought Stress

Water is essential for plant growth. Many physiological processes depend on it. Compared to other species, the potato is a drought sensitive plant (Harris, 1978; Salter and Goode, 1967; Shepherd, 1972; Singh, 1969; van Loon, 1981). Water shortage may inhibit or even completely stop one or more physiological processes such as transpiration, photosynthesis, cell enlargement and enzymatic activities, affecting total and marketable yield and tuber quality (Robin and Domingo, 1956; Struik and van Voorst, 1986). Many reports (Blake, et al., 1955; Bradley, 1955; Bradley and Pratt, 1954, 1955; Corey and Myers, 1955; Cykler, 1946; Edmundson, et al., 1951; Jensen and Morris, 1931; Prince and Blood, 1962; Struchtemeyer, 1954; Taylor, 1952; Werner, 1947; van Loon, 1981) indicate that the yield and percentage of U.S. No.1 grade of potato will be reduced by drought stress. Iritani (1981) summarized the quality factors influenced by stress conditions as "total dry matter or starch content and distribution of starch, sugar content, type of sugar and distribution, texture, mealiness, flesh color, tuber size and shape, and tuber defects such as growth cracks and hollow heart".

It is well known that the results of the effects of drought stress on tuber depend on the physiological stage of the growth of plant at the time of stress (Iritani, 1981; Harris, 1978; Robin and Domingo, 1956). Early stress is likely to be much more detrimental to potato quality than is late occurring stress (Iritani, et al.,

mentioned previously, are pointed on the basal end with low starch content and high reducing sugars, are generally believed to be caused by drought stress during the early growth of the tubers (Iritani, et al, 1973a; Iritani and Weller, 1973b; Iritani, 1981; Kunkel, 1957; Kunkel and Gardner, 1958; Lugt, 1960; Murphy, 1936; Nielson and Sparks, 1953). Normally irrigated potatoes contain high starch in the basal end (Iritani, et al., 1973a; Kunkel and Gardner, 1958; Reeve, et al., 1971). The reason for the movement of carbohydrates from the basal to the apical portion has been postulated by some researchers (Lugt, 1960; Nielson and Sparks, 1953; Penman, 1929; van Loon, 1981) as due to renewed active growth after a stress period with associated utilization of carbohydrates from the basal portion. Workers (Zalewski, et al., 1986) at the Oregon State University Malheur Experiment Station observed that irrigation immediately after planting increased sugar-end. Yield and quality appeared to be optimized by first irrigation immediately after first emergence, with irrigation moderate to heavy from emergence until row closure minimizing sugar-end problems.

Stress during late season potato growth has been reported to cause the "second type of sugar-end" (Iritani and Weller, 1980; Iritani, 1981). This tuber is somewhat pointed on the apical end which is immature due to late, rapid growth after the stress period. There is a lower starch content and higher sugar content in the apical portion compared with the basal end. Such conditions affect quality of final processing potatoes.

There are varietal differences in resistance or tolerance to drought stress (Harris, 1978; Iritani, 1981; Levy, 1983a, b; Smith, 1977; Steckel and Gray, 1979). In their research using three varieties--Russet Burbank, Nooksack and Lemh, Miller and Martin (1987) concluded that Russet Burbank was most injured by drought stress in most grade categories, especially in percent U.S. No.1 tubers.

Drought stress can be defined by infrared thermometry (Jackson, 1982). It has been shown that drought-stressed potato plants can be 5°C or more hotter than non-stressed plants (Stieber, et al., 1986). Small differences in plant canopy temperature have great impact on potato growth. Potatoes are known to have a precipitous drop in photosynthesis above 30°C (Dwelle, 1985). Thus, the increasing temperature associated with drought stress would influence the carbohydrate composition. At high soil temperature, Khedher and Ewing (1985) observed that plants were negatively affected in terms of both tuber yield and percent dry matter. Maturity was also delayed. Again, varieties differed greatly in the degree to which they were affected by the heat.

In addition to the sugar-end problem, stress also causes undesirable flavor and poor texture of processed products, such as tough texture of French fries as well as a lack of mealiness (Iritani, 1981). Growth cracks and hollow heart, caused by uneven growth of potato tubers due to stress, are also detrimental for both potato processing and the fresh market.

2.3.2 Storage Condition

Potato processing is a year-round operation, and so most of the potato crop must be put into cold storage to extend the processing period of time. As the harvested tubers are still living when stored, tubers will respond to the stress of the storage environment, change their composition, and influence the final processing quality of the tubers (Augustin, 1975).

The variable effects of different storage conditions on the rate and extent of sugar accumulation and some other components is well documented (Campbell and Kilpatrick, 1945; Denny and Thornton, 1940, 1942; Ross, et al., 1946; Wright, et al., 1945). It is a common knowledge that sugar accumulation is generally higher at lower storage temperature. The rate at which reducing sugar accumulates during cold storage depends upon the storage temperatures (Agle and Woodbury, 1968; Burton, 1969), variety with different length of dormancy (Agle and Woodbury, 1968; Coleman and King, 1984; Denny and Thornton, 1941; Ewing, et al., 1981; Miller, et al., 1975; Samotus and Schwimmer, 1962; Samotus, et al., 1974; Schwimmer, et al., 1954; Weaver, et al., 1978b), tuber maturity at harvest (Iritani and Weller, 1973a; Iritani, 1981; Sowokinos, 1978), duration of storage (Agle and Woodbury, 1968; Ewing, et al., 1981; Iritani and Weller, 1977), and position in the tuber (Hughes and Fuller, 1984). Reducing sugars are readily accumulated when tuber temperature falls 4.4$^{o}$C (Wright, et al., 1945) to 7$^{o}$C (Ross, et al., 1946). The non-reducing sugar sucrose shows a greater increase than reducing sugars (Coffin, et al., 1987) when stored at 5$^{o}$C. Research

done by Hughes and coworkers (Hughes and Fuller, 1984) on tubers stored at 10°C for up to 320 days showed levels of reducing sugars in the tissue at the basal end considerably higher than those at the apical end. The difference in the sucrose between the two tissues was not as remarkable. As mentioned earlier, immature and over-mature tubers due to drought stress accumulate greater amount of sugar in storage than tubers properly matured (Iritani, 1981; Iritani and Weller, 1973a).

Previous work reported by Woodbury and Weinheimer (1965) showed that regression coefficients for percent dry matter on specific gravity increased with storage length. The results from Habib's research (Habib and Brown, 1956) showed that total solid content does not significantly change after cold storage. Total nitrogen and soluble nitrogen varies little with storage time (Talley, 1983; Desborough and Weiser, 1974). However, insoluble nitrogen tends to decrease during the first few months of storage with a partial recovery as storage is continued.

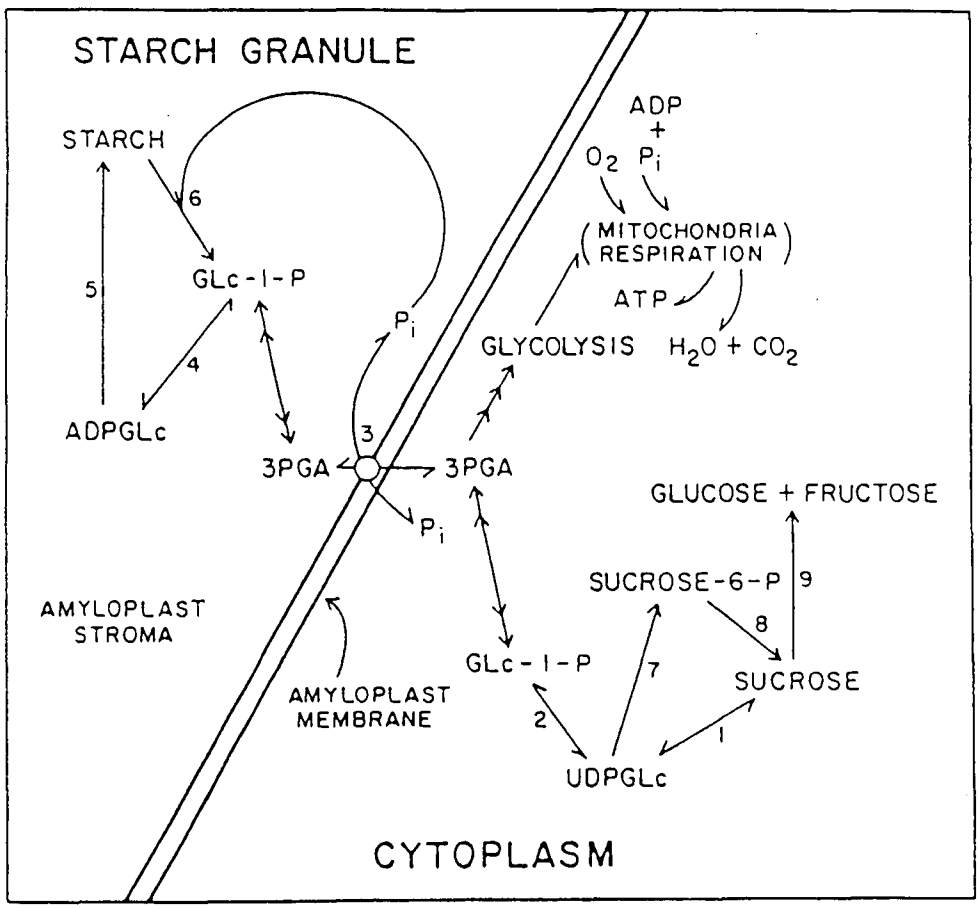
Since the sugar content increases during cold storage, it should be reduced prior to frying. One of the methods most often used is reconditioning, i.e. holding stored tubers at higher temperatures, usually about 20°C, for several days before processing (Weaver, et al., 1978a). The rate at which sugars disappear during conditioning depends upon the variety, the length and temperature of previous storage, the temperature during curing (Denny and Thornton, 1941, 1942; Richardson and Phillips, 1949), and kind of sugar (Iritani and Weller, 1977).

The fact that sugar of tubers accumulates on cold storage and reverses by holding at a higher temperature indicates that the cell both metabolizes the sugar and reconverts sugar to starch. This reaction does not appear to occur in sugar-end potatoes. Although the mechanism of sweetening has received considerable investigation at the membrane (Isherwood, 1976; Ohad, et al., 1971) and enzyme level (Lulai, et al., 1986; Sowokinos, et al., 1985), the carbohydrate synthesis, catabolism and transformation mechanisms of sugar to starch are still unknown. A tentative scheme showing an interdependence of starch-sugar formation for triose phosphates in potato cells is showed in Figure 1 (Sowokinos, et al., 1985). Sowokinos and coworkers found that the level of Pi increased in the translucent tissue. They suggested that this elevated Pi in the translucent tuber tissue coupled with increased phosphorylase and sucrose 6-p synthase (Figure 1, reaction 7) activities, may lead to an increased concentration of cytoplasmic precusors of sucrose and reducing sugars.

### 2.3.3 Summary

The utilization of quality processed potatoes is important for the convenience food industry. Such utilization is dependent upon the production of high quality potato chips and French fries. One of the most important problems in the potato processing industry is the maintenance of desirable color of chips and French fries. The Maillard reaction, which occurs during frying of potato chips and French fries should be even and adequate for optimum quality.

Figure 1. Tentative scheme showing an interdependence of starch-sugar formation for triose phosphates in potato cells. Enzymic steps indicated are:(1), sucrose synthase;(2), UDPglucose pyrophosphorylase;(3),triose-P,inorganic phosphate translocator protein;(4),ADPglucose pyrophosphorylase; (5),starch synthase; (6),phosphorylase; (7),sucrose-6-P synthase; (8),sucrose-6-P phosphatase, and (9),invertase (Sowokinos, et al., 1985).



Primary factors affecting the production of the Maillard reaction can be traced to the chemical composition of the tubers, especially the reducing sugars and associated amino acids. Chemical composition of the tubers is dependent on many environmental factors in the field and also on conditions during handling and storage. Significant variations in composition are known to occur among cultivars, within cultivar, among tubers, and within the different tissue zones of individual tubers in response to cultural practices. The drought stress on the potato during development in the growing fields is one of the most influential factors causing poor quality or variability in quality. Means exist to relate the changes occurring in the potato under a variety of drought stress condition to the chemical composition and optimum quality of the potato. For this reason, the literature base is an important starting point.

Considerable information is available on the influence of production, storage, and preparation upon potato carbohydrate composition and associated texture and color. Unfortunately, these data are frequently unique for the experimental conditions. Additionally, less information on the influence of the conditions of production, such as drought stress, is available on the whole picture of carbohydrate composition and other components correlated with the final quality of potato products. To date, the exact nature of the carbohydrate synthesis, catabolism and transformation mechanisms of sugar to starch transformation are still unknown. A better understanding of mechanisms inherent in sugar and starch synthesis, catabolism and transformation is requisite to development

of potato progeny and to better management of the environment during production.

Potato growers have a serious production problem because of drought stress in the potato during growing season. The industry needs to solve this production problem to improve the processed potato quality, thus minimizing financial loss. There is considerable interest in trying to find why this problem occurs. The literature indicates that the range of conditions affect the constituents that are the likely source of the problem. Our study is attempting to determine how these constituent are directly affected. Analyzing the sugar spectrum and other important components of tubers at selected stages of stress and non-stress will help determine the carbohydrate mechanism flawed by the drought impact.

# CHAPTER 3

# PROCEDURES

## 3.1 Potato Plant Growing and Stress Procedures

Two potato varieties, Russet Burbank potatoes and A082260-8, were used in this study. Russet Burbank is a stress-sensitive cultivar that dominates Northwest production, while the line A082260-8 was chosen due to tolerance against the formation of high reducing sugars and dark stem-end fry colors. All samples were planted in April, 1988 on Owyhee silt loam soil (Appendix, p. 85) at the Malheur Agricultural Experiment Station, Ontario, Oregon. The experiment used normal cultural practices except water infiltration rates were controlled. Two separate water stress time trials were conducted. The early season stress period (June stress) was begun on June 23 and ended on July 7. Late season stress period (August stress) was begun on August 3 and ended on August 16. Each trial included a stress, which was water limiting, and a control, which was optimally watered, for each variety. All treatments in both trials were replicated four times and arranged at random within block using a complete block experimental design (Figure 2). The "soil water potential" and "crop water stress index (CWSI)" were used to measure the water stress. The more negative value of soil water potential means the plant was more stressed. The CWSI was measured using an infrared thermometer in a Scheduler (equipment trademark of Standard Oil of Ohio). The Scheduler also

calculates a crop canopy temperature, the air temperature and the air relative humidity. CWSI values range from 0 to 1. A non-stressed plant has a CWSI close to zero and a highly stressed plant that is not cooling itself adequately with evaporative cooling has a CWSI reading of 1. The soil water potential and crop water stress index during late-June mid-July, and early-August heat-moisture stress periods are summarized in Table 1.

Table 1. Soil moisture and crop water stress index (CWSI).[1]

| Irrigation Treatment | Late June | | August | |
|---|---|---|---|---|
| | Soil Moisture (bars) | CWSI (0-1) | Soil Moisture (bars) | CWSI (0-1) |
| Control | -0.48 | -1.6 | 0.64 | +0.9 |
| June Stress | -1.10 | +0.97 | -0.62 | +0.5 |
| August Stress | -0.51 | -1.4 | -1.08 | +1.6 |
| F Test | *** | ** | *** | *** |
| LSD .05 | 0.27 | 0.9 | 0.22 | -- |

[1]Data from Clinton C. Shock, Malheur Experiment Station, Oregon State University, Ontario, OR 97914.

## 3.2 Tuber Tissue Selection and Preparation

Samples were obtained at beginning of stress, end of stress, and two weeks after stress, respectively, for each trial. Five plants out of the middle of each plot were harvested. The tubers were washed with water, 20 of the large tubers were selected and were sectioned longitudinally into a one square centimeter strip.

Two strips from the center of each tuber were used and the skins removed. From each strip, a one centimeter cube was cut from the apical, central and basal end of the tuber. These potato cubes were placed in a glass vial and frozen with liquid nitrogen immediately. The liquid nitrogen frozen samples were stored at -80°C until freeze-dried. Using a mortar, freeze-dried potatoes were finely ground to a homogenous powder and stored in air tight containers at room temperature until analyzed.

## 3.3 Chemical Composition Analysis

Total solid was determined on the freeze-dried unpowdered potato cubes. Total reducing sugar, sucrose, fructose, glucose, nitrogen, total dietary fiber, ash and calcium analysis were done on the powdered sample. Methodology is summarized as follows. Further details for selected analyses are described (Appendix, p. 63). Unless indicated as a composite sample, all analysis was done on each replication for each treatment.

### 3.3.1 Total Solids

Percent total solids was calculated by 100 - percent total moisture. Moisture analysis was determined by a freeze-dried method. The initial weights before and after freeze-drying were used. Verification of adequacy of freeze-drying was done utilizing the AOAC (1984) method.

### 3.3.2 Total Reducing Sugars

Total reducing sugars were determined with a modification of the dinitrophenol method of Ross (Ross, 1959). One gram of homogenized powder sample was washed with 5 mL of distilled water into a 50 mL conical centrifuge tube, vortexed 45 seconds, and centrifuged at 200 rpm for 10 minutes. The supernatant was used to determine total reducing sugars (percent dry weight basis).

### 3.3.3 Sucrose, Fructose, Glucose

These three sugars (ug/g) were determined by gas liquid chromatography (Long and Chism, 1987). Reducing sugars such as fructose and glucose were analyzed as trimethylsilylated oxime (TMS/OX) derivatives while sucrose was analyzed as its TMS derivative.

### 3.3.4 Nitrogen

Nitrogen determination was done utilizing the micro-Kjeldahl of AOAC (AOAC 47.021-47.023, 1984). The sample of powdered freeze-dried potato was digested with the aid of sulfuric acid. Nitrogen present in the sample was held in solution as ammonium sulfate. Alkali was used to displace the ammonia, which, in turn, was distilled into the boric acid. The amount of ammonia present was then titrated with standardized HCl.

### 3.3.5 Total Dietary Fiber

Total dietary fiber was determined by AOAC method 43.A14-

43.A20 (AOAC, 1985). This is a combination of enzymatic and gravimetric procedures. Duplicate samples of freeze-dried, fat-free potato flour are gelatinized with heat stable alpha-amylase and then enzymatically digested with protease and amyloglucosidase to remove the protein and starch present in the sample. Ethanol is added to precipitate the soluble dietary fiber. The residue is then filtered and washed with 78% ethanol, 95% ethanol and acetone. After drying, residue is weighed. One duplicate was analyzed for protein, and the other was ashed. Total dietary fiber is the weight of the residue less the weight of the protein and ash.

### 3.3.6 Calcium

Two gram samples were ashed at 525°C for 24 hr, dissolved in 3 mL of 3N HCl solution and made to 25 mL volume with redistilled water. The solution was analyzed using a Perkin Elmer 2380 atomic absorption spectrophotometer.

## 3.4 Stored Potato Quality Characteristics

All data evaluation of the quality characteristics of the stored potatoes was done at the Malheur Agricultural Experiment Station, Ontario, OR. Potatoes were stored at ambient temperatures until fried. Dark-end fry color was determined by frying slabs of potatoes for 2-5 minutes at 109.5°C. The light reflectance of each piece was read using a photovolt reflectance meter with a green tristimulus filter. The lighter the fried potato strip, the greater

the light reflectance. Tuber stem-end fry color also related to the USDA color chart (USDA, 1972).

## 3.5 Experimental Design

Potatoes were grown at the Malheur Experiment Station utilizing field plots (B6; Appendix, p.85) that had not been planted to potatoes during 1987. The design of four row plots (replications) 100 feet long was done according to acceptable agricultural practices. Control versus stressed potato treatments were varied in order to minimize soil and location differences. The row and treatment application are shown in Figure 2. The collection of soil potential and CWSI data permitted monitoring of data from expected treatment. With this occurrence an alternate row of identical treatment was collected for sampling. The assumption was that the experimental design allowed for this.

Chemical analysis of the sample during the June and August stress period was not identical due to financial and time constraints. Utilizing the results of the 1987 growth period, additional analyses to determine sucrose, fructose, glucose, fiber, nitrogen, and calcium was added as an exploratory aspect to the project. The potential of these selected components for enhancing an understanding of factors related to the sugar-end problem and the mechanisms for sugar content had been noted from the literature. August stress was the focus as it showed the greatest influence during the 1987 growth period.

Figure 2. The row and treatment application. Treatment 1, 2 and 3 were randomly arranged in plot of 3, 7, 12, 18, 19, 24 29, 30, 33, 36, and 40, respectively.[1,2]

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 (7) | 2(4) | 3(1) | 4(5) | 5(9) | 6(3) | 7(2) | 8(8) | 9(10) | 10(6) |
| REPLICATION ONE | | | | | | | | | |
| 11(6) | 12(3) | 13(8) | 14(7) | 15(5) | 16(9) | 17(10) | 18(2) | 19(1) | 20(4) |
| REPLICATION TWO | | | | | | | | | |
| 21(7) | 22(6) | 23(5) | 24(1) | 25(8) | 26(10) | 27(4) | 28(9) | 29(3) | 30(2) |
| REPLICATION THREE | | | | | | | | | |
| 31(9) | 32(10) | 33(3) | 34(6) | 35(8) | 36(1) | 37(7) | 38(4) | 39(5) | 40(2) |
| REPLICATION FOUR | | | | | | | | | |

[1]first number represents plot.

[2]number in parenthesis represents treatment.

## 3.6 Statistical Analysis

Data means (Table 2) and P-values (Table 4) were calculated to study the interrelationships of variety, test period, tuber portion and stress. Because of the differences in stress, each period was treated as a separate experiment. Analysis of variance was determined utilizing the "Statistical Interactive Programming System (SIPS) Command Reference Manual" (Rowe and Stillinger, 1987). P-values at the 5 percent level or less for those interrelationships which were significiant are reported.

# CHAPTER 4

# RESULTS AND DISCUSSION

## 4.1 Composition During Growth

A summary of the effect of drought stress on chemical composition of Russet Burbank and A082260-8 is reported in Table 2. Generally, percent total solids increased during potato development for both Russet Burbank and A082260-8 potatoes, in agreement with the previous studies by Appleman and Miller (1926) and Snyder, et al. (1977). Basal and apical portions were generally higher in percent total solids than the center portion indicating that starch content was the lowest at center portion. Weaver, et al. (1978a) have pointed out that solids content was lowest in core tissue in normal growth potatoes. A082260-8 appeared to have higher percent total solid than Russet Burbank at the basal and apical portion indicating A082260-8 probably is a potential good variety for processing.

Total reducing sugar content (Table 2) generally decreased during potato development for both Russet Burbank and A082260-8 potatoes. This is as would be expected, because the very immature potatoes were high in sugar content and low in starch (Yamaguchi, et al., 1960). The percent reducing sugar content on dry weight was higher at apical portion at early stage of potato development than basal and center portions. This is understandable because the apical portion is relatively more immature(Iritani, et al., 1973a). As the

Table 2. Effect of Drought Stress on Chemical Composition of Russet Burbank and A082260-8.[1,2]

| | | June - July Stress Period | | | | | | July - August Stress Period | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Chemical | | Before Stress | | End of Stress | | After Stress | | Before Stress | | End of Stress | | After Stress | |
| Composition | | Control | Stressed | Control | Stressed | Control | Stressed | Control | Stressed | Control | Stressed | Control | Stressed |
| Reducing | Basal | 1.80 | 2.29 | 1.08 | 0.36 | 0.40 | 0.36 | 0.22 | 0.30 | 0.39 | 0.27 | 1.38 | 0.69 |
| Sugars (%) | Center | 1.50 | 1.78 | 0.99 | 0.46 | 0.53 | 0.59 | 0.28 | 0.23 | 0.21 | 0.18 | 0.12 | 0.17 |
| | Apical | 3.68 | 3.54 | 3.68 | 1.70 | 1.73 | 2.58 | 0.43 | 0.34 | 0.56 | 0.33 | 0.17 | 0.27 |
| Total | Basal | 13.96 | 14.61 | 13.76 | 14.00 | 14.78 | 13.78 | 9.80 | 10.94 | 16.79 | 15.79 | 18.11 | 18.91 |
| Solids (%) | Center | 11.73 | 11.86 | 11.84 | 12.26 | 13.82 | 13.13 | 12.74 | 10.12 | 14.57 | 14.15 | 18.08 | 16.24 |
| R | Apical | 12.17 | 12.14 | 13.16 | 13.86 | 14.78 | 13.38 | 12.97 | 12.50 | 18.27 | 18.24 | 21.55 | 20.88 |
| U | | | | | | | | | | | | | |
| S Nitrogen (%) | Basal | | | | | | | | | | | 1.12 | 1.30 |
| S | Center | | | | | | | | | | | 1.57 | 1.55 |
| E | Apical | | | | | | | | | | | 1.24 | 1.26 |
| T | | | | | | | | | | | | | |
| Total Dietary | Basal | | | | | | | 7.07 | 6.67 | 6.98 | 7.17 | 7.91 | 7.30 |
| 8 Fiber (%) | Center | | | | | | | 7.10 | 6.34 | 5.68 | 6.38 | 6.23 | 5.91 |
| U | Apical | | | | | | | 5.56 | 5.50 | 5.69 | 6.31 | 6.79 | 6.08 |
| R | | | | | | | | | | | | | |
| B Calcium (ug/g) | Basal | | | | | | | 2248.82 | 1874.92 | 3535.10 | 3324.87 | 2843.40 | 2554.94 |
| A | Center | | | | | | | 852.46 | 928.14 | 787.36 | 734.66 | 819.28 | 1338.68 |
| N | Apical | | | | | | | 1015.50 | 1416.21 | 1750.54 | 2267.66 | 1704.23 | 1872.09 |
| K | | | | | | | | | | | | | |

Table 2. continued

| Chemical Composition | | June - July Stress Period | | | | | | July - August Stress Period | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Before Stress | | End of Stress | | After Stress | | Before Stress | | End of Stress | | After Stress | |
| | | Control | Stressed | Control | Stressed | Control | Stressed | Control | Stressed | Control | Stressed | Control | Stressed |
| Reducing | Basal | 2.01 | 1.59 | 0.87 | 0.52 | 0.34 | 0.34 | 0.20 | 0.21 | 0.20 | 0.17 | 0.12 | 0.14 |
| A Sugars (%) | Center | 1.50 | 1.92 | 0.55 | 0.39 | 0.33 | 0.36 | 0.37 | 0.27 | 0.22 | 0.19 | 0.14 | 0.17 |
| 0 | Apical | 2.74 | 2.98 | 1.20 | 0.54 | 0.63 | 1.13 | 0.22 | 0.22 | 0.23 | 0.23 | 0.13 | 0.18 |
| 8 | | | | | | | | | | | | | |
| 2 Total | Basal | 14.41 | 15.15 | 15.11 | 14.93 | 16.74 | 16.49 | 15.28 | 13.41 | 21.36 | 23.41 | 21.51 | 22.22 |
| 2 Solids (%) | Center | 11.93 | 12.39 | 12.22 | 12.63 | 12.85 | 12.92 | 10.28 | 8.99 | 10.45 | 10.98 | 13.72 | 15.06 |
| 6 | Apical | 13.21 | 13.08 | 13.76 | 14.58 | 15.95 | 15.65 | 15.32 | 15.61 | 19.43 | 19.76 | 23.30 | 21.32 |
| 0 | | | | | | | | | | | | | |
| - Nitrogen (%)[3] | Basal | | | | | | | | | | | 1.10 | 1.16 |
| 8 | Center | | | | | | | | | | | 2.16 | 2.18 |
| | Apical | | | | | | | | | | | 1.18 | 1.29 |
| Total Dietary | Basal | | | | | | | 5.78 | 5.99 | 6.56 | 7.07 | 7.46 | 6.86 |
| Fiber (%)[3] | Center | | | | | | | 6.70 | 6.41 | 6.99 | 6.81 | 7.04 | 6.65 |
| | Apical | | | | | | | 5.19 | 4.98 | 6.60 | 6.81 | 6.27 | 6.32 |
| Calcium (ug/g)[3] | Basal | | | | | | | 1406.59 | 1278.79 | 2187.70 | 3571.01 | 2226.23 | 2477.71 |
| | Center | | | | | | | 666.90 | 647.81 | 630.18 | 849.43 | 585.56 | 588.16 |
| | Apical | | | | | | | 1145.37 | 1326.15 | 1303.35 | 1881.68 | 1378.64 | 1342.31 |

[1]Average of 4 replications

[2]Based on dry weight

[3]Based on July - August Stress only.

potato matures, this difference disappeared or reversed. For Russet Burbank, the basal portion had the highest reducing sugar content at early September sampling time.

Composite samples of the four replications in each treatment were tested FOR individual sugarS (including fructose, glucose and sucrose) (Table 3). An analysis of reducing sugars (Table 3) in late June to early July and that of early to mid-August drought stressed potatoes indicated a decrease in reducing sugar as tubers developed. This change was apparent in all three portions. In looking at the normal irrigated potatoes (control) throughout the whole experiment period from June 23 to September 2, the apical end had greater differences between the mature and immature tubers than basal end, which has been pointed out by Iritani, et al. (1973). Of the reducing sugars, glucose content (Table 3) was much greater than fructose for both varieties and both basal and apical ends. Four to five percent fructose was found in the basal portion during the mid-June growing period. Fructose was less likely to be found later in the growing period. Sucrose predominated over glucose and fructose during the whole experiment period, representing more than 50 percent of the total sugars with glucose and fructose the next in order of importance. Similar results were reported by Nelson and Shaw (1976). Sucrose, as well as glucose, generally was higher at the apical end than at the basal end. In their research, Samotus and Schwimmer (1962); Clegg and Chapman (1962b); Yamaguchi, et al. (1966); and Iritani and Weller (1980) had already indicated that immature tubers contain large amounts of sucrose. So, it is not

Table 3. Effect of Drought Stress on Individual Sugar Content of Russet Burbank and A082260-8.[1,2]

| Chemical Composition[1] | | June - July Stress Period | | | | | | July - August Stress Period | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Before Stress | | End of Stress | | After Stress | | Before Stress | | End of Stress | | After Stress | |
| | | Control | Stressed | Control | Stressed | Control | Stressed | Control | Stressed | Control | Stressed | Control | Stressed |
| Reducing Sugars (ug/g) | Basal | 0.01 | 0.01 | ---[2] | 0.00 | --- | --- | --- | --- | --- | --- | 0.04 | --- |
| | Apical | 0.02 | 0.02 | --- | 0.00 | 0.00 | --- | 0.00 | 0.01 | --- | --- | 0.02 | --- |
| Soluble Sugars (ug/g) | Basal | 0.03 | 0.05 | 0.00 | 0.01 | --- | --- | --- | --- | --- | --- | 0.01 | 0.00 |
| | Apical | 0.20 | 0.20 | 0.07 | 0.03 | 0.02 | 0.04 | 0.02 | 0.01 | 0.01 | --- | --- | --- |
| Sucrose (ug/g) | Basal | 0.18 | 0.26 | 0.08 | 0.09 | 0.06 | 0.07 | 0.01 | 0.01 | 0.04 | 0.03 | 0.09 | 0.03 |
| | Apical | 0.31 | 0.26 | 0.28 | 0.28 | 0.15 | 0.15 | 0.14 | 0.14 | 0.15 | 0.08 | 0.03 | 0.03 |
| Total (ug/g) | Basal | 0.22 | 0.32 | 0.08 | 0.10 | 0.06 | 0.07 | 0.01 | 0.01 | 0.04 | 0.03 | 0.14 | 0.03 |
| | Apical | 0.52 | 0.48 | 0.35 | 0.31 | 0.17 | 0.20 | 0.16 | 0.15 | 0.16 | 0.08 | 0.06 | 0.03 |
| Fructose (ug/g) | Basal | 0.02 | 0.02 | 0.01 | 0.00 | 0.01 | --- | --- | --- | --- | --- | --- | --- |
| | Apical | 0.01 | 0.01 | 0.00 | --- | --- | --- | --- | --- | 0.00 | --- | --- | 0.00 |
| Glucose (ug/g) | Basal | 0.07 | 0.04 | 0.03 | 0.01 | 0.01 | --- | 0.00 | --- | --- | --- | --- | --- |
| | Apical | 0.09 | 0.09 | 0.04 | 0.01 | 0.01 | 0.01 | --- | --- | --- | --- | --- | --- |
| Sucrose (ug/g) | Basal | 0.31 | 0.25 | 0.25 | 0.19 | 0.14 | 0.08 | 0.02 | 0.01 | 0.01 | 0.02 | 0.01 | 0.01 |
| | Apical | 0.25 | 0.24 | 0.38 | 0.23 | 0.16 | 0.13 | 0.11 | 0.06 | 0.07 | 0.04 | 0.02 | 0.03 |
| Total (ug/g) | Basal | 0.39 | 0.31 | 0.29 | 0.20 | 0.15 | 0.08 | 0.02 | 0.01 | 0.01 | 0.02 | 0.01 | 0.01 |
| | Apical | 0.36 | 0.34 | 0.42 | 0.24 | 0.17 | 0.14 | 0.11 | 0.06 | 0.07 | 0.04 | 0.02 | 0.04 |

[1]Based on dry weight.

[2]Can not be detected.

surprising that the apical portion, since it is more immature, had more sucrose than the basal portion. The amount of sucrose decreased rapidly as tubers developed and matured. A minimum level of sucrose at the basal end was reached at approximately mid-August for A082260-8 which is slightly earlier than Russet Burbank and could be considered as an indication of physiological maturity (Iritani and Weller, 1977).

Based on the 1987 data, total dietary fiber and calcium were determined for the three August stress dates, and nitrogen was determined for samples which were two weeks recovery from stress. Exploration of these components (Table 2) indicated their potential to improve the understanding of potato physiology. The center portion of potato tubers had the highest nitrogen content (Table 2) compared with the apical and basal end, especially for A082260-8 potatoes. This result is in agreement with an inverse relationship between the distribution of starch (total solids) and nitrogen (Schwimmer and Burr, 1967). Total dietary fiber content was generally the highest at basal portion for both varieties. Russet Burbank appeared to have higher total dietary fiber than A082260-8 at this end. The results indicate the need for further exploration into the components of total dietary fiber. Analysis as to whether the fiber is cellulose or pectic substances would be enlightening. Russet Burbank has a higher calcium content than A082260-8 (Table 2). Basal and apical portions were markedly higher in calcium content than the center portion for both varieties. Maturity showed

no consistent pattern as to relative calcium variation among the different portions of tuber.

## 4.2 Composition During Drought Stress

Variety or drought stress or date of sampling did not significantly influence total solids, reducing sugars, nitrogen or total dietary fiber (Table 2, 3). Although, there was no main factor affect, a number of the trends are of interest. Generally, stressed potatoes had higher total solids levels at the end of stress than the control potato due to limiting available moisture (Table 2). When water was reapplied, percent total solids decreased due to absorption of water. In contrast with total solids, reducing sugars in stressed potatoes increased after moisture was reapplied. The range of increase was especially high for Russet Burbank. Late season stress appeared to show no immediate effect on solids or reducing sugar (Table 2, 3). No apparent pattern of type of sugar (Table 3) was noted due to stress.

It is of interest that total dietary fiber (Table 2) is higher in stressed potato tubers than in normal irrigated potatoes at the end of August stress, and the relationship became reverse after two weeks recovery from stress. This phenomenon is especially true for Russet Burbank. The reason is unknown. August stress produced no short run effects on tuber nitrogen or calcium contents (Table 2) except that stressed Russet Burbank appeared to have more calcium than that of its control at two weeks after stress.

Although the main factors were not significant influences on composition, the interactions show the complexity of the sugar-end problem (Table 4). For early season drought stress, differences in total solids due to the interaction between treatment and sampling date were significant. The second order interaction, variety x position x sampling date, was also significant, indicating that the degree of change in total solids depends upon the particular combination of physiological characteristics. Response factors of total solids in later season drought were different from that in early season stress. The total solids responded differently for different varieties depending on different portions of the tuber, as indicated by significant interaction between variety and position. A082260-8 appeared to a have higher percentage of total solids than Russet Burbank at the basal and apical portion. The interaction between position and sampling date was also significant. The difference in total solids between ends and center of tuber was the highest at the end of later season stress.

Significant differences in reducing sugars at early season stress were related to the interaction effects of treatment x sampling date and variety x position (Table 4). No significant effects were observed for the treatment alone or variety alone. The effect of drought stress were observed only at the time of two weeks recovery from the stress, when the reducing sugar content increased for stressed potatoes. The results showed that drought stress at early development stage does have a detrimental effect on reducing sugar content in agreement with the previous studies (Iritani, et

Table 4. Statistical significance for main effect and interactions of data in a study of potato composition and distribution.[1]

| Factors considered[2] | Total Solids | | Reducing Sugars | | | | |
|---|---|---|---|---|---|---|---|
| | Early season stress | Later season stress | Early season stress | Later season stress | Nitrogen[3] | Total dietary fiber[3] | Calcium[3] |
| Variety | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | ** |
| Treatment | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. |
| VARxTRT | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. |
| Position | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | ** |
| VARxPOS | n.s. | ** | ** | n.s. | ** | ** | n.s. |
| TRTxPOS | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. |
| VARxTRTxPOS | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. |
| Date | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | ** |
| VARxDate | n.s. | n.s. | n.s. | n.s. | n.s. | ** | n.s. |
| TRTxDate | * | n.s. | * | n.s. | n.s. | * | n.s. |
| VARxTRTxDate | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. |
| POSxDate | n.s. | ** | n.s. | n.s. | n.s. | ** | ** |
| VARxPOSxDate | * | n.s. | n.s. | ** | n.s. | n.s. | n.s. |
| TRTxPOSxDate | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. |
| VARxTRTxPOSxDate | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. |

[1] $P < 0.05$, $P \leq 0.01$ and not significant are denoted by *, **, and n.s., respectively.
[2] VAR represents variety, TRT represents treatment, and POS represents position.
[3] Late season stress only.

al, 1973; Iritani and Weller, 1973a; Iritani, 1981; Kunkel, 1957; Kunkel and Gardner, 1958; Lugt, 1960; Murphy, 1936; Nielson and Sparks, 1953). Variety difference in reducing sugar content occurred at the apical end. Russet Burbank had more reducing sugars than A082260-8, and thus appears to have a greater genetic potential for accumulating reducing sugars. The reason for the difference in reducing sugars at the apical portion can be attributed to the relative less maturity at this end in an early development stage (Iritani, et al., 1973). Sugar-end potatoes were not produced with late season stress as indicated by Iritani and Weller (1973a, 1973b), Iritani, et al. (1973), and Owings, et al. (1978) reenforces the need for greater understanding of the mechanism of drought stress. Significant differences in reducing sugar at this period were due to the interaction effect of variety x position x sampling date. The basal end of Russet Burbank had the highest reducing sugar content at early September sampling time.

The one factor which showed a main effect was calcium. The significance ($P<0.05$) of variety, position, date, and their interaction on calcium deserves more study. It may be reflective of established varietal differences in texture. The interaction ($P<0.01$) of variety and position for both nitrogen and dietary fiber may be a result of growth pattern differences in the two treatments. The interaction of variety and position and treatment with date and the potato total dietary fiber raises a number of interesting questions with no conclusive answers.

Is the potato more sensitive to stress at stages of its growth? The current literature and previous studies at the Malheur Agricultural Experiment Station would substantiate that. Iritani (1981) had already indicated that stress early in the tuber development generally has the most effect on the tubers. However, these studies have focused on reducing sugars. The implied assumption has been that the underlying mechanism is the sugar-starch metabolic system. The exploration in the current study would raise the question of cell wall integrity. However, the projection of this as a sole factor is also negated by the significant ($P<0.01$) position and date interaction for both total dietary fiber and calcium. These results would indicate a variety of mechanism, must be pursued if one is going to solve the problem of quality for drought stressed potatoes.

## 4.3 Implication For The Future

Although the focus of this research was on the chemical composition of the potato during growth and drought stress, the implications of results are strengthened by viewing (Table 5) the data on the fried potato done at the Malheur Agricultural Experiment Station.

Although stress alone did not have a significant influence on total solids and reducing sugar content during this study period, its effect was reflected (at least in some degree) in quality characteristics of stored potatoes at frying time. Russet Burbank and A082260-8 potatoes grown in control plots had no critical dark-

Table 5. Chemical composition and quality characteristics of stored potatoes at frying time.

| Tests | Russet Burbank | | | A082260-8 | | | Statistical Analyses[2] | | |
|---|---|---|---|---|---|---|---|---|---|
| | Control | Early season stress | Later season stress | Control | Early season stress | Later season stress | VAR | TRT | VARxTRT |
| Total Solids (%)[1] | 18.11 | 13.78 | 18.91 | 21.51 | 16.49 | 22.22 | | | |
| Reducing Sugars (%))[1] | 1.38 | 0.36 | 0.69 | 0.12 | 0.34 | 0.14 | | | |
| Oark End (%)[2,3] | 13.10 | 55.00 | 16.30 | 0.60 | 0.00 | 2.50 | 8.1 | 22.1 | 14.1 |
| Fry Color[2,4] | 43.8 | 34.2 | 43.3 | 53.8 | 49.7 | 50.4 | 3.2 | 6.3 | ns |
| Specific Gravity[2] | 1.085 | 1.082 | 1.086 | 1.091 | 1.094 | 1.091 | .0022 | .0033 | ns |

[1]Analyses done in Oepartment of Foods and Nutrition, Oregon State University as reported in Procedures section. Data represented are those values at basal end of tuber at time of two weeks after stress.

[2]Oata and results from Malheur Agricultural Experiment Station. The Statistical Analyses are expressed as Least Significant Oifference (LSO) at the 0.05 level, "ns" represents not significant at this level.

[3]Total of USDA #3 and #4.

[4]Photovolt Reflection Trisimulus value for green filter.

ends (#3 and #4 USDA fry color). Drought stress in late June and early July was associated with a high incidence of dark basal-end fry colors for Russet Burbank. Russet Burbank potatoes that underwent the early August stress did not appear significantly different ($P<0.05$) in fry color. Statistical analysis showed no trend or influence of drought stress on the fry color and percentage dark-end of A082260-8 potatoes, indicating the high tolerance to short periods of drought stress of this cultivar. It is interesting to note that Russet Burbank and A082260-8 potatoes grown in control treatment had significant difference in fry color and percent dark-end. A082260-8 had significantly ($P<0.05$) lighter fry color and lower incidence of dark basal-end fry colors.

The drought stress at early season which was associated with a high incidence of dark basal-end fry colors can be traced back to the significant interaction between treatment and sampling date (Table 4) for both total solids and reducing sugars. Later season stress did not show any significant differences between treatments. Percent total solids decreased and reducing sugars increased in early season stressed potatoes from the end of stress to two weeks recovery from stress. This pattern is similar to that of translucent-end tubers (Iritani, et al, 1973; Iritani and Weller, 1973b; Iritani, 1981; Kunkel, 1957; Kunkel and Gardner, 1958; Lugt, 1960; Murphy, 1936; Nielson and Sparks, 1953). Therefore, it is not surprising that they are associated with dark-ends.

Extensive literature on potato composition is available, but comparison of results is often difficult due to the different

experiment conditions. Information on nitrogen, total dietary fiber and calcium in potato development and the relationships to growing condition is relatively short. The present study was to evaluate the effects of drought stress during tuber development on chemical composition and distribution in potatoes, to investigate the metabolic pathways of sugar and starch accumulation and the related sugar-end problem. Early season drought stress had more detrimental effects on total solids and reducing sugar content of potato tubers then later season stress. A082260-8 was more tolerant of drought stress than Russet Burbank. Of the three major sugars investigated, sucrose content gave the best indication of relative maturity.

Exploration of total dietary fiber, calcium and nitrogen trends indicate the potential to improve the understanding of potato physiology. Total dietary fiber, as a major component of cell wall, was higher in Russet Burbank tubers than in A082260-8 at the basal end may indicate some potential relationship with sugar-end development. Since dietary fiber is a mixture of many complex organic substances, there is little double that different components will have different effects on both micro- and macro-characteristics of potato tubers. It is of interest to know the effect of particular dietary fibers on the quality of potato. The importance of calcium in the metabolic cycle is well-established. Unfortunately, there is limited knowledge of the effect of calcium in sugar-end problem of potato. Significant differences of variety and position in calcium content in the present study indicate the necessity of further detailed research.

It would seem it is no longer adequate to document the effects of stress on gross carbohydrate content. Investigation of some other components, such as nitrogen, protein, total dietary fiber and calcium, are imperative because they may predict the influence of a stress on mechanisms of carbohydrate composition. The elucidation of the focal point of the stress on the pathways of starch-sugar synthesis, catabolism or transformation in the potato and interactions with calcium and fiber would enhance the ability to control the ultimate quality of the potato.

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# APPENDIX

# I. DETAILED METHODOLOGY

## Part I. Dinitrophenol Method For Determination Of Total Reducing Sugars In Potato Tubers

This method is a modified colorimetric method of Ross (1959). Reducing sugars were extracted by water and reacted with dinitrophenol solution. The color produced was measured at the absorption at 600 nm for determination of reducing sugar content.

Reagent:

Solution A: Dissolve 7.145 g of 2,4-dinitrophenol in 230 mL of 5 per cent sodium hydroxide. Heat on hot water bath to dissolve. Then add 2.5 g phenol. Heat some more if the solution does not remain clear.

Solution B: Dissolve 100 g of Nak tartrate in 500 mL of distilled water.

To make dinitrophenol solution, mix solution A and B together, then transfer to 1000 mL volumetric flask and bring to mark with distilled water.

Preparation of standard: A stock glucose standard was made by dissolving 1 g of anhydrous glucose in distilled water and making the volume up to 100 mL. A crystal of thymol was added in order to keep this standard solution for long periods in the refrigerator. This gave a solution containing 10 mg per mL and could be diluted to any desired extent.

Procedure:

One gram of homogenized powder sample was washed with 5 mL of

distilled water into a 50 mL conical centrifuge tuber, vortexed 45 seconds, and centrifuged at 200 rpm for 10 minutes. The supernatant was used to determine total reducing sugars.

Exactly 1.0 mL of potato supernatant material was pipetted into a 16 cm test tube. Add 3.0 mL of dinitrophenol solution to each tube. Mix thoroughly (vortex 10 seconds) and heat in boiling water for exactly 6 minutes. Cool 3 minutes in cool water (approximately 6$^{o}$C). Keep cold and read at 600 nm before 20 minutes elapse. Sample is read in a cell of one centimeter path length in a Gilford spectrophotometer (Oberlin, Ohio). The meter was first set at zero for the water solution.

The calibration curve was prepared each time by using standard anhydrous glucose solution. In preparing the calibration curve, 1 mL of serial standard glucose solutions with concentrations of 0, 0.2, 0.5 and 1.0 mg/mL were treated respectively exactly as were the potato samples. A linear regression equation was generated using a Hewlett Packard Model 10 Calculator with standards and this equation was used to determine the reducing sugar concentration in samples.

## Part II. The Rapid Direct Extraction-Derivation Method For Determining Fructose, Glucose And Sucrose In Potato Tubers

The three major sugars in potato tubers, fructose, glucose and sucrose, were determined by gas liquid chromatography (Long and Chism, 1987). Reducing sugars such as fructose and glucose were analyzed as trimethylsilylated oxime (TMS/OX) derivatives while sucrose was analyzed as its TMS derivative.

Reagent:

1. Silylation-grade pyridine.

2. STOX: oxime-internal standard reagent--25 mg/mL hydroxylamine hydrochloride and 6 mg/mL phenyl-beta-D-glucopyranoside in pyridine.

3. Fructose, glucose and sucrose standard.

4. Bis-(trimethysilyl)trifluoroacetamide (BSTFA).

Chromatography condition:

Hewlett-Packard HP 5890A gas chromatograph equipped with a data station, a 6 foot Supelco glass column 2 mm I.D. with 3% SP-2330 on 100/120 mesh Suplecoport and Flame-ionization detector (FID) was used for this analysis. The FID and injector were both maintained at 235°C. The oven was programmed from 160°C to 225°C at 10 degrees/min with a 3 minute delay. Purified helium was the carrier gas at a flow rate of 30 mL/min.

Procedure:

Five mg samples of the ground powder were weighed on weighing paper and transferred to 1.0 mL Teflon-capped reaction vials. 75 uL of pyridine and 75 uL of STOX were transferred into the vials using a positive displacement pipet. The mixture was mixed by vortexing and placed into an 80°C block heater for 40 minutes with additional mixing at 10, 20, and 30 minutes. At the end of 40 minutes the samples were cooled in cooled water, 150 uL of BSTFA added, mixed and heated 10 minutes at 80°C. One uL samples were injected into the GC column. Each analysis took 15 minutes.

Response factors for standards were determined utilizing a Hewlett-Packard Model HP3392A integrator. Standard fructose, glucose and sucrose were derivatized as described above and analyzed to determine response factors compared to the internal standard phenyl-beta-D-glucopyranoside prior to each assay. Analyses were completed using the data station using a calibration table to determine the fructose, glucose and sucrose content in the sample.

Part III. Micro-Kjeldahl Method For Determination Of Nitrogen In Potato Tubers

Nitrogen determination was done utilizing the Micro-kjeldahl method of AOAC (AOAC 47.021-47.023, 1984). The sample of powdered freeze-dried potato is digested with the aid of sulfuric acid. Nitrogen present in the sample is held in solution as ammonium sulfate. Alkali is used to displace the ammonia, which, in turn, is distilled into boric acid. The amount of ammonia present is then titrated with standardized hydrogen chloride.

Reagents:

1. Sulfuric acid: concentrated, Sp. Gr. 1.84, N-free.
2. Catalyst: Mix well 190 g potassium sulfate and 4 g mercuric oxide.
3. Sodium hydroxide-sodium thiosulfate solution(Alkali solution): Dissolve 60 g sodium hydroxide and 5 g sodium thiosulfate ($Na_2S_2O_3.5H_2O$) in redistilled water and dilute to 100 mL.
4. Boric acid solution (saturated solution): Dissolve 50 g of boric acid to about 400-500 mL hot redistilled water, be sure all the

crystals are dissolved. Cool the solution to room temperature and stand for overnight, allow this supersaturated solution to reprecipitate. Filter the solution for using.

5. Mixed indicator solution (methyl red-bromocresol green): Dissolve 100 mg methyl red and 500 mg bromocresol green individually in 95% ethanol, mix these two solution well and dilute to 100 mL with 95% ethanol.

Add 10 mL mixed indicator to 1 liter saturated boric acid solution, mix well.

6. Standardized hydrochloric acid, 0.02N.

Digestion:

1. Place 2.0 g of catalyst in each 30 mL digestion flask, Including a blank contained all reagents except the sample.
2. Add 100 mg freeze-dry potato flour, accurate to 0.1 mg, to the flask.
3. Add 3 mL concentrated sulfuric acid to each flask.
4. Add 2 glass beads (6 mm) to each flask.
5. Place flasks on micro-kjeldahl digestion rack, digest for about 1-1.5 hour after all the water has been boiled off. Totally take about 2-3 hours for digestion. Digests should be clear and colorless.
7. Remove from rack and allow to cool. Stopper flasks to await distillation.

Distillation:

1. Transfer digest to distillation apparatus (add minimum distilled

water to dissolve solids), and rinse flask 5-6 times with 1-2 mL water.

2. Place 125 mL Erlenmeyer flask containing 20 mL saturated boric acid with indicator under condenser with tip extending below surface of solution.

3. Add 10 mL alkali solution to still.

4. Collect about 30 mL distillate into boric acid solution.

Titration:

1. Titrate the contents of the Erlenmeyer collection flask with standardized HCl (0.02N) to end point.

2. Titrate the blank in the same way.

3. Calculations:

$$N\ \% = \frac{[mL\ HCl(sample) - mL\ HCl(blank)] \times Normality\ HCl \times 14}{Sample\ weight\ (mg)} \times 100$$

Part IV. Determination Of Total Dietary Fiber In Potato Tubers

Total dietary fiber was determined by AOAC method 43.A14-43.A20 (AOAC, 1985). This is a combination of enzymatic and gravimetric procedures. Duplicate samples of freeze-dried, fat-free potato flour are gelatinized with heat stable alpha-amylase and then enzymatically digested with protease and amyloglucosidase to remove the protein and starch present in the sample. Ethanol is added to precipitate the soluble dietary fiber. The residue is then filtered and washed with 78 percent ethanol, 95 percent ethanol and acetone. After frying, residue is weighed. One duplicate is analyzed for protein, and the other is ashed. Total dietary fiber

is the weight of the residue less the weight of the protein and ash.

Reagents:

1. 95% Ethanol(v/v): technical grade.
2. 78% Ethanol: place 207 mL of distilled water into a one liter volumetric flask. Dilute to volume with 95% ethanol. Mix well and bring to volume again with 95% ethanol if necessary. Mix.
3. Acetone: reagent grade.
4. Phosphate buffer, 0.05 M, pH 6.0: Dissolve 0.875 g Na phosphate dibasic, anhydrated ($Na_2HPO_4$) and 6.05 g Na phosphate monobasic monohydrate ($NaH_2PO_4$) in approximately 700 mL of water. Dilute to one liter with distilled water. Check pH and adjust if necessary with either NaOH or $H_3PO_4$.
5. Alpha-amylase, Heat Stable: Sigma Product No. A 0164.
6. Protease: Sigma Product No. P 3910
7. Amyloglucosidase: Sigma Product No. 9913.
8. Sodium Hydroxide Solution, 0.171 N. Dilute 171 mL of 1.0 N NaOH solution (Sigma product No. S 7513) to one liter with water in a one liter volumetric flask.
9. Phosphoric Acid Solution, 0.205 M: Dilute 205 mL of 1.0 M $H_3PO_4$ solution (Sigma Product No. P 4285) to one liter with water in a one liter volumetric flask.
10. Celite, Acid Washed: Sigma Product No. C 8656.

Pretest:

To ensure absence of undesirable enzymatic activity in enzymes used in this procedure, run materials listed in Table 7 through

entire procedure each time lot of enzymes is changed, or at maximum interval of 6 months to ensure that enzymes have not degraded.

Table 6. Enzyme effectiveness testing

| Test Sample | Activity Tested | Sample Wt.,g | Expected Rec., % |
|---|---|---|---|
| Citrus pectin | pectinase | 0.1 | 95-100 |
| Stractan(larch gum) | hemicellulose | 0.1 | 95-100 |
| Wheat starch | amylase | 1.0 | 0-1 |
| Corn starch | amylase | 1.0 | 0-2 |
| Casein | protease | 0.3 | 0-2 |
| Beta-Glucan(barley gum) | beta-glucanase | 0.1 | 95-100 |

Procedure:

1. Run blanks through the entire procedure along with samples to measure any contributions from reagents to residue.

2. Weigh duplicate 1 gram freeze dried samples, accurate to 0.1 mg, into 400 mL tall form beakers. Sample weights should not differ by more than 20 mg.

3. Add 50 mL of pH 6.0 phosphate buffer to each beaker.

4. Add 0.2 mL alpha-amylase solution to each beaker and mix well. NOTE: The alpha-amylase got from Sigma Co. has one-half the enzyme concentration of that recommended in the procedure of AOAC method. For this reason, it is necessary to add 0.2 mL in this procedure rather than 0.1 mL as in the procedure of AOAC.

5. Cover each beaker with aluminum foil and place in a boiling water bath 30 minutes. Shake beaker gently at 5 minute intervals. Cool solutions to room temperature.

6. Adjust pH of solution to 7.5 $\pm$ 0.1 by adding 10 mL of 0.171 N NaOH to beaker. Check pH with pH meter. Adjust again, if necessary, with either NaOH or $H_3PO_4$.

7. Add 5 mg of Protease to each beaker. Since this enzyme is a dry

powder, it will be easier to make a 50 mg/mL solution in phosphate buffer immediately before use and then pipet 0.1 mL into each beaker.

8. Cover beaker beakers with aluminum foil and incubate for 30 minutes at 60°C with continuous agitation. Cool solutions to room temperature.

9. Add 10 mL of 0.205 M $H_3PO_4$ to each beaker to adjust pH of solutions to 4.5 $\pm$ 0.2. Check with pH meter. Adjust pH carefully, if necessary, with either NaOH or $H_3PO_4$. NOTE: Phosphate is a very weak buffer in the pH 4.5 region, hence the use of a pH meter to obtain pH 4.5 is essential at this step.

10. Add 0.3 mL of Amyloglucosidase to each beaker.

11. Cover each beaker with aluminum foil and incubate for 30 minutes at 60°C with continuous agitation.

12. Add 280 mL or 4 volumes of 95% ethanol, preheated to 60°C (measure volume before heating), to each beaker.

13. Let precipitate form at room temperature overnight. Precipitation time should be approximately the same for all samples and blanks.

14. Filtration:

Clean fritted crucible (porosity #2--coarse 40-60 microns) thoroughly, heat one hour at 525°C and cool. Soak and rinse in water. Air dry crucible and add 0.5 g of Celite to each. Wash Celite with 78% Ethanol to remove fines. Dry at 130°C to constant weight (one hour or more). Cool in desiccator and weigh to nearest 0.1 mg. Record this as 'Celite + Crucible Weight.'

Before filtration, wet and redistribute the bed of Celite in each crucible using 78% ethanol. Apply suction to draw Celite onto fritted glass as an even mat. Maintain gentle suction and quantitatively transfer precipitate and suspension from each beaker to its respective crucible.

Wash residue successively with three 20-mL portions of ethanol, two 10-mL portions of 95% ethanol, and then two 10 mL portions of acetone. Time for filtration and washing vary from 15 to 40 minutes, averaging 20 minutes per crucible.

15. Dry crucibles containing residues overnight in a 105°C air oven.

16. Cool all crucibles in desiccator, weigh to nearest 0.1 mg, and record this weight as 'Residue + Celite + Crucible Weight'.

Residue Weight = (Residue + Celite + Crucible Weight)
- (Celite + Crucible Weight)

17. Ash residue from 1 sample of set of duplicates in the crucibles at 525°C overnight.

18. Analyze second residue sample of duplicate for protein by the AOAC method 47.021-47.023. Using N x 6.25 as conversion factor.

Calculations

$$\text{BLANK} = \text{Ave. W. of Blank Residues(mg)} - \left\{\left[\frac{\text{Ave. \% Pro. in Blank Residues} + \text{Ave. \%Ash in Blank Residue}}{100}\right] \times \text{Ave. W. of Blank Residues(mg)}\right\}$$

$$\text{TOTAL DIETARY FIBER} = \frac{\text{Ave.W. samp. Resi.(mg)} - \left\{\left[\frac{\text{Ave.\% Pro. in Samp.Resi.} + \text{Ave. \% ash in Samp.Resi.}}{100}\right] \times \text{Ave. W. of Samp. Resi.(mg)}\right\} - \text{BLANK}}{\text{Ave. Weight of Sample (mg)}} \times 100$$

Part V. Determination Of Calcium In Potato Tubers

Calcium content was determined by atomic absorption spectrophotometry. The powder freeze-dried samples were analyzed as follows:

1. Weigh 2 g freeze-dried potato.
2. Ash at 525°C overnight. Take temperature up slowly or it will "explode".
3. Add 3 mL of 3N HCl, heat gently and transfer to 25 mL volumetric by filtering through glass wool.
4. Analyze by using Atomic Absorption. Used Perkin Elmer 2380, Norwalk, CT. with a Ca++-Mg++ lamp and a single slot burner.
5. Calculations:

   mg/sample = (sample O.D./5 ppm O.D.)(5ug/mL/1000ug/mg)(25mL)

Table 7. Detail data for replications of treatments in timing of stress in potatoes.

| Variety | Position | Test | Treatment | Replication | Total Solids(%) | Reducing Sugars (%) | Total Dietary Fiber(%) | Calcium (ug/g) | Nitrogen (%) |
|---|---|---|---|---|---|---|---|---|---|
| Russet Burbank | Basal | 6/23/88 | 1 | 1 | 14.09 | 0.99 | | | |
| | | | | 2 | 13.79 | 1.62 | | | |
| | | | | 3 | 13.74 | 3.60 | | | |
| | | | | 4 | 14.22 | 0.99 | | | |
| | | | Mean | | 13.96 | 1.80 | | | |
| | | | Standard Dev. | | 0.23 | 1.24 | | | |
| Russet Burbank | Basal | 6/23/88 | 2 | 1 | 14.90 | 1.45 | | | |
| | | | | 2 | 13.81 | 2.20 | | | |
| | | | | 3 | 14.37 | 4.76 | | | |
| | | | | 4 | 15.36 | 0.74 | | | |
| | | | Mean | | 14.61 | 2.29 | | | |
| | | | Standard Dev. | | 0.67 | 1.75 | | | |
| A082260-8 | Basal | 6/23/88 | 1 | 1 | 13.57 | 2.94 | | | |
| | | | | 2 | 14.56 | 1.59 | | | |
| | | | | 3 | 14.44 | 2.13 | | | |
| | | | | 4 | 15.08 | 1.37 | | | |
| | | | Mean | | 14.41 | 2.01 | | | |
| | | | Standard Dev. | | 0.63 | 0.70 | | | |
| A082260-8 | Basal | 6/23/88 | 2 | 1 | 15.22 | 1.11 | | | |
| | | | | 2 | 14.88 | 2.32 | | | |
| | | | | 3 | 15.15 | 1.59 | | | |
| | | | | 4 | 15.35 | 1.33 | | | |
| | | | Mean | | 15.15 | 1.59 | | | |
| | | | Standard Dev. | | 0.20 | 0.53 | | | |
| Russet Burbank | Basal | 7/07/88 | 1 | 1 | 12.34 | 1.60 | | | |
| | | | | 2 | 12.68 | 1.91 | | | |
| | | | | 3 | 14.81 | 0.42 | | | |
| | | | | 4 | 15.23 | 0.38 | | | |
| | | | Mean | | 13.76 | 1.08 | | | |
| | | | Standard Dev. | | 1.46 | 0.79 | | | |
| Russet Burbank | Basal | 7/07/88 | 2 | 1 | 13.42 | 0.43 | | | |
| | | | | 2 | 15.28 | 0.29 | | | |
| | | | | 3 | 14.36 | 0.32 | | | |
| | | | | 4 | 12.93 | 0.40 | | | |
| | | | Mean | | 14.00 | 0.36 | | | |
| | | | Standard Dev. | | 1.04 | 0.06 | | | |

| Variety | Position | Test | Treatment | Replication | Total Solids(%) | Reducing Sugars(%) | Total Dietary Fiber(%) | Calcium (ug/g) | Nitrogen (%) |
|---|---|---|---|---|---|---|---|---|---|
| A082260-8 | Basal | 7/07/88 | 1 | 1 | 14.37 | 0.82 | | | |
| | | | | 2 | 15.03 | 1.08 | | | |
| | | | | 3 | 14.82 | 1.06 | | | |
| | | | | 4 | 16.23 | 0.52 | | | |
| | | | Mean | | 15.11 | 0.87 | | | |
| | | | Standard Oev. | | 0.80 | 0.26 | | | |
| A082260-8 | Basal | 7/07/88 | 2 | 1 | 15.31 | 0.37 | | | |
| | | | | 2 | 14.21 | 0.71 | | | |
| | | | | 3 | 15.32 | 0.61 | | | |
| | | | | 4 | 14.88 | 0.38 | | | |
| | | | Mean | | 14.93 | 0.52 | | | |
| | | | Standard Oev. | | 0.52 | 0.17 | | | |
| Russet Burbank | Basal | 7/21/88 | 1 | 1 | 15.75 | 0.38 | | | |
| | | | | 2 | 13.13 | 0.58 | | | |
| | | | | 3 | 15.28 | 0.33 | | | |
| | | | | 4 | 14.96 | 0.33 | | | |
| | | | Mean | | 14.78 | 0.40 | | | |
| | | | Standard Oev. | | 1.14 | 0.12 | | | |
| Russet Burbank | Basal | 7/21/88 | 2 | 1 | 14.32 | 0.29 | | | |
| | | | | 2 | 12.73 | 0.47 | | | |
| | | | | 3 | 14.28 | 0.33 | | | |
| | | | | 4 | 13.78 | 0.36 | | | |
| | | | Mean | | 13.78 | 0.36 | | | |
| | | | Standard Oev. | | 0.74 | 0.08 | | | |
| A082260-8 | Basal | 7/21/88 | 1 | 1 | 17.15 | 0.54 | | | |
| | | | | 2 | 18.58 | 0.26 | | | |
| | | | | 3 | 16.23 | 0.24 | | | |
| | | | | 4 | 15.02 | 0.34 | | | |
| | | | Mean | | 16.74 | 0.34 | | | |
| | | | Standard Oev. | | 1.50 | 0.14 | | | |
| A082260-8 | Basal | 7/21/88 | 2 | 1 | 16.30 | 0.30 | | | |
| | | | | 2 | 15.52 | 0.38 | | | |
| | | | | 3 | 15.76 | 0.40 | | | |
| | | | | 4 | 18.40 | 0.26 | | | |
| | | | Mean | | 16.49 | 0.34 | | | |
| | | | Standard Oev. | | 1.31 | 0.07 | | | |
| Russet Burbank | Basal | 8/03/88 | 1 | 1 | 8.51 | 0.28 | 7.87 | 2509.28 | |
| | | | | 2 | 9.80 | 0.22 | 7.07 | 2248.82 | |
| | | | | 3 | 13.82 | 0.23 | 6.36 | 1928.64 | |
| | | | | 4 | 7.06 | 0.16 | 6.98 | 2308.55 | |
| | | | Mean | | 9.80 | 0.22 | 7.07 | 2248.82 | |
| | | | Standard Oev. | | 2.91 | 0.05 | 0.62 | 240.78 | |

| Variety | Position | Test | Treat-ment | Repli-cation | Total Solids(%) | Reducing Sugars(%) | Total Dietary Fiber(%) | Calcium (ug/g) | Nitrogen (%) |
|---|---|---|---|---|---|---|---|---|---|
| Russet Burbank | Basal | 8/03/88 | 3 | 1 | 19.28 | 0.51 | 6.19 | 1341.94 | |
| | | | | 2 | 8.97 | 0.29 | 7.13 | 2306.68 | |
| | | | | 3 | 7.39 | 0.26 | 7.18 | 1838.18 | |
| | | | | 4 | 8.12 | 0.13 | 6.18 | 2012.88 | |
| | | | Mean | | 10.94 | 0.30 | 6.67 | 1874.92 | |
| | | | Standard Dev. | | 5.59 | 0.16 | 0.56 | 404.50 | |
| A082260-8 | Basal | 8/03/88 | 1 | 1 | 14.54 | 0.17 | 6.51 | 1541.00 | |
| | | | | 2 | 18.30 | 0.24 | 4.93 | 1445.39 | |
| | | | | 3 | 14.67 | 0.22 | 5.76 | 1567.05 | |
| | | | | 4 | 13.62 | 0.14 | 5.91 | 1072.94 | |
| | | | Mean | | 15.28 | 0.20 | 5.78 | 1406.59 | |
| | | | Standard Dev. | | 2.06 | 0.04 | 0.65 | 228.50 | |
| A082260-8 | Basal | 8/03/88 | 3 | 1 | 17.77 | 0.21 | 5.63 | 1039.09 | |
| | | | | 2 | 11.12 | 0.28 | 6.54 | 1886.62 | |
| | | | | 3 | 13.86 | 0.25 | 6.80 | 1215.76 | |
| | | | | 4 | 10.87 | 0.09 | 4.98 | 973.68 | |
| | | | Mean | | 13.41 | 0.21 | 5.99 | 1278.79 | |
| | | | Standard Dev. | | 3.21 | 0.08 | 0.84 | 417.92 | |
| Russet Burbank | Basal | 8/16/88 | 1 | 1 | 16.85 | 0.49 | 6.66 | 4080.82 | |
| | | | | 2 | 13.45 | 0.53 | 7.75 | 4164.88 | |
| | | | | 3 | 18.75 | 0.16 | 7.01 | 1632.03 | |
| | | | | 4 | 18.11 | 0.38 | 6.50 | 4262.67 | |
| | | | Mean | | 16.79 | 0.39 | 6.98 | 3535.10 | |
| | | | Standard Dev. | | 2.36 | 0.16 | 0.56 | 1270.89 | |
| Russet Burbank | Basal | 8/16/88 | 3 | 1 | 17.00 | 0.24 | 6.77 | 2948.28 | |
| | | | | 2 | 18.32 | 0.26 | 6.67 | 3712.64 | |
| | | | | 3 | 15.29 | 0.34 | 7.35 | 4956.86 | |
| | | | | 4 | 12.53 | 0.22 | 7.89 | 1681.69 | |
| | | | Mean | | 15.79 | 0.27 | 7.17 | 3324.87 | |
| | | | Standard Dev. | | 2.50 | 0.06 | 0.57 | 1373.03 | |
| A082260-8 | Basal | 8/16/88 | 1 | 1 | 20.47 | 0.13 | 6.36 | 2483.85 | |
| | | | | 2 | 23.68 | 0.13 | 5.17 | 4689.66 | |
| | | | | 3 | 18.72 | 0.20 | 7.81 | 323.26 | |
| | | | | 4 | 22.56 | 0.34 | 6.89 | 1254.05 | |
| | | | Mean | | 21.36 | 0.20 | 6.56 | 2187.70 | |
| | | | Standard Dev. | | 2.21 | 0.10 | 1.10 | 1888.15 | |
| A082260-8 | Basal | 8/16/88 | 3 | 1 | 24.52 | 0.19 | 6.08 | 6977.27 | |
| | | | | 2 | 20.43 | 0.19 | 7.20 | | |
| | | | | 3 | 24.80 | 0.18 | 7.82 | 1369.19 | |
| | | | | 4 | 23.89 | 0.10 | 7.19 | 2366.58 | |
| | | | Mean | | 23.41 | 0.16 | 7.07 | 3571.01 | |
| | | | Standard Dev. | | 1.75 | 0.04 | 2.66 | 2991.76 | |

| Variety | Position | Test | Treat-ment | Repli-cation | Total Solids(%) | Reducing Sugars(%) | Total Dietary Fiber(%) | Calcium (ug/g) | Nitrogen (%) |
|---|---|---|---|---|---|---|---|---|---|
| Russet Burbank | Basal | 9/02/88 | 1 | 1 | 18.28 | 1.20 | 7.62 | 3242.19 | 1.19 |
| | | | | 2 | 17.65 | 0.52 | 8.30 | 2711.27 | 1.20 |
| | | | | 3 | 19.62 | 0.79 | 7.66 | 2281.25 | 1.19 |
| | | | | 4 | 16.89 | 2.99 | 8.06 | 3138.91 | 0.91 |
| | | | **Mean** | | **18.11** | **1.38** | **7.91** | **2843.40** | 1.12 |
| | | | Standard Dev. | | 1.16 | 1.11 | 0.33 | 439.63 | 0.14 |
| Russet Burbank | Basal | 9/02/88 | 3 | 1 | 17.84 | 1.34 | 7.41 | 3105.33 | 1.39 |
| | | | | 2 | 20.70 | 0.36 | 7.00 | 1053.57 | 1.46 |
| | | | | 3 | 17.68 | 0.61 | 7.70 | 3449.28 | 1.33 |
| | | | | 4 | 19.43 | 0.44 | 7.10 | 2611.57 | 1.04 |
| | | | **Mean** | | **18.91** | **0.69** | **7.30** | 2554.94 | **1.30** |
| | | | Standard Dev. | | 1.43 | 0.44 | 0.32 | 1058.32 | 0.18 |
| A082260-8 | Basal | 9/02/88 | 1 | 1 | 22.39 | 0.13 | 7.35 | 2237.29 | 1.06 |
| | | | | 2 | 23.03 | 0.10 | 7.83 | 2643.44 | 1.14 |
| | | | | 3 | 20.00 | 0.14 | 7.78 | 2322.80 | 1.13 |
| | | | | 4 | 20.63 | 0.10 | 6.90 | 1701.41 | 1.06 |
| | | | **Mean** | | **21.51** | **0.12** | **7.46** | 2226.23 | **1.10** |
| | | | Standard Dev. | | 1.43 | 0.02 | 0.43 | 391.13 | 0.04 |
| A082260-8 | Basal | 9/02/88 | 3 | 1 | 23.40 | 0.13 | 6.67 | 2490.91 | 1.13 |
| | | | | 2 | 20.12 | 0.15 | 6.65 | 2272.55 | 1.24 |
| | | | | 3 | 24.16 | 0.13 | 6.53 | 2874.15 | 1.15 |
| | | | | 4 | 21.21 | 0.13 | 7.58 | 2273.21 | 1.14 |
| | | | **Mean** | | **22.22** | **0.14** | **6.86** | **2477.71** | **1.16** |
| | | | Standard Dev. | | 1.88 | 0.01 | 0.48 | 283.58 | 0.05 |
| Russet Burbank | Center | 6/23/88 | 1 | 1 | 12.24 | 0.97 | | | |
| | | | | 2 | 11.51 | 1.72 | | | |
| | | | | 3 | 11.42 | 1.83 | | | |
| | | | | 4 | 11.74 | 1.49 | | | |
| | | | **Mean** | | **11.73** | **1.50** | | | |
| | | | Standard Dev. | | 0.36 | 0.38 | | | |
| Russet Burbank | Center | 6/23/88 | 2 | 1 | 11.89 | 2.46 | | | |
| | | | | 2 | 11.95 | 2.01 | | | |
| | | | | 3 | 11.62 | 1.45 | | | |
| | | | | 4 | 11.98 | 1.24 | | | |
| | | | **Mean** | | **11.86** | **1.79** | | | |
| | | | Standard Dev. | | 0.16 | 0.55 | | | |
| A082260-8 | Center | 6/23/88 | 1 | 1 | 11.36 | 1.37 | | | |
| | | | | 2 | 12.06 | 1.19 | | | |
| | | | | 3 | 11.78 | 2.26 | | | |
| | | | | 4 | 12.52 | 1.16 | | | |
| | | | **Mean** | | **11.93** | **1.50** | | | |
| | | | Standard Dev. | | 0.48 | 0.52 | | | |

| Variety | Position | Test | Treatment | Replication | Total Solids(%) | Reducing Sugars(%) | Total Dietary Fiber(%) | Calcium (ug/g) | Nitrogen (%) |
|---|---|---|---|---|---|---|---|---|---|
| A082260-8 | Center | 6/23/88 | 2 | 1 | 12.42 | 1.07 | | | |
| | | | | 2 | 11.96 | 3.11 | | | |
| | | | | 3 | 12.58 | 2.55 | | | |
| | | | | 4 | 12.60 | 0.94 | | | |
| | | | | **Mean** | 12.39 | 1.92 | | | |
| | | | | Standard Dev. | 0.30 | 1.08 | | | |
| Russet 8urbank | Center | 7/07/88 | 1 | 1 | 10.82 | 1.19 | | | |
| | | | | 2 | 11.61 | 1.47 | | | |
| | | | | 3 | 12.47 | 0.87 | | | |
| | | | | 4 | 12.45 | 0.44 | | | |
| | | | | **Mean** | 11.84 | 0.99 | | | |
| | | | | Standard Dev. | 0.79 | 0.44 | | | |
| Russet 8urbank | Center | 7/07/88 | 2 | 1 | 12.25 | 0.43 | | | |
| | | | | 2 | 13.35 | 0.47 | | | |
| | | | | 3 | 12.42 | 0.41 | | | |
| | | | | 4 | 11.01 | 0.52 | | | |
| | | | | **Mean** | 12.26 | 0.46 | | | |
| | | | | Standard Dev. | 0.96 | 0.05 | | | |
| A082260-8 | Center | 7/07/88 | 1 | 1 | 13.78 | 0.59 | | | |
| | | | | 2 | 12.00 | 0.66 | | | |
| | | | | 3 | 10.52 | 0.52 | | | |
| | | | | 4 | 12.56 | 0.42 | | | |
| | | | | **Mean** | 12.22 | 0.55 | | | |
| | | | | Standard Dev. | 1.35 | 0.10 | | | |
| A082260-8 | Center | 7/07/88 | 2 | 1 | 13.07 | 0.37 | | | |
| | | | | 2 | 12.91 | 0.42 | | | |
| | | | | 3 | 12.61 | 0.33 | | | |
| | | | | 4 | 11.92 | 0.45 | | | |
| | | | | **Mean** | 12.63 | 0.39 | | | |
| | | | | Standard Dev. | 0.51 | 0.05 | | | |
| Russet 8urbank | Center | 7/21/88 | 1 | 1 | 13.98 | 0.44 | | | |
| | | | | 2 | 12.90 | 0.71 | | | |
| | | | | 3 | 14.26 | 0.48 | | | |
| | | | | 4 | 14.13 | 0.50 | | | |
| | | | | **Mean** | 13.82 | 0.53 | | | |
| | | | | Standard Dev. | 0.62 | 0.12 | | | |
| Russet 8urbank | Center | 7/21/88 | 2 | 1 | 12.91 | 0.34 | | | |
| | | | | 2 | 12.86 | 0.88 | | | |
| | | | | 3 | 13.31 | 0.38 | | | |
| | | | | 4 | 13.47 | 0.76 | | | |
| | | | | **Mean** | 13.13 | 0.59 | | | |
| | | | | Standard Dev. | 0.30 | 0.27 | | | |

| Variety | Position | Test | Treatment | Replication | Total Solids(%) | Reducing Sugars(%) | Total Dietary Fiber(%) | Calcium (ug/g) | Nitrogen (%) |
|---|---|---|---|---|---|---|---|---|---|
| A082260-8 | Center | 7/21/88 | 1 | 1 | 12.92 | 0.33 | | | |
| | | | | 2 | 13.30 | 0.34 | | | |
| | | | | 3 | 13.14 | 0.28 | | | |
| | | | | 4 | 12.06 | 0.36 | | | |
| | | | Mean | | 12.85 | 0.33 | | | |
| | | | Standard Dev. | | 0.55 | 0.03 | | | |
| A082260-8 | Center | 7/21/88 | 2 | 1 | 13.09 | 0.28 | | | |
| | | | | 2 | 12.16 | 0.46 | | | |
| | | | | 3 | 12.51 | 0.35 | | | |
| | | | | 4 | 13.90 | 0.34 | | | |
| | | | Mean | | 12.92 | 0.36 | | | |
| | | | Standard Dev. | | 0.76 | 0.08 | | | |
| Russet Burbank | Center | 8/03/88 | 1 | 1 | 17.42 | 0.22 | 6.84 | 635.76 | |
| | | | | 2 | 10.64 | 0.32 | 7.32 | 988.36 | |
| | | | | 3 | 10.16 | 0.30 | 7.15 | 933.25 | |
| | | | | 4 | 12.74 | 0.28 | 7.10 | 852.46 | |
| | | | Mean | | 12.74 | 0.28 | 7.10 | 852.46 | |
| | | | Standard Dev. | | 3.31 | 0.05 | 0.20 | 154.87 | |
| Russet Burbank | Center | 8/03/88 | 3 | 1 | 8.22 | 0.24 | 7.27 | 1149.68 | |
| | | | | 2 | 12.36 | 0.28 | 5.84 | 730.00 | |
| | | | | 3 | 8.10 | 0.27 | 6.79 | 1100.89 | |
| | | | | 4 | 11.80 | 0.12 | 5.44 | 732.00 | |
| | | | Mean | | 10.12 | 0.23 | 6.34 | 928.14 | |
| | | | Standard Oev. | | 2.27 | 0.07 | 0.84 | 228.51 | |
| A082260-8 | Center | 8/03/88 | 1 | 1 | 7.85 | 0.24 | 7.21 | 545.19 | |
| | | | | 2 | 11.28 | 0.28 | 7.38 | 751.69 | |
| | | | | 3 | 11.63 | 0.27 | 6.48 | 703.82 | |
| | | | | 4 | 10.37 | 0.69 | 5.75 | | |
| | | | Mean | | 10.28 | 0.37 | 6.70 | 666.90 | |
| | | | Standard Oev. | | 1.71 | 0.21 | 0.74 | 108.08 | |
| A082260-8 | Center | 8/03/88 | 3 | 1 | 12.57 | 0.24 | 6.68 | 442.42 | |
| | | | | 2 | 6.06 | 0.29 | 6.35 | 811.22 | |
| | | | | 3 | 10.09 | 0.44 | 6.07 | 621.34 | |
| | | | | 4 | 7.23 | 0.12 | 6.52 | 716.24 | |
| | | | Mean | | 8.99 | 0.27 | 6.41 | 647.81 | |
| | | | Standard Oev. | | 2.93 | 0.13 | 0.26 | 157.34 | |
| Russet Burbank | Center | 8/16/88 | 1 | 1 | 13.03 | 0.16 | 5.93 | 531.94 | |
| | | | | 2 | 12.62 | 0.14 | 5.88 | 948.80 | |
| | | | | 3 | 16.42 | 0.18 | 5.63 | 215.37 | |
| | | | | 4 | 16.23 | 0.37 | 5.27 | 1453.34 | |
| | | | Mean | | 14.57 | 0.21 | 5.68 | 787.36 | |
| | | | Standard Dev. | | 2.03 | 0.11 | 0.30 | 536.05 | |

| Variety | Position | Test | Treat-ment | Repli-cation | Total Solids(%) | Reducing Sugars(%) | Total Dietary Fiber(%) | Calcium (ug/g) | Nitrogen (%) |
|---|---|---|---|---|---|---|---|---|---|
| Russet Burbank | Center | 8/16/88 | 3 | 1 | 17.25 | 0.17 | 5.49 | 967.74 | |
| | | | | 2 | 13.01 | 0.20 | 6.43 | 629.35 | |
| | | | | 3 | 15.08 | 0.23 | 6.99 | 949.75 | |
| | | | | 4 | 11.27 | 0.11 | 6.62 | 391.81 | |
| | | | Mean | | 14.15 | 0.18 | 6.38 | 734.66 | |
| | | | Standard Dev. | | 2.59 | 0.05 | 0.64 | 276.42 | |
| A082260-8 | Center | 8/16/88 | 1 | 1 | 11.73 | 0.16 | 7.26 | 674.23 | |
| | | | | 2 | 8.98 | 0.15 | 6.33 | 696.79 | |
| | | | | 3 | 7.74 | 0.22 | 7.35 | 531.43 | |
| | | | | 4 | 13.63 | 0.35 | 7.01 | 618.28 | |
| | | | Mean | | 10.45 | 0.22 | 6.99 | 630.18 | |
| | | | Standard Dev. | | 2.56 | 0.93 | 0.46 | 73.64 | |
| A082260-8 | Center | 8/16/88 | 3 | 1 | 15.60 | 0.23 | 6.15 | 1041.38 | |
| | | | | 2 | 10.95 | 0.22 | 6.82 | 641.94 | |
| | | | | 3 | 8.96 | 0.19 | 6.86 | 1031.71 | |
| | | | | 4 | 8.41 | 0.13 | 7.43 | 682.68 | |
| | | | Mean | | 10.98 | 0.19 | 6.81 | 849.43 | |
| | | | Standard Dev. | | 3.27 | 0.04 | 0.52 | 216.74 | |
| Russet Burbank | Center | 9/02/88 | 1 | 1 | 17.88 | 0.15 | 5.71 | 720.93 | 1.74 |
| | | | | 2 | 16.68 | 0.11 | 6.72 | 920.86 | 1.20 |
| | | | | 3 | 19.38 | 0.09 | 6.88 | 831.93 | 1.81 |
| | | | | 4 | 18.40 | 0.11 | 5.60 | 803.42 | 1.54 |
| | | | Mean | | 18.08 | 0.12 | 6.23 | 819.28 | 1.57 |
| | | | Standard Dev. | | 1.12 | 0.34 | 0.66 | 82.47 | 0.27 |
| Russet Burbank | Center | 9/02/88 | 3 | 1 | 17.53 | 0.14 | 5.58 | 929.13 | 0.81 |
| | | | | 2 | 11.77 | 0.27 | 5.72 | 2870.48 | 1.85 |
| | | | | 3 | 16.54 | 0.15 | 6.61 | 796.59 | 1.99 |
| | | | | 4 | 19.12 | 0.13 | 5.73 | 758.53 | 1.56 |
| | | | Mean | | 16.24 | 0.17 | 5.91 | 1338.68 | 1.55 |
| | | | Standard Dev. | | 3.16 | 0.06 | 0.47 | 1023.81 | 0.53 |
| A082260-8 | Center | 9/02/88 | 1 | 1 | 15.34 | 0.14 | 6.51 | 575.95 | 2.21 |
| | | | | 2 | 14.79 | 0.10 | 7.53 | 629.14 | 2.10 |
| | | | | 3 | 15.31 | 0.15 | 7.19 | 574.19 | 2.14 |
| | | | | 4 | 9.45 | 0.15 | 6.94 | 562.98 | 2.20 |
| | | | Mean | | 13.72 | 0.13 | 7.04 | 585.56 | 2.16 |
| | | | Standard Dev. | | 2.86 | 0.02 | 0.43 | 29.61 | 0.05 |
| A082260-8 | Center | 9/02/88 | 3 | 1 | 14.84 | 0.13 | 6.63 | 577.64 | 2.31 |
| | | | | 2 | 15.72 | 0.14 | 6.14 | 476.19 | 2.21 |
| | | | | 3 | 15.02 | 0.26 | 7.18 | 717.11 | 2.30 |
| | | | | 4 | 14.67 | 0.15 | 6.64 | 581.69 | 1.89 |
| | | | Mean | | 15.06 | 0.17 | 6.65 | 588.16 | 2.18 |
| | | | Standard Dev. | | 3.88 | 0.06 | 0.42 | 98.86 | 0.20 |

| Variety | Position | Test | Treat-ment | Replication | Total Solids(%) | Reducing Sugars(%) | Total Dietary Fiber(%) | Calcium (ug/g) | Nitrogen (%) |
|---|---|---|---|---|---|---|---|---|---|
| Russet Burbank | Apical | 6/23/88 | 1 | 1 | 13.40 | 1.98 | | | |
| | | | | 2 | 11.79 | 6.66 | | | |
| | | | | 3 | 11.60 | 1.27 | | | |
| | | | | 4 | 11.88 | 4.78 | | | |
| | | | | **Mean** | 12.17 | **3.68** | | | |
| | | | | Standard Dev. | 0.83 | 2.50 | | | |
| Russet Burbank | Apical | 6/23/88 | 2 | 1 | 12.15 | 2.87 | | | |
| | | | | 2 | 12.21 | 6.40 | | | |
| | | | | 3 | 12.08 | 1.35 | | | |
| | | | | 4 | 12.14 | 3.54 | | | |
| | | | | **Mean** | 12.14 | **3.54** | | | |
| | | | | Standard Dev. | 0.05 | 2.12 | | | |
| A082260-8 | Apical | 6/23/88 | 1 | 1 | 12.43 | 3.90 | | | |
| | | | | 2 | 13.12 | 2.60 | | | |
| | | | | 3 | 12.84 | 1.45 | | | |
| | | | | 4 | 13.82 | 3.00 | | | |
| | | | | **Mean** | 13.21 | **2.74** | | | |
| | | | | Standard Dev. | 0.46 | 1.02 | | | |
| A082660-8 | Apical | 6/23/88 | 2 | 1 | 13.43 | 3.04 | | | |
| | | | | 2 | 12.63 | 4.26 | | | |
| | | | | 3 | 13.11 | 2.38 | | | |
| | | | | 4 | 13.68 | 2.24 | | | |
| | | | | **Mean** | 13.08 | **2.98** | | | |
| | | | | Standard Dev. | 0.69 | 0.92 | | | |
| Russet Burbank | Apical | 7/07/88 | 1 | 1 | 11.75 | 4.30 | | | |
| | | | | 2 | 12.05 | 5.27 | | | |
| | | | | 3 | 14.54 | 3.28 | | | |
| | | | | 4 | 14.30 | 1.87 | | | |
| | | | | **Mean** | 13.16 | **3.68** | | | |
| | | | | Standard Dev. | 1.47 | 1.46 | | | |
| Russet Burbank | Apical | 7/07/88 | 2 | 1 | 13.69 | 1.46 | | | |
| | | | | 2 | 15.15 | 0.79 | | | |
| | | | | 3 | 14.18 | 2.62 | | | |
| | | | | 4 | 12.42 | 1.91 | | | |
| | | | | **Mean** | 13.86 | **1.70** | | | |
| | | | | Standard Dev. | 1.14 | 0.77 | | | |
| A082260-8 | Apical | 7/07/88 | 1 | 1 | 12.92 | 1.67 | | | |
| | | | | 2 | 13.30 | 1.00 | | | |
| | | | | 3 | 13.54 | 1.38 | | | |
| | | | | 4 | 15.28 | 0.76 | | | |
| | | | | **Mean** | 13.76 | **1.20** | | | |
| | | | | Standard Dev. | 1.04 | 0.40 | | | |

| Variety | Position | Test | Treatment | Replication | Total Solids(%) | Reducing Sugars(%) | Total Dietary Fiber(%) | Calcium (ug/g) | Nitrogen (%) |
|---|---|---|---|---|---|---|---|---|---|
| A082620-8 | Apical | 7/07/88 | 2 | 1 | 14.64 | 0.56 | | | |
| | | | | 2 | 13.90 | 0.76 | | | |
| | | | | 3 | 16.34 | 0.41 | | | |
| | | | | 4 | 13.44 | 0.44 | | | |
| | | | | Mean | 14.58 | 0.54 | | | |
| | | | | Standard Oev. | 1.28 | 0.16 | | | |
| Russet Burbank | Apical | 7/21/88 | 1 | 1 | 15.06 | 2.20 | | | |
| | | | | 2 | 13.47 | 2.08 | | | |
| | | | | 3 | 14.78 | 1.46 | | | |
| | | | | 4 | 15.82 | 1.19 | | | |
| | | | | Mean | 14.78 | 1.73 | | | |
| | | | | Standard Oev. | 0.98 | 0.48 | | | |
| Russet Burbank | Apical | 7/21/88 | 2 | 1 | 12.82 | 3.10 | | | |
| | | | | 2 | 11.33 | 3.86 | | | |
| | | | | 3 | 14.11 | 2.92 | | | |
| | | | | 4 | 15.28 | 0.42 | | | |
| | | | | Mean | 13.38 | 2.58 | | | |
| | | | | Standard Oev. | 1.70 | 1.49 | | | |
| A082260-8 | Apical | 7/21/88 | 1 | 1 | 16.40 | 0.52 | | | |
| | | | | 2 | 16.41 | 0.87 | | | |
| | | | | 3 | 16.60 | 0.32 | | | |
| | | | | 4 | 14.41 | 0.82 | | | |
| | | | | Mean | 15.95 | 0.63 | | | |
| | | | | Standard Oev. | 1.03 | 0.26 | | | |
| A082260-8 | Apical | 7/21/88 | 2 | 1 | 15.16 | 0.89 | | | |
| | | | | 2 | 13.70 | 1.83 | | | |
| | | | | 3 | 15.38 | 1.35 | | | |
| | | | | 4 | 18.34 | 0.45 | | | |
| | | | | Mean | 15.65 | 1.13 | | | |
| | | | | Standard Oev. | 1.94 | 0.59 | | | |
| Russet Burbank | Apical | 8/03/88 | 1 | 1 | 12.97 | 0.43 | 5.56 | 1015.50 | |
| | | | | 2 | 12.73 | 0.86 | 5.69 | 890.44 | |
| | | | | 3 | 15.88 | 0.26 | 5.38 | 1087.33 | |
| | | | | 4 | 10.30 | 0.17 | 5.61 | 1068.72 | |
| | | | | Mean | 12.97 | 0.43 | 5.56 | 1015.50 | |
| | | | | Standard Dev. | 2.29 | 0.30 | 0.13 | 88.75 | |
| Russet Burbank | Apical | 8/03/88 | 3 | 1 | 14.27 | 0.19 | 5.51 | 1705.75 | |
| | | | | 2 | 14.45 | 0.62 | 5.24 | 821.54 | |
| | | | | 3 | 9.42 | 0.44 | 5.19 | 1760.16 | |
| | | | | 4 | 11.87 | 0.12 | 6.08 | 1377.38 | |
| | | | | Mean | 12.50 | 0.34 | 5.50 | 1416.21 | |
| | | | | Standard Oev. | 2.37 | 0.23 | 0.41 | 431.00 | |

| Variety | Position | Test | Treatment | Replication | Total Solids(%) | Reducing Sugars(%) | Total Dietary Fiber(%) | Calcium (ug/g) | Nitrogen (%) |
|---|---|---|---|---|---|---|---|---|---|
| A082260-8 | Apical | 8/03/88 | 1 | 1 | 19.06 | 0.19 | 4.47 | 1222.47 | |
| | | | | 2 | 8.64 | 0.32 | 6.15 | 1637.87 | |
| | | | | 3 | 18.96 | 0.24 | 4.80 | 939.63 | |
| | | | | 4 | 14.64 | 0.14 | 5.36 | 781.53 | |
| | | | Mean | | 15.32 | 0.22 | 5.19 | 1145.37 | |
| | | | Standard Oev. | | 4.91 | 0.08 | 0.74 | 375.59 | |
| A082260-8 | Apical | 8/03/88 | 3 | 1 | 18.89 | 0.22 | 4.84 | 1386.81 | |
| | | | | 2 | 17.49 | 0.26 | 5.08 | 1355.85 | |
| | | | | 3 | 12.88 | 0.27 | 5.24 | 1208.90 | |
| | | | | 4 | 13.18 | 0.13 | 4.75 | 1353.02 | |
| | | | Mean | | 15.61 | 0.22 | 4.98 | 1326.14 | |
| | | | Standard Oev. | | 3.04 | 0.06 | 0.22 | 79.65 | |
| Russet Burbank | Apical | 8/16/88 | 1 | 1 | 18.39 | 0.90 | 5.56 | 2184.14 | |
| | | | | 2 | 16.38 | 0.38 | 6.09 | 2372.30 | |
| | | | | 3 | 19.38 | 0.39 | 5.88 | 1374.30 | |
| | | | | 4 | 18.92 | 0.56 | 5.23 | 1071.40 | |
| | | | Mean | | 18.27 | 0.56 | 5.69 | 1750.54 | |
| | | | Standard Oev. | | 1.32 | 0.24 | 0.38 | 626.47 | |
| Russet Burbank. | Apical | 8/16/88 | 3 | 1 | 21.44 | 0.18 | 5.50 | 1930.23 | |
| | | | | 2 | 17.29 | 0.48 | 6.25 | 3624.53 | |
| | | | | 3 | 18.34 | 0.40 | 6.33 | 1777.78 | |
| | | | | 4 | 15.90 | 0.25 | 7.14 | 1738.09 | |
| | | | Mean | | 18.24 | 0.32 | 6.31 | 2267.66 | |
| | | | Standard Oev. | | 2.36 | 0.14 | 0.67 | 908.37 | |
| A082260-8 | Apical | 8/16/88 | 1 | 1 | 19.40 | 0.14 | 6.40 | 1854.67 | |
| | | | | 2 | 22.32 | 0.14 | 5.59 | 1351.66 | |
| | | | | 3 | 15.18 | 0.20 | 7.59 | 1017.52 | |
| | | | | 4 | 20.81 | 0.42 | 6.81 | 989.53 | |
| | | | Mean | | 19.43 | 0.23 | 6.60 | 1303.35 | |
| | | | Standard Oev. | | 3.07 | 0.13 | 0.83 | 402.69 | |
| A082260-8 | Apical | 8/16/88 | 3 | 1 | 21.81 | 0.26 | 5.37 | 1524.32 | |
| | | | | 2 | 17.33 | 0.34 | 7.34 | 2220.40 | |
| | | | | 3 | 16.78 | 0.18 | 8.18 | 2125.52 | |
| | | | | 4 | 23.10 | 0.14 | 6.37 | 1656.49 | |
| | | | Mean | | 19.76 | 0.23 | 6.82 | 1881.68 | |
| | | | Standard Oev. | | 3.17 | 0.09 | 1.22 | 342.84 | |
| Russet Burbank | Apical | 9/02/88 | 1 | 1 | 21.88 | 0.24 | 5.61 | 1818.79 | 1.26 |
| | | | | 2 | 19.96 | 0.19 | 6.71 | 2098.59 | 1.22 |
| | | | | 3 | 21.80 | 0.11 | 6.19 | 1554.48 | 1.22 |
| | | | | 4 | 22.58 | 0.13 | 8.65 | 1345.07 | 1.26 |
| | | | Mean | | 21.55 | 0.17 | 6.79 | 1704.23 | 1.24 |
| | | | Standard Oev. | | 1.12 | 0.06 | 1.32 | 326.63 | 0.02 |

| Variety | Position | Test | Treat-ment | Repli-cation | Total Solids(%) | Reducing Sugars(%) | Total Dietary Fiber(%) | Calcium (ug/g) | Nitrogen (%) |
|---|---|---|---|---|---|---|---|---|---|
| Russet Burbank | Apical | 9/02/88 | 3 | 1 | 21.46 | 0.15 | 5.50 | 1673.32 | 1.29 |
| | | | | 2 | 20.09 | 0.49 | 6.25 | 2714.29 | 1.41 |
| | | | | 3 | 20.89 | 0.23 | 6.63 | 1781.02 | 1.29 |
| | | | | 4 | 21.10 | 0.20 | 5.94 | 1319.73 | 1.04 |
| | | | **Mean** | | **20.88** | **0.27** | 6.08 | **1872.09** | **1.26** |
| | | | Standard Oev. | | 0.58 | 0.15 | 0.48 | 595.04 | 0.16 |
| A082260-8 | Apical | 9/02/88 | 1 | 1 | 23.19 | 0.15 | 5.78 | 1295.77 | 1.19 |
| | | | | 2 | 22.76 | 0.11 | 6.51 | 1756.10 | 1.20 |
| | | | | 3 | 23.46 | 0.10 | 6.57 | 1477.27 | 1.18 |
| | | | | 4 | 23.78 | 0.16 | 6.22 | 985.40 | 1.13 |
| | | | **Mean** | | **23.30** | **0.13** | **6.27** | **1378.64** | **1.18** |
| | | | Standard Oev. | | 0.43 | 0.03 | 0.36 | 323.37 | 0.03 |
| A082260-8 | Apical | 9/02/88 | 3 | 1 | 22.62 | 0.19 | 5.37 | 1229.17 | 1.23 |
| | | | | 2 | 23.44 | 0.17 | 5.46 | 1051.09 | 1.34 |
| | | | | 3 | 21.28 | 0.19 | 7.65 | 1757.14 | 1.36 |
| | | | | 4 | 17.93 | 0.16 | 6.80 | 1331.85 | 1.24 |
| | | | **Mean** | | **21.32** | **0.18** | **6.32** | **1342.31** | **1.29** |
| | | | Standard Oev. | | 2.43 | 0.02 | 1.01 | 299.89 | 0.07 |

Figure 3. Field designation at Malheur Experimental Station, Ontario, OR.