Evaluation of Yield and Quality of Five Potato Cultivars Grown in Southwest Virginia

by

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Thesis Presented to the Faculty of The Virginia Polytechnic Institute and State University in Partial Fulfillment of the Requirement for the Degree of

Master of Science
in
Horticulture

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October, 1992
Blacksburg, Virginia

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(ABSTRACT)

Potato (Solanum tuberosum L.) cultivars Atlantic, BelRus, Kennebec, Superior, and Yukon Gold, grown at six locations in Southwest Virginia, were analyzed for yield, percent dry weight, specific gravity, soluble protein, and ascorbic acid. Thereafter, tubers were cold stored at 3 C for six weeks, reconditioned at 25 C for two weeks, and analyzed for percent dry weight, specific gravity, soluble protein, and ascorbic acid. Potato grown in one location was analyzed for glucose, fructose, sucrose, and total sugars. Another experiment was conducted to evaluate the effect of seed type and in-row spacing on yield and quality of Yukon Gold.

Cultivar and location influenced yield and quality of potato at harvest, after cold storage, and following reconditioning. Kennebec, Atlantic, and Yukon Gold produced higher yield of US No. 1 tubers than Superior and BelRus. Atlantic and BelRus had higher percent dry weight and specific gravity than the other cultivars. Specific gravity increased during cold storage and following reconditioning. Percent dry weight increased during reconditioning but did not change during cold storage. In all five cultivars,

ascorbic acid content decreased during cold storage and reconditioning, while soluble protein content increased during cold storage and decreased during reconditioning.

At harvest, the concentrations of glucose, sucrose, and total sugars were the same in all cultivars; however, Kennebec had higher fructose than the other cultivars. Concentration of sugars in Yukon Gold and Superior increased during cold storage and decreased during reconditioning; however, in Kennebec, cold storage and reconditioning had no effect on the concentration of sugars except glucose, which increased during cold storage.

Yukon Gold grown from whole seed had higher yield of US No. 1 than those grown from fresh and healed-cut seeds. In-row spacing of 15 cm produced higher yield of small tubers and low soluble protein than 20 and 25 cm. Curing of Yukon Gold tubers resulted in reduced loss of ascorbic acid but had no effect on soluble protein content.

Data indicate that cultivar, location, and storage temperature affected potato quality. Based on the quality factors analyzed, the five potato cultivars were ranked starting with the highest as follows; Superior, Yukon Gold, Atlantic, Kennebec, and BelRus.

Dedication

To my wife Ruphina Nyawade.

Acknowledgements

I am grateful to everyone who contributed to the successful completion of this project. I especially thank my advisor, Dr. Mosbah M. Kushad for his guidance, support, and critical evaluation of this project.

I extend gratitude to Dr. Ronald D. Morse for his support in planning the field operations of this project. I would also like to thank the other committee members, Drs. Richard E. Veilleux, and Russell L. Weiser for their assistance and expertise to this project. I would like especially to thank Mr. Arthur Pfeister for his tireless effort and contributions during the entire field operations of this project. I appreciate the technical assistance from Lucy Taylor and Carol Leda during laboratory analysis. Thanks also go to Mrs. Michelle Marini for her assistance with the statistical analysis.

I am grateful to the head of Horticulture department, Dr. Robert D. Wright, for his words of encouragement and financial support. I would like to thank Joyce Shelton, Marilyn Echols, Donna Long and all the faculty, staff, and graduate students for their help and company. I am grateful to Virginia State Department of Agriculture for purchasing potato seed.

My deep gratitude goes to Ms. Risper Omondi in particular, and our entire extended family, for providing excellent care for our children in our absence. Special thanks go to Ms. Jean Bunge, of Jackson, MS, without whom I would not be in graduate school. Her moral and financial support are deeply appreciated. I wish to thank Mrs. Beulah Kline of Blacksburg, VA for her support.

I am grateful to our children, Ogaya and Nyawade, for their patience and understanding. Finally, I am grateful to my wife, Ruphina Nyawade, for her love and support and for typing this thesis.

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Chapter 1. Effect of Cultivar and Location on Potato Yield

Abstract

Five potato cultivars, Atlantic, BelRus, Kennebec, Superior, and Yukon Gold, grown in six locations in Southwest Virginia, were analyzed for percent marketable yield and yield of US No. 1 tubers. Both cultivar and location had significant effect on percent marketable yield and, yield of US No. 1 tubers. Yields were 17.0, 16.7, 16.0, 13.6, and 6.9 metric ton/ha, for Kennebec, Atlantic, Yukon Gold, Superior, and BelRus, respectively. Yukon Gold and Atlantic produced significantly higher percent marketable yield than the other cultivars.

Introduction

Potato (Solanum tuberosum L.) production in Virginia is mainly in the eastern region. The southwestern part of the state is also suitable for potato growth, however, competition from burley tobacco has limited production. Kennebec is the most commonly planted cultivar in southwest Virginia. However, because of its poor chipping quality, the bulk of potato processed by the two factories in the area is obtained from outside the state.

Introducing other cultivars into the region could help farmers to tap into this nearby processing market. In addition, some of the crop could be sold in the fresh market throughout Virginia and in the neighboring states.

In the United States, commercial potato production is dominated by white-fleshed cultivars such as Russet Burbank, Kennebec, Superior, Atlantic, and several other cultivars. Recently, however, yellow-fleshed potato has been introduced in the USA, mainly from Canada (Chase et al., 1989; Coffin et al., 1988a, 1988b; Johnston and Rowberry, 1981; Sorensen, 1992; Young et al., 1988). The most popular among the domestic yellow-fleshed cultivars is Yukon Gold. Yukon Gold was developed through the potato breeding project of the Horticultural Science Department, University of Guelph, Ontario, Canada. It was released for commercial production in 1980 (Johnston and Rowberry, 1981).

Previous research conducted in eastern Virginia and elsewhere established that potato yield and size are affected by cultivar and location (Johnston and Rowberry, 1981; Fontenot et al., 1991; Webb et al., 1978, 1981). This study was conducted to evaluate the effect of cultivar and location on marketable yield and size of Atlantic, BelRus, Kennebec, Superior, and the yellow-fleshed cultivar, Yukon Gold grown in southwest Virginia.

Materials and Methods

Healed-cut seedpieces supplied by Carl Hessler and Son (Rockford, MI) were planted by hand in five locations and by a potato planter in one location. The locations (Appendix 3) had different soils and different altitudes (Appendix 4). Each plot consisted of three 12 m rows. The plants were established at 0.90 m between the rows and 0.20 m within the row. Compound fertilizer 10:20:20 (N:P:K) was used to side dress the plots after four weeks from the time of planting according to the rates listed in Appendix 1.

Weed control was accomplished by pre-emergence application of a mixture of 2.06 l/ha of Dual 8E and 1.68 kg/ha of linex 50 DF. In addition, the plots were sprayed with Asana-XL at 0.56 kg/ha and Bravo 720 at 1.17 l/ha for control of insects and blight, respectively. Other cultural practices were based on recommendations for white potato production in Virginia (Baldwin et al., 1986).

The treatments were arranged in a nested design consisting of four replications. The plots were harvested after 93 to 123 days depending on cultivar and location (Appendix 2) and graded according to USDA standards (USDA, 1991). Data were analyzed by two-way analysis of variance (ANOVA) for nested design according to SAS (1982).

Results

There were significant interaction effects between cultivar and location in yield of US No. 1 tubers and percent marketable yield (Table 1). Yield of US No. 1 tubers (>4.8 cm diam) was significantly influenced by cultivar (Table 1). Total yield of US No. 1 varied from 17.0 metric ton/ha for Kennebec to 6.8 metric ton/ha for BelRus. Kennebec, Atlantic, and Yukon Gold produced higher total yield of US No. 1 than Superior and BelRus. However, percent marketable yield was higher in Yukon Gold and Atlantic than the remaining three cultivars. Percent marketable yield varied between 67% for Yukon Gold to 48% for BelRus (Table 1).

Location also influenced percent marketable yield and yield of US No. 1 grades (Table 2). Hayters Gap 1 and Rich Valley produced higher yield of US No. 1 and higher percent marketable yield than Broadford and Gladesboro. While Mendota location produced very low yield (Table 2).

Discussion

Potato yield differences are caused in part by inherent variation among cultivars (Johnston and Rowberry, 1981; Fontenot et al., 1991; Webb et al., 1978, 1981). This may explain the yield differences observed among Atlantic, Kennebec, Superior, and Yukon Gold as reported in this study. The very low marketable total yield and percent marketable yield of BelRus compared to the other cultivars was possibly caused by its susceptibility to blight. In addition, Webb et al. (1981) reported that BelRus is susceptible to water stress and high temperature. Water stress has been shown to reduce potato yield and tuber size (Miller and Martin, 1987; Mackerron and Jefferies, 1986, 1988; Ojala et al., 1990; Van Loon, 1981).

High temperature also causes severe yield decrease by interfering with tuber initation and expansion (Ewing, 1981; Marinus and Bodlaender, 1975; Mendoza and Estrada, 1979). It was reported that potatoes are adapted to growth and tuberization at 15 to 20 C (Sipos and Prange, 1986). In this study the plots were not irrigated and natural rain was not evenly distributed during the growing season. Atlantic, Kennebec, and Superior are drought tolerant (Bhagsari et al., 1988; Sipos and Prange, 1986). These cultivars produced large tubers and higher yield, suggesting that water stress and high temperatures could have been limiting factors in Yukon Gold and BelRus yield, which are not known for their stress tolerance.

Early blight (Alternaria solani) and late blight (Phytophthora infestans) were controlled effectively in other cultivars but not in BelRus. Susceptibility of BelRus to blight has been reported previously (Webb et al., 1981).

Potato yield and size were also influenced by location. Other researchers (Fontenot, 1991; Webb et al., 1978) reported similar results. Webb et al. (1978) reported total yield of 13.4 and 13.8 metric tons per hectare for Atlantic and Superior, respectively, in eastern Virginia. Yield for Superior, in this study, was similar, to that obtained in eastern Virginia; however, Atlantic produced higher yield in the southwest than in the eastern part of Virginia.

The very low yield in Mendota location could be due to excessive soil compactness and high pH. Previous research showed that potatoes grown in compact soil produced low yield and misshapen tubers (Flocker and Timm, 1960; Timm and Flocker, 1966; Steckel and Gray, 1979). Ideal soil pH for potato production should be between pH 5.2 and pH 5.4 (Beukema and Van Der Zaag, 1990; Smith, 1977). Potatoes grown in soil with high pH (7.8-8.4) produce smaller tubers and low yields (Smith, 1977). As a result, Mendota soil pH of 7.8 could have contributed to the lower yields compared to other locations (pH 5.2-7.4).

In conclusion, Atlantic, Kennebec, Superior, and Yukon Gold are adaptable to southwest Virginia conditions. BelRus, however, should not be grown in the region because of its poor yield. Because of its high demand as a gourmet potato, Yukon Gold can be grown successfully in southwest Virginia.

Table 1. Yield of US No. 1 (metric ton/ha) and percent marketable yield of five potato cultivars.

Cultivar	US No. 1 > 4.8 cm diam	Marketable yield (%)
Atlantic	16.6 a	65 a
BelRus	6.8 c	48 c
Kennebec	17.0 a	55 b
Superior	13.6 b	57 b
Yukon Gold	16.0 a	67 a
	***	***

Mean separation within columns by Duncan's multiple range test at $p = 0.05$; ***, significant at $p = 0.001$.

Table 2. Marketable yield of US No. 1 (metric ton/ha) and percent marketable yield at six locations in southwest Virginia.

Location	US No. 1 > 4.8cm diam	Marketable yield (%)
Broadford	11.8 c	50 c
Gladesboro	16.5 b	55 c
Hayters Gap 1	19.5 a	70 a
Hayters Gap 2	11.2 c	59 bc
Mendota	6.8 d	50 d
Rich Valley	18.4 ab	63 b
	***	***

Mean separation within columns by Duncan's multiple range test at $p = 0.05$; ***, significant at $p = 0.001$.

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Chapter 2. Dry Weight, Specific Gravity, and Sugar Content in Potato at Harvest, During Cold Storage and Reconditioning

Abstract

The potato cultivars, Atlantic, BelRus, Kennebec, Superior, and Yukon Gold, were grown in six locations in southwest Virginia. Tubers from all locations were analyzed at harvest, after cold storage, and following reconditioning for percent dry weight and specific gravity. Tubers from one location were analyzed for glucose, fructose, sucrose, and total sugars. Both cultivar and location affected percent dry wt and specific gravity at the three storage treatments. Specific gravity increased in all five cultivars during cold storage and following reconditioning. Percent dry wt, however, increased only during reconditioning but did not change significantly during cold storage. At harvest, the concentrations of glucose, sucrose, fructose, and total sugars were the same in all cultivars; however, fructose concentration in Kennebec was significantly higher than in the other cultivars. Sugars increased during cold storage and decreased following reconditioning; however, the changes were not significant for all cultivars.

Introduction

Sugar content is one of the most important characteristics which influences quality of processed potato. Sucrose, fructose, and glucose are the major sugars found in potato tubers (Beukema and Van Der Zaag, 1990; Smith, 1977; Van Es and Hartmans, 1987). Potatoes which contain high concentration of sugars, produce dark brown products due to the Maillard reaction, the reaction between sugar and free amino acids (Ehlenfeldt et al, 1990; Iritani and Weller, 1974; Iritani et al., 1976; Mackay et al., 1990. Growing environment and temperatures during cold storage and during reconditioning are among the factors which influence sugar content (Agle and Woodbury, 1968; Kissimeyer and Weckel, 1967). During low temperature storage, sugar content increases in most cultivars (Dogras et al., 1989; Ewing et al., 1981; Isherwood, 1976; Joshi et al., 1990; Orr et al., 1985; Timm et al., 1968). Sugar accumulation during cold storage is usually reduced before processing by reconditioning the tubers for several days at temperatures above 15 C (Iritani and Weller, 1978; Samotus et al., 1974). Potato quality is also determined through estimates of dry matter content by specific gravity (Johnson et al., 1970; Kleinkopf et al., 1987; Mazza, 1983; Santerre et al., 1986; Sayre et al., 1975; Schippers, 1976; Zak and Holt, 1973). Potato cultivars with high specific gravity or dry matter content are preferred for chips and french fries because they accumulate less sugar during cold storage (Johnson et al., 1970; Sayre et al., 1975; Zak and Holt, 1973).

The objectives of this study were to examine the influence of cultivar, location, cold storage, and reconditioning on percent dry weight, specific gravity, and sugar composition in Atlantic, BelRus, Kennebec, Superior, and Yukon Gold grown in southwest Virginia.

Materials and Methods

Five potato cultivars, Atlantic, BelRus, Kennebec, Superior, and Yukon Gold, were grown in six locations in southwest Virginia (Appendix 3). Soil in each location was analyzed for nutrients and pH. The results of soil analysis were used to determine rate of fertilizer application in each plot (Appendix 1). Potato seed was obtained from Carl Hessler and Son (Rockford, Mi). Other cultural practices were based on recommendations for white potato production in Virginia (Baldwin et al., 1986).

The treatments were arranged in a nested design consisting of four replications. Depending on cultivar and location, the plots were harvested after 93 to 123 d from the date of planting (Appendix 2) and graded according to USDA grading standards (USDA, 1991). Potato tubers (4.8-6.4 cm diam) from all locations were used for measuring percent dry wt and specific gravity. Sugars were determined in potatoes grown in one location. A 6 kg sample from each replicate was washed and cured in the dark at 18 C and 90% R.H. for one wk. After curing, the tubers were stored at 3 C and 90% R.H. for six wk and then reconditioned for two wk at 25 C and 90% R.H. The storage experiment was arranged in a randomized complete block design with four replications.

Percent Dry Weight and Specific Gravity

Percent dry wt and specific gravity of tubers were determined at harvest, after cold storage, and following reconditioning. Specific gravity was determined by dividing tuber weight in air by their weight in air minus their weight in water (USDA, 1983). A sub-sample of 5 kg was used from each replication of each cultivar. Percent dry wt was determined by freeze-drying a 100 g sub-sample from 10 tubers from each replication.

Sugar Content

For sugar determination, 2 g of freeze-dried potato tissue was Soxhlet extracted with 80% (v/v) boiling ethanol for 2 h. After filtration, ethanol was removed by vacuum and the residue was dissolved in 10 ml distilled water. The mixture was deionized with 1 g mixed resin AG1 X 8 (OH-) and AG50(H+) (1:1), centrifuged at 8,000 x g for 2 minutes, and then filtered through 0.2 micron filters (Gelman Sciences). A 150 ul aliquot was injected into a Beckman HPLC equipped with a refractive index detector and a carbohydrate column (phenomenex, Torrance, CA) using water as mobile phase at a flow of 0.6 ml/min and 80 C temperature. Data were analyzed by two-way analysis of variance (ANOVA) for nested design and randomized complete block design according to SAS (SAS, 1982).

Results

Percent dry wt and specific gravity of the five cultivars are shown in Table 3. Atlantic and BelRus produced tubers with higher percent dry wt than Superior, Yukon Gold, or Kennebec. After harvest, percent dry wt varied from 23.3% in Atlantic to 19.3% in Kennebec. Percent dry wt of tubers stored at 3 C for 6 wk did not change significantly in any cultivar. During the two wk of reconditioning at 25 C, however, all cultivars showed significant increase in percent dry wt.

Atlantic and BelRus produced tubers with higher specific gravity than Yukon Gold, Superior, or Kennebec (Table 3). During cold storage specific gravity was highest in Atlantic (1.099) and lowest in Kennebec (1.092). When tubers were reconditioned, there was an increase in specific gravity in BelRus, Superior, and Yukon Gold, but not in Atlantic and Kennebec (Table 3).

Location influenced percent dry wt and specific gravity of potato after harvest, during cold storage, and following reconditioning (Table 4). There were significant interaction effects between cultivar and location for both percent dry wt and specific gravity during the three periods (Table 3).

At harvest, there were no significant differences among cultivars in the concentrations of glucose, sucrose, and total sugars (Tables 4 and 5). However, the concentration of fructose varied among the cultivars. Kennebec contained more fructose than Atlantic, BelRus, Superior, or Yukon Gold (Table 4). The average concentrations of glucose, fructose, sucrose, and total sugars among the cultivars were 0.5, 1.6, 2.3, and 4.4 mg/g dry weight, respectively.

The concentration of all sugars increased significantly during cold storage; however, the rate of increase varied among the cultivars. Glucose concentration increased by 6.8-fold in Atlantic and by more than 14-fold in Superior. Similarly, the concentration of fructose also increased during cold storage in all the cultivars (Table 4). Sucrose concentration increased five fold during cold storage in Yukon Gold, three fold in Superior, and by more than two fold in Atlantic. However, the concentration of sucrose did not change significantly in Kennebec and BelRus (Table 5). Total sugars were higher during cold storage in Yukon Gold, Superior, BelRus, and Kennebec (Table 5).

Reconditioning significantly reduced the concentration of sugars in most cultivars. Glucose concentration in reconditioned BelRus, Superior, and Yukon Gold were nearly 50% lower than the cold stored tubers of the same cultivars (Table 4). Reconditioning also reduced the concentration of sucrose in Atlantic, Superior, and Yukon Gold and reduced total sugars in BelRus, Superior, and Yukon Gold (Table 5). In contrast, reconditioning had no influence on fructose concentration, except in Yukon Gold which was 49% less than the cold stored tubers (Table 4).

Discussion

Results of this study show that potato cultivars vary in percent dry wt and specific gravity at the time of harvest. Previous studies reported similar results on percent dry wt (Dogras et al., 1989; Ifenkwe et al., 1974; Cole, 1975; Schippers, 1976; Manrique and Bartholomew, 1991; Van Heemest, 1986) and specific gravity (Agle and Woodbury, 1968; Lana et al., 1970; Ridley and Hogan, 1976).

Tubers of the same size were used in this study in order to limit the effect of size on specific gravity or percent dry weight. It was reported that smaller potato tubers have higher specific gravity and percent dry weight than large tubers (Cole, 1975; Schippers, 1976).

In this study, percent dry weight and specific gravity of potato were also influenced by location . These results are in agreement with work previously reported by others (Agle and Woodbury, 1968; Dogras et al., 1989; Manrique and Barthlomew, 1991; Santerre et al., 1986; Schippers, 1976). Variation in soil type among the locations could have contributed to these differences. Soil type has been shown to influence specific gravity and percent dry weight of potato (Beukema and Van Der Zaag, 1990).

The very low percent dry weight and specific gravity observed in potatoes grown in Gladesboro and Mendota locations could have resulted from low soil moisture and high temperatures experienced during the growing season. Previous reports showed that, during warm weather, potato accumulates dry matter in vegetative tissue instead of the tuber (Ewing; 1981, Khedher and Ewing, 1985; Manrique et al., 1984; Manrique and Barthlomew, 1991).

Isherwood (1976) stated that 60 to 80 percent of the dry matter of potato consists of starch. During cold storage (4 C and below), potato starch degrades into simple sugars (Samotus et al., 1974; Isherwood, 1976) and at high temperatures, these sugars reconvert to starch (Samotus et al., 1974). Therefore, percent dry weight and specific gravity of potato should decrease during prolonged cold storage and increase during reconditioning. Results from this study showed that specific gravity increased during cold storage, while percent dry weight did not change. Decrease in specific gravity of potato during cold storage was reported previously (Dogras et al., 1991; Lana et al., 1970; Ridley and Hogan, 1976). Reconditioning results on percent dry weight and specific gravity were in agreement with previous research (Beale et al., 1966, Verma et al., 1974).

The concentration of total sugars at harvest was far below the 3-4% recommended for mature tubers (Burton and Wilson, 1970; Bredemeijer et al., 1991; Claassen et al., 1991; Richardson et al., 1990a, b; Trevanion and Kruger, 1991). Warm and sunny conditions experienced during harvest could have caused the low sugar accumulation. Such effects of weather on potato sugars were reported by several researchers (Iritani and Weller, 1977; Kissmeyer and Weckel, 1967; Miller et al.,1975; Weaver et al., 1978). In this study, however, only the concentration of fructose varied among cultivars at harvest.

Sugar accumulation in potatoes during cold storage as observed in this study is an established phenomenon (Dogras et al., 1991; Joshi et al., 1990; Richardson et al., 1990a,b; Weaver and Timm 1983). Sugar accumulation during cold storage results from breakdown of starch (Isherwood, 1976; Levitt 1980; Sowokinos et al., 1987) and the inactivation of the glycolytic enzymes (ApRees et al., 1981; ApRees, 1988; Bredemeijer et al., 1991; Brown et al., 1990; Claassen et al., 1991; Dixon and ApRees, 1980; Hammond et al., 1990; Pollock and ApRees, 1975a; Trevanion and Kruger, 1991). The principle sugar formed during low temperature storage is sucrose. However, glucose and fructose also accumulate due to enzymatic hydrolysis of sucrose (Isherwood, 1973; Pollock and ApRees, 1975b).

In this study, however, potatoes accumulated more glucose during cold storage than any other sugar except for Superior which accumulated sucrose.
The change from 1:4.2 ratio of glucose to sucrose at harvest to approximately equal proportions after cold storage at 3 C, supports previously suggested enzymatic involvement of invertase in the hydrolysis of sucrose (Pollock and ApRees, 1975b; Pressey, 1970).

Superior and Yukon Gold, accumulated sucrose during cold storage despite their high glucose and fructose levels. These results are in contrast to an earlier report (Sowokinos et al., 1987) that glucose did not increase to the same level as sucrose. Atlantic and Kennebec accumulated less sugars during cold storage than the remaining three cultivars. During reconditioning, sugar concentrations did not change in these two cultivars. Previous studies on the relationship between sucrose changes and enzymatic activity in Kennebec during cold storage reported increased activity of both sucrose synthetase and sucrose phosphate synthetase even after sugar accumulation was complete (Pressey 1970), which suggests that enzymatic activity and sugar accumulation could be independently controlled in this cultivar. In most cultivars, the increase in sugar content after cold storage diminishes when the tubers are exposed to 25 C. Van Es and Hartmans (1987) reported that during reconditioning 80% of reducing sugars (glucose and fructose) are converted into starch and the remaining 20% is lost in respiration.

Sugar decline during reconditioning is caused by the increased activity of the glycolytic enzymes (phosphofructokinase and pyrophosphate:fructose 6-phosphate phosphotransferase) at high temperatures (Claassen et al., 1991; Trevanion and Kruger, 1991). Since glucose, fructose, sucrose, and total sugars declined during reconditioning in Superior and Yukon Gold, it is possible that reconditioning increased the activity of the glycolytic enzymes, (phosphofructokinase and pyrophosphate: fructose 6-phosphate phosphotransferase) in these cultivars. Reconditioning, however, did not change sugar accumulation in Atlantic, BelRus, and Kennebec. Previous work reported that factors such as change in permeability of amyloplast membrane (Ohad et al., 1971; Workman et al., 1976; Isherwood, 1976) and cellular pH changes (Bredemeijer et al., 1991) also affect sugar metabolism during storage; however, we have not evaluated any of these factors.

Reconditioning for two weeks at 25 C eliminated fructose and sucrose, which accumulated in tubers of Superior and Yukon Gold during cold storage. Previous research reported that only sugars formed during cold storage could be eliminated by reconditioning (Burton and Wilson, 1978; Iritani and Weller, 1978; Isherwood, 1976).

After reconditioning, all the cultivars had sprouted. Increase in hexose sugars coincident with the time of sprouting has been reported by several researchers (Bailey et al., 1978; Davies and Ross, 1987; Davies and Viola, 1988; Edelman and Singh, 1969).

In conclusion, cultivar, location and storage temperature affected potato quality. Specific gravity and percent dry wt can be used to measure potato quality at harvest and during storage. All cultivars produced low sugars at harvest. Yukon Gold, Superior, and BelRus, accumulated total sugars during cold storage and also lost most of it after reconditioning. Kennebec accumulated total sugars during cold storage and did not lose it during reconditioning. Atlantic accumulated the least amount of total sugars during cold storage and retained it during reconditioning.

Table 3. Percent dry wt and specific gravity at harvest, after cold storage, and following reconditioning of five potato cultivars[z].

Cultivar	Harvest	Cold stored	Reconditioned	
	Percent dry weight			
Atlantic	23.3 a B	23.8 a B	25.4 b A	***
BelRus	22.7 ab B	22.6 a B	26.0 b A	***
Kennebec	19.3 c B	20.0 c B	22.4 c A	***
Superior	21.2 b B	21.2 b B	24.8 b A	***
Yukon Gold	22.0 b B	22.2 a B	27.2 a A	***
	***	***	***	
Cultivar x location	***	***	***	
	Specific gravity			
Atlantic	1.097 a B	1.099 a A	1.099 a A	***
BelRus	1.096 a B	1.097 a B	1.100 a A	***
Kennebec	1.083 c B	1.092 c A	1.092 c A	***
Superior	1.091 b C	1.093 c B	1.097 b A	***
Yukon Gold	1.092 b C	1.095 b B	1.100 a A	***
	***	***	***	
Cultivar x location	***	***	***	

Mean separation within columns (lower case letters) and within rows (upper case letters) by Duncan's multiple range test at $p = 0.05$; *** Significant at $p = 0.001$.

[z]Potatoes were cold stored at 3 C for 6 wk period and reconditioned at 25 for 2 wk.

Table 4. Percent dry wt and specific gravity of potato at harvest, after storage, and following reconditioning at six locations in southwest Virginia[z].

Location	Harvest	Cold Stored	Reconditioned	
	-- Percent dry weight --			
Broadford	21.7 ab B	21.9bc B	24.5 b A	***
Gladesboro	20.5 c B	21.3 c A	21.5 c A	**
Hayters Gap 1	22.1 a B	22.4 b B	25.0 a A	***
Hayters Gap 2	22.3 a C	23.6 a B	26.0 a A	***
Mendota	21.2 bc B	21.7 bc B	23.6 b A	***
Rich Valley	22.3 a C	23.5 a B	26.3 a A	***
	***	***	***	
	Specific gravity			
Broadford	1.082 abC	1.095b B	1.098 b A	***
Gladesboro	1.090 b B	1.091c B	1.092 c A	**
Hayters Gap 1	1.093 a C	1.095b B	1.098 b A	***
Hayters Gap 2	1.094 a C	1.097a B	1.099 b A	***
Mendota	1.087 c C	1.096abB	1.100 ab A	***
Rich Valley	1.094 a B	1.094abB	1.102 a A	***
	***	***	***	

Mean separation within columns (lower case letters) and within rows (upper case letters) by Duncan's multiple range test at p = 0.05; **, *** Significant at p = 0.1 and 0.001, respectively.

[z] Potatoes were cold stored at 3 C for 6 wk and reconditioned at 25 C for 2 wk.

Table 5. Concentration of sugars (mg/g dry weight) among five potato cultivars at harvest, after cold storage, and following reconditioning[z]

Cultivar	Harvest	Cold Storage	Reconditioned	
		Glucose		
Atlantic	0.4 a B	2.9 c A	3.0 a A	*
BelRus	0.5 a C	5.6 b A	3.5 a B	***
Kennebec	0.5 a B	5.3 b A	5.3 a A	*
Superior	0.7 a C	10.1 a A	5.0 a B	***
Yukon Gold	0.6 a C	5.7 b A	2.8 a B	***
	NS	***	NS	
		Fructose		
Atlantic	1.3 b A	3.3 b A	2.0 a A	NS
BelRus	0.6 b B	4.2 ab A	3.1 a A	**
Kennebec	3.5 a A	3.3 b A	3.9 a A	NS
Superior	1.5 b B	6.3 a A	3.5 a B	**
Yukon Gold	1.1 b B	4.4 ab A	2.1 a B	***
	*	*	NS	

Mean separation within columns (lower case letters) and within rows (upper case letters) by Duncan's multiple range test at $p = 0.05$; *, **, ***, NS, Significant at $p=0.05$, 0.01, 0.001 or not significant, respectively.

[z]Potatoes were cold stored at 3 C for 6 wk and reconditioned at 25 C for 2 wk.

Table 6. Concentration of sucrose and total sugars (mg/g dry wt) among five potato cultivars at harvest, after cold storage, and following reconditioning[z].

Cultivar	Harvest	Cold Stored	Reconditioned	
		Sucrose		
Atlantic	1.7 a A	3.7 b A	2.5 a A	NS
BelRus	2.6 a A	3.7 b A	2.4 a A	NS
Kennebec	2.6 a A	3.7 b A	3.1 a A	NS
Superior	2.0 a B	5.9 b A	3.1 a B	***
Yukon Gold	2.4 a B	13.6 a A	4.2 a B	***
	NS	***	NS	
		Total sugar		
Atlantic	3.4 a B	8.9 b A	7.4 a A	*
BelRus	3.7 a C	13.3 b A	9.0 a B	***
Kennebec	6.6 a A	12.3 b A	12.4 a A	NS
Superior	4.2 a C	22.2 a A	11.6 a B	***
Yukon Gold	4.1 a C	23.7 a A	9.0 a B	***
	NS	***	NS	

Mean separation within columns (lower case letters) and within rows (upper case letters) by Duncan's multiple range test at $p = 0.05$; *, **, ***, ^{NS}, significant at $p = 0.05$, 0.01, 0.001,or not significant, respectively.

[z]Potatoes were cold stored at 3 C for 6 wk and reconditioned at 25 C for 2 wk.

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Chapter 3. Ascorbic Acid and Protein Content in Potato at Harvest and after Cold Storage and Reconditioning

Abstract

Five potato cultivars, Atlantic, BelRus, Kennebec, Superior, and Yukon Gold were grown at six locations in southwest Virginia. Ascorbic acid and soluble protein were evaluated at harvest, after storage for 6 wk at 3 C, and following reconditioning for 2 wk at 25 C. Both cultivar and location had significant effects on soluble protein and ascorbic acid content at harvest, after cold storage, and following reconditioning. At harvest, Yukon Gold had the highest amount of soluble protein and ascorbic acid whereas Atlantic had the least amount of both compounds. During cold storage, soluble protein increased and vitamin C decreased in all cultivars. Of the five cultivars, Superior contained the highest amount of ascorbic acid whereas Atlantic had the least amount after cold storage. Soluble protein was highest in Atlantic and least in Yukon Gold after cold storage. Reconditioning reduced ascorbic acid and soluble protein content in all cultivars.

Introduction

Potato (Solanum tuberosum L.) is the most important vegetable in the world (Beukema and Van Der Zaag, 1990a; Thakral et al., 1989). With an annual per capita consumption of 50 to 55 kg, potato ranks number one by weight among all vegetables consumed in the US (USDA, 1977). Approximately one-quarter of the daily human requirement of ascorbic acid is supplied by potato (Fox and Cameron, 1970; Van Der Slice et al., 1990). In addition, potato can also serve as an important source of protein (Kaldy et al., 1972; Kapoor et al., 1975; Markakis, 1975; Talley et al., 1984).

Potatoes are usually stored for several months in cold at 2 to 4 C (Joshi et al., 1990). After cold storage, tubers are reconditioned above 15 C to lower their sugar content to a tolerable level for processing (Iritani and Weller, 1978; Weaver and Timm, 1983).

Cultivar and location are among the most important factors which affect potato quality (Beukema and Van Der Zaag, 1990b, Van Es and Hartmans, 1987; Smith, 1977). Noonan et al. (1951) reported that potato cultivars did not vary in ascorbic acid content, whereas Shekhar et al. (1978) found differences in ascorbic acid content among potato cultivars. Variation among potato cultivars in protein content has also been reported (Hannapel, 1991; Perras and Sarhan, 1988; Weaver et al., 1978).

Location also affects ascorbic acid (Augustin et al., 1978) and protein content of potato (Hannapel, 1991). Studies have shown that ascorbic acid content of potato tubers stored at 5 C decreases more than that of tubers stored at 20 C (Kida et al., 1991; Linnemann et al., 1985). Studies on potato protein showed insignificant change during cold storage (Yamaguchi et al., 1960). However, other plant species such as alfalfa, black locust, and spinach increased in soluble protein during exposure to cold temperature (Brown and Bixby, 1975; Gerloff et al., 1967; Guy and Haskell, 1987; and Siminovitch et al., 1968).

In contrast, effect of reconditioning on soluble protein and ascorbic acid content of potato tubers has not been reported. In this paper, we present the results of experiments designed to investigate the effect of cultivar and location on soluble protein and ascorbic acid content of potato at harvest, after cold storage and reconditioning.

Materials and Methods

Five cultivars, Atlantic, BelRus, Kennebec, Superior, and Yukon Gold, were grown in six locations in southwest Virginia in 1990. Seed was supplied by Carl Hessler and son (Rochford,MI). The treatments were arranged in a nested design consisting of four replications. Potatoes were grown using cultural practices recommended for white potato production in Virginia (Baldwin et al., 1986). Harvesting was done after 93 to 123 days, depending on cultivar and location (Appendix 2) and tubers were graded according to USDA standards (USDA, 1991). Three subsamples of ten uniform tubers (4.8-6.4 cm diam) were selected at random from each replication and washed with tap water, placed in plastic bags and, brought to Blacksburg, VA for analysis. One subsample was analyzed for soluble protein and ascorbic acid content. The remaining two sub samples were cured for 7 d at 18 C and 90% RH and then stored at 3 C and 90% RH for 6 wk. After storage, one subsample was analyzed immediately for ascorbic acid and soluble protein while the other sub sample was reconditioned at 25 C and 90% RH for 2 wk and then analyzed for ascorbic acid and soluble protein contents.

Ascorbic Acid Determination

Duplicate freeze-dried tissue samples (0.5 g) were weighed and placed in 50 ml flasks; 10 ml metaphosphoric acid-acetic acid dissolved in distilled water (30 g metataphosphoric acid, 80 ml glacial acetic acid in 400 ml water/l) was added to each flask. The samples were allowed to sit for 20 min with intermittent stirring, then filtered through Whatman no. 1 filter paper. The filtrate was brought to 10 ml with metaphosphoric acid-acetic acid extraction solution. For ascorbic acid determination, 5 ml of the filtrate was titrated against standardized 2,6-dichloro-indophenol solution as outlined by AOAC (1984).

Soluble Protein Determination

Ten tubers from each replication were cut longitudinally into two halves. One slice measuring about 5 mm in diameter was removed from each half, weighed and then quickly frozen in liquid nitrogen and freeze-dried. The freeze-dried samples were ground in a Cyclone mill (UD Corporation, Boulder, Colorado) and stored in a desiccator at -40 C.

Soluble protein was extracted from 1 g of the freeze dried tissue in a 0.2 M potassium phosphate buffer (pH 7.2) using a mortar and pestle at 4 C. The extract was centrifuged at 20,000 x g for 20 minutes and the supernatant analyzed for soluble protein according to Bradford (1976). Data were analyzed by two-way analysis of variance (ANOVA) employing procedures of SAS (1982).

Results

Ascorbic acid contents at harvest, after cold storage, and following reconditioning are shown in Table 7. Ascorbic acid content varied significantly among the cultivars. Superior and Yukon Gold contained higher ascorbic acid at harvest than BelRus, Kennebec, and Atlantic. Ascorbic acid ranged from 82 mg/100 g dry wt for Atlantic to 154 mg/100 g dry wt for Yukon Gold.

Ascorbic acid content of potato decreased significantly during the six months of cold storage (Table 7). Decrease in ascorbic acid during cold storage varied between 45% for Atlantic and 65% for Yukon Gold. Ascorbic acid decreased additonally after the two weeks of reconditioning. The decrease in ascorbic acid during reconditioning varied between 28% for Atlantic and 42% for BelRus (Table 7). These results suggested that cultivar differences at harvest did not predict levels after reconditioning. Location influenced ascorbic acid and soluble protein contents at harvest and in storage (Table 8).

Soluble protein at harvest varied from 41 mg/g dry wt for Atlantic to 46 mg/g dry wt for Superior. During cold storage, soluble protein increased significantly in all cultivars (Table 9). The highest increase in soluble protein (36%) occurred in Atlantic, while the lowest increase of (6%) was observed in Yukon Gold. At the end of the cold storage, soluble protein varied between 48.1 mg/g dry wt for Yukon Gold and 56.2 mg/g dry wt for Atlantic.

Reconditioning significantly decreased soluble protein in all cultivars compared to cold storage. Soluble protein decreased in Kennebec and Atlantic decreased to levels similar to those at harvest. The decreases in soluble protein content during reconditioning for the other cultivars brought the levels lower than observed at harvest (Table 9).

Discussion

Data on ascorbic acid content at harvest are in agreement with previous work (Augustin et al., 1975, 1978; Shekhar et al., 1978; Wills et al., 1984). Yukon Gold and Superior contained higher ascorbic acid content than Kennebec, BelRus or Atlantic. Results on ascorbic acid content of Kennebec and Superior were similar to those reported by Augustin et al. (1978). However, Shekhar et al. (1978) reported lower ascorbic acid concentration in Kennebec than those obtained in this study. The dichloroindophenol titration procedure used in this study is specific for ascorbic acid and does not analyze dehydroascorbic acid (AOAC, 1984). This together with other possible losses due to freezing and freeze drying (Shekhar et al., 1978) and respiration and dehydration (Sparks, 1973) suggest that the actual amount of ascorbic acid might be higher than reported.

Location influenced ascorbic acid content of potato more than cultivar. Augustin et al. (1978) reported that potatoes harvested early contain more ascorbic acid than those harvested late. In this study, however, differences in ascorbic acid among locations remained, even when harvesting was done on the same day. This suggested that factors other than harvesting date might be responsible for the differences in ascorbic acid among the locations.

It has been reported that variations in environmental conditions, such as light intensity, temperature, water, (Wills et al., 1984; Wills and Suthilucksanavanish, 1991), and soil type and fertility (Augustin, 1975; Augustin et al., 1975, 1978) among locations influence ascorbic acid content of potato. Any or all of these factors could have caused the variation in ascorbic acid among the six locations.

There was a decrease in ascorbic acid content of potato during cold storage. This is in agreement with results in other studies (Augustin et al., 1978; Linnemann et al., 1985; Shekhar et al., 1978, Sweeney et al., 1969). Ascorbic acid losses varied greatly among the cultivars. Four of the five cultivars lost 50% or more ascorbic acid during cold storage. Yukon Gold lost most ascorbic acid compared with the other four cultivars, suggesting need for utilization of this cultivar as soon as it is harvested. Ascorbic acid losses for Kennebec and Supeior during cold storage were similar to the results reported by Augustin et al. (1978) and Shekhar et al., (1978). However, Atlantic lost the least ascorbic acid, suggesting that it could be kept under short term storage without greater loss in this vitamin.

Location had a greater influence on ascorbic acid than cultivar. This is in disagreement with work done by Augustin et al. (1978) who reported ascorbic acid variation in only few locations. Comparison between cold stored and reconditioned potatoes showed that potatoes lost more ascorbic acid during reconditioning than during cold storage. These findings were in disagreement with work reported by Augustin et al. (1978) which showed that reconditioning of tubers at 25 C did not affect ascorbic acid concentration. Previous research (Joshi et al., 1990; Kida et al., 1991) reported that ascorbic acid content decreased more rapidly when potatoes are stored at cold temperature (below 5 C) than when stored at warmer temperatures (18-35 C).

According to Kida et al. (1991), the changes in ascorbic acid are due to the influence of storage temperature on the activity of six enzymes (ascorbate oxidase, monodehydroascorbate reductase, dehydroascorbate reductase, glutathione reductase, polyphenol oxidase, and dehydrogenase) involved in the metabolism of ascorbic acid.

The results for soluble protein content of potato in this study were in agreement with those reported previously (Clouter, 1983, 1984; Davis, 1977; Kaldy and Markakis, 1972; Weaver et al., 1978). Yukon Gold and Superior contained higher soluble protein than the other cultivars. Elecrophoretic analysis of Kennebec and other cultivars by Siebles (1979) reported variations in soluble protein patterns . Research on potato by Hannapel (1991) showed differences in soluble protein content among Kennebec Superior and other potato cultivars.

Location had a greater influence on soluble protein than cultivar. Variation in potato protein among locations was attributed to differences in growing temperature, soil type or soil nitrogen content (Augustin, 1975; Davis, 1977; Desborough and Weiser, 1974; Hannapel, 1991; Hoffman et al., 1971; Mica, 1971; Talley et al., 1970). It is possible that some of these factors could have caused the differences in soluble protein among the locations. Soluble protein increased during cold storage. The increase was higher in Atlantic than in the other cultivars. Accumulation of soluble protein during exposure to low temperatures has been reported in potato and other plant species (Brown and Bixby, 1975; Chen and Li, 1980; Davis and Gilbert, 1970; Faw et al., 1976; Meza-Basso et al., 1986; Siminovitch et al., 1968; Racusen, 1983). Increase in soluble protein concentrations during cold storage reflects either increase in production of new proteins, or increase in release of bound forms (Krasnuk et al., 1976; Guy and Carter, 1984; Guy and Haskell, 1987; Kacperska-Palacz, 1978; Kacperska-Palacz et al., 1977; Rhodes et al., 1979; Uemura and Yoshida, 1984;).

The increase in soluble protein during cold storage was reversed during reconditioning at 25 C. Such changes were reported previously in other plant species (Davis and Gilbert, 1970; Guy and Haskell, 1987). The decrease in soluble protein at 25 C may be attributed to degradation and/or reduced synthesis of high molecular weight proteins (Davis and Gilbert, 1970; Guy and Haskell, 1987). The intimate association of protein with plant tissues, either as components of enzyme systems or in structural organization of cellular organelles could explain the observed sensitivity of soluble protein to temperature changes (Guy and Haskell, 1987).

In conclusion, the fluctuation of soluble protein and ascorbic acid reported in this study show that location, cultivar, cold storage, and reconditioning alter the concentration of these components drastically. Therefore, to preserve these important nutrients prolonged storage of tubers should be discouraged.

Table 7. Ascorbic acid content at harvest, after cold storage and following reconditioning of five potato cultivars[z].

Cultivar	Harvest	Cold stored	Reconditioned	
	Ascorbic acid content (mg/100 g dry wt.)			
Atlantic	82.0 c A	44.9 c B	32.7 b C	***
BelRus	108.4 b A	54.5 b B	31.6 b C	***
Kennebec	112.3 b A	53.4 b B	35.5 b C	***
Superior	140.3 a A	70.0 a B	44.1 a C	***
Yukon Gold	154.0 a A	54.1 b B	31.8 b C	***
	***	**	***	
Cultivar x location	***	***	***	

Mean separation within columns (lower case letters) and within rows (upper case letters) by Duncan's multiple range test at p = 0.05; **, *** significant at p = 0.01, 0.001, respectively.

[z]Potatoes were stored at 3 C for 6 wk and reconditioned at 25 C for 2 wk.

Table 8. Ascorbic acid and soluble protein content of potato at harvest, after cold storage, and following reconditioning at six locations in southwest Virginia.[z]

Location	Harvest	Cold stored	Reconditioned	
	Ascorbic acid content (mg/100 g dry wt)			
Broadford	135.3 a A	57.6bc B	28.6c C	***
Gladesboro	121.1 b A	51.9 c B	37.5a C	***
Hyters Gap-1	108.9 c A	59.6 b B	37.2a C	***
Hyters Gap-2	107.0 c A	43.5 d B	31.5bcC	***
Mendota	126.1 ab A	66.3 a B	39.9a C	***
Rich Valley	129.4 ab A	53.4 bc B	35.9abC	***
	***	***	***	
	Soluble protein content (mg/g dry wt.)			
Broadford	44.8 ab B	51.9 a A	40.7abC	***
Gladesboro	46.6 a B	50.6 ab A	37.6b C	***
Hayters Gap-1	46.4 a B	50.4 ab A	39.4abC	***
Hayters Gap-2	41.6 bc B	47.2 b A	40.4abC	***
Mendota	38.9 c C	51.0 ab A	42.0a B	***
Rich Valley	46.3 a B	54.1 a A	41.3a C	***
	***	*	*	

Mean separation within columns (lower case letters) and within rows (upper case letters) by Duncan's multiple range test at $p = 0.05$; *, *** significant at $p = 0.05$ and 0.0001.

[z]Potatoes were stored at 3 C for 6 wk and reconditioned at 25 C for 2 wk.

Table 9. Soluble protein content at harvest, after cold storage and following reconditioning of five potato cultivars[z].

Cultivar	Harvest	Cold stored	Reconditioned	
	Soluble protein (mg/g dry weight)			
Atlantic	41.5 c B	56.2 a A	40.4 ab B	***
BelRus	45.4 ab B	49.3 b A	40.3 ab C	***
Kennebec	42.2 bc B	51.4 b A	42.9 a B	***
Superior	46.0 a B	49.4 b A	37.7 b C	***
Yukon Gold	45.4 ab B	48.1 b A	39.9 ab C	***
	*	***	*	
Cultivar x location	***	NS	*	

Mean separation within columns (lower case letters), and within rows (upper case letters) by Duncan's multiple range test at $p = 0.05$; **, ***, NS, significant at $p = 0.05, 0.001$,and not significant, respectively.

[z]Potatoes were stored at 3 C for 6 wk and reconditioned at 25 C for 2 wk.

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Chapter 4. Effect of Seed Type and In-row Spacing on Yield and Quality of Yukon Gold

Abstract

The influence of in-row spacing and seed type on yield, ascorbic acid, and soluble protein content of Yukon Gold was evaluated. Whole, fresh-cut, and healed-cut seeds were planted at 15, 20, and 25 cm within row. Potatoes harvested from each treatment were analyzed for number of stems per plant, tuber yield and size, percent dry weight, specific gravity, soluble protein and ascorbic acid at harvest and after storage. Narrower in-row spacing (15 cm) resulted in higher yield of US No.1 and smaller tubers than the wider spacings (20 and 25 cm). Twenty and 25 cm in-row spacings produced higher percent marketable yield and tubers with higher soluble protein than 15 cm. Percent dry weight, specific gravity, ascorbic acid, and number of stems per plant were not influenced by in-row spacing. Yukon Gold grown from whole seed produced higher yield of US No. 1 (4.8-6.4 cm tuber diameter), high ascorbic acid, and more stems per plant than those grown from healed-cut and fresh-cut seed. Both whole and healed-cut seed produced tubers higher in specific gravity than fresh cut. Yield of medium tubers, percent dry weight, percent marketable yield, and soluble protein were not affected by seed type.

Introduction

Yukon Gold was bred and selected within the potato breeding project of the Horticultural Science Department, University of Guelph, Ontario, Canada. Yukon Gold is a medium to early maturing cultivar exhibiting upright growth habit, medium to large size plants with little tendency to spread (Johnston and Rowberry, 1981). This cultivar was bred for the large European population of central Canada who prefer yellow flesh potato (Johnston and Rowberry, 1981).

Since its release for commercial production in 1980, Yukon Gold has gained popularity in northern United States as a gourmet potato. However, in Michigan, farmers growing this cultivar have encountered problems of delayed emergence, slow and uneven development, and reduced plant stands (Chase et al., 1989). McKeown (1990b) reported that Yukon Gold tubers have strong apical dominance or dormancy and are prone to variation in yield among seed portions.

Research conducted with other potato cultivars has shown that tuber yield depends on spacing (Entz and LaCroix, 1984; Iritani et al., 1972; Lynch and Rowberry, 1977; Rex et al., 1987; Schotzko et al., 1984). The effect of spacing on potato size (Nelson 1967; White et al., 1974; Ridley et al., 1980) and quality (Bleasdale and Thompson, 1969; Nelson, 1967; Ounsworth, 1963; White and Sanderson, 1983) has also been reported.

Variation between the bud-end and stem-end of potato tubers has been reported for both ascorbic acid content in Russet Burbank and Kennebec (Shekhar et al., 1978) and nitrogen content (Weaver et al., 1978c). No such work, however, has been reported for Yukon Gold.

Potato tubers are cured immediately after harvest for suberization before storage (Meijers, 1987; Smith, 1977). Previous research on the effect of curing on potato quality during storage concentrated on its effect on sugars and tuber weight (Burton, 1969; Iritani and Weller, 1976). However, research on the effect of curing on specific gravity, percent dry weight, soluble protein, or ascorbic acid has not been reported. This study was conducted to evaluate the effect of seed type and spacing on yield, size, percent dry weight, specific gravity, soluble protein, and ascorbic acid content of Yukon Gold. The effect of bud-end and stem-end and curing on tuber quality was also evaluated.

Materials and Method

Potato seed used in this study were certified Yukon Gold, supplied by Carl Hessler and Son (Rochford, MI). The seeds were treated with captan and stored at 4 C for 4 wk. Seeds were hand-cut and healed at 4 C for 4 wk before planting.

Each plot consisted of three 12 m rows but only the center row was used for experimental analyses. Fresh-cut seeds were planted on the same day at 90 cm between rows and 15, 20, and 25 cm within row spacing. The experimental design was randomized complete block with four replications. Plots were side dressed with 450 kg/ha of 50:10:10: (N:P:K) four weeks after planting. Weed control was done by pre-emergence application of a mixture of 2.06 l/ha of Dual 8E and 1.68 kg/ha of linex 50 DF. Plants were sprayed with 1.17 l/ha of Bravo 720 and 0.56 kg/ha of Asana-XL to control blight and insects, respectively. Other cultural practices were done as recommended for white potato production in Virginia (Baldwin et al., 1986). Twenty-five plants were harvested 107 days after planting and graded according to USDA standard (USDA, 1991).

Five kg of tubers (4.8 - 6.4 cm in diam) were picked at random from each replication, washed and analyzed for percent dry wt, specific gravity, soluble protein, and ascorbic acid content. Tissue samples were also cut from 1 cm portion of bud-end and stem end and analyzed for percent dry weight, soluble protein, and ascorbic acid content. Two subsamples of 5 kg from each replicate were placed in ventilated plastic bags (60 cm x 40 cm). One sub sample was cured at 18 C and 90% RH for 10 d and the other sublot was not cured. Both sub samples were stored at 3 C for 12 wk and analyzed for percent dry wt, soluble protein, specific gravity, and ascorbic acid content.

Soluble protein determination

Ten tubers from each replication were cut longitudinally into two halves. One slice was sampled from each half, weighed then quickly frozen in liquid nitrogen and freeze-dried for 48 h. The freeze-dried tissue was ground in a cyclone mill (UD Corporation, Boulder, Colorado, USA) and stored in the desiccator at -40 C until analysis. Soluble protein was extracted from 1 g sample of the freeze-dried tissue in a 0.2 M potassium phosphate buffer (pH 7.2) using mortar and pestle at 4 C. The extract was centrifuged at 27,000 x g for 20 minutes and analyzed for soluble protein (Bradford, 1976).

Ascorbic acid determination

Duplicate samples of 0.5 g each were placed in 50 ml flasks and 10 ml metaphosphoric acid-acetic acid extracting solution (30 g metaphosphoric acid, 80 ml glacial acetic acid dissolved in 400 ml distilled water/l) was added to each sample. After 20 minutes with intermittent stirring, the samles were filtered through a Whatman no. 1 paper and brought to 10 ml with metaphosphoric acid-acetic acid extraction solution. For ascorbic acid determination, 5 ml of the filtrate was titrated against a standardized 2,6-dichloro-indophenol sodium salt solution as outlined by AOAC (1984).

Specific gravity and per cent dry wt determination

Specific gravity was determined by weight in air versus weight in water method, USDA (1983). A 5 kilogram sample of uniform tubers (4.8-6.4 cm in diam) from each replication was weighed in air and then reweighed in water. Specific gravity was calculated by dividing weight in air by weight in air minus weight in water. A sample of 100 g of fresh potato tissue was sliced from 10 tubers per replication and freeze-dried for 48 h for calculating percent dry wt. Data were analyzed by two-way factorial analysis of variance (ANOVA) according to SAS (1982).

Results

Potato grown from whole seed emerged earlier and were more vigorous than those grown from fresh or healed-cut seed. Plant stand establishment was not affected by seed type or in-row spacing (Data not included). In-row spacing influenced yield of small tubers (4.8-6.4 cm diam), percent marketable yield, number of tubers per plant, and soluble protein content of Yukon Gold (Table 10). Yield of small tubers was higher for Yukon Gold planted at 15 cm than 20 cm and 25 cm within row. Interaction effects between seed type and in-row spacing were not significant for all parameters tested.

Potato plants spaced at 15 cm within the row produced higher yield of US No. 1 tubers than plants spaced at 20 and 25 cm. Plants spaced at 20 cm and 25 cm produced tubers higher in percent marketable yield (Table 10) and soluble protein (Table 11) content than plants spaced at 15 cm. In-row spacing, however, did not influence the number of stems per hill (Table 10). Percent dry wt, specific gravity, and ascorbic acid content of Yukon Gold were also not affected by within-row spacing (Table 11).

Seed type had significant effect on yield of US No. 1, yield of small tubers (4.8-6.4 cm diam), number of stems per hill (Table 12), as well as ascorbic acid content and specific gravity (Table 13). Yukon Gold grown from whole seed produced higher marketable yield and yield of small tubers than plants grown from healed-cut and fresh-cut seed pieces (Table 12). Whole- and fresh-cut seed pieces produced more stems per hill than healed-cut seed (Table 12). Specific gravity and soluble protein content, however, were higher in Yukon Gold grown from whole and healed-cut than fresh-cut seed (Table 13). Seed type had no significant effect on yield of medium tubers (6.4-8.3 cm diam), percent marketable yield (Table 12), percent dry wt, and soluble protein content (Table 13).

The stem end of the tuber contained higher percent dry weight than the bud end (Table 14). Soluble protein and ascorbic acid, however, were higher in the bud end than the stem end (Table 14).

Storage of Yukon Gold at 3 C for 12 weeks resulted in a significant increase in soluble protein content of cured as well as noncured tubers (Table 15). Curing, however, did not affect the rate of decrease in soluble protein during cold storage.

Ascorbic acid content during cold storage was lower in non cured tubers than in cured tubers (Table 15). In contrast, specific gravity of cured and noncured tubers increased equally during cold storage (Table 15). Percent dry wt of cured tubers did not change, while that of noncured tubers increased during cold storage (Table 15).

Discussion

In this study, yield of US No. 1 remained uniform despite increase of in-row spacing. These results are in agreement with work reported previously (DeBuchananne and Lawson, 1991; Iritani et al., 1972; Van Der Zaag et al., 1990). The increase in yield of smaller tubers at closer in-row spacing (15 cm) was also reported previously (Nelson, 1967; Ridley et al., 1980; Rex et al., 1987; Rex, 1990). Increase in interplant competition could have been responsible for the low percent marketable yield and high yield of smaller tubers in Yukon Gold planted at 15 cm in- row spacing. Reduction in yield of larger tubers has also been attributed to interplant competition (Rex et al., 1987; Rex, 1990). Results on yield of US No. 1 (6.4-8.3 cm diam) in this study were not in agreement with those obtained for Russet Burbank by Rex et al. (1987) who reported insignificant effect of spacing on yield of tubers greater than 5 cm diam. Entz and LaCroix (1984) obtained similar yield results for Russet Burbank as those reported in this study.

In-row spacing did not affect ascorbic acid, percent dry weight, and specific gravity of Yukon Gold. Lynch and Rowberry, (1977) and White et al. (1974) reported similar results on specific gravity of Russet Burbank and Netted Gem potatoes. Increase in specific gravity of potato at closer in-row spacing (Rex et al., 1987; White and Sanderson, 1983) was not observed in this study. Inconsistent relationship between specific gravity and spacing has been reported for other potato cultivars (Rex et al., 1987).

Use of whole seed increased yield of US No. 1 potatoes and number of tubers compared to healed- cut and fresh cut seed. Similar results were reported for Russet Burbank (Ent and LaCroix, 1984). The higher yields reported previously for healed-cut Yukon Gold compared with fresh-cut seed (Chase et al., 1989) were not observed in this study. The yield advantage of using healed-cut compared to fresh-cut seed of Yukon Gold was attributed to combined effects of early emergence and vigorous early growth (Chase et al., 1989). Storage of seed for four weeks instead of the two weeks used in previous experiments could have broken the seed dormancy. Research conducted with Yukon Gold (McKeown, 1990a) reported insignificant effect of seed type on number of stems per hill. In this study, however, plants grown from whole-seed and fresh-cut seed produced more stems per plant than those grown from healed-cut seed.

Use of whole seed also resulted in increased ascorbic acid content and specific gravity without affecting soluble protein content, percent marketable yield and percent dry weight. Results on specific gravity are in agreement with work done by others (Nelson, 1967; Ounsworth, 1963; Rex, 1990).

Studies have shown that stem-end of potato contains more sugar than bud-end (Iritani and Weller, 1973; Iritani et al., 1973; Weaver et al., 1972, 1978b). Stem-end or basal portion of potato has been shown to contain higher percent dry weight than the bud-end or the apical portion (Johnson et al., 1968; Reeve et al., 1970, 1971; Ross and Porter, 1971; Weaver et al., 1978a). Similar pattern of distribution of percent dry weight was observed in this study. This trend was reversed with soluble protein content. Johnston et al. (1968) reported that total nitrogen content of potato was significantly higher in the stem-end of Russet Burbank than bud-end whereas Weaver et al. (1978c) obtained similar concentrations of total nitrogen in bud-end and stem-end of six potato cultivars including Russet Burbank.

Results on ascorbic acid content of Yukon Gold in this study were in agreement with those reported for Kennebec and Russet Burbank (Shekhar et al., 1978), with ascorbic acid concentration higher in the bud-end than the stem end of the tuber.

Curing of tubers before storage is practiced to harden tubers against pathogens (Meijers, 1987). In this study, curing preserved ascorbic acid content of Yukon Gold without affecting soluble protein content and specific gravity. In addition, curing reduced percent dry weight of Yukon Gold. In conclusion, Yukon Gold should be planted using whole seed spaced at 90 cm between rows and 20 cm within-row and the tubers should be cured after harvest to enhance storage life.

Table 10. Yield (metric ton/ha), percent marketable yield, and number of stems/plant of Yukon Gold as influenced by in-row spacing.

	In-row spacing (cm)			
	15	20	25	
US No. 1[z]	21.7 a	20.1 a	19.2 a	NS
Small tubers	14.1 a	12.5 b	12.6 b	***
Medium tubers	7.6 a	7.6 a	6.6 a	NS
% Marketable	61.0 b	68.0 a	68.0 a	***
Stems/plant	2.3 a	2.9 a	3.3 a	NS

Mean separation within rows by Duncan's multiple range test at $p = 0.05$; *, ***, NS, significant at $p = 0.05$, 0.001, or not significant respectively.

[z]Tuber sizes are: US No. 1 tubers, > 4.8 cm; small tubers, 4.8 - 6.4 cm; medium tubers, 6.4 - 8.3 cm in diameter.

Table 11. Percent dry weight, specific gravity, soluble protein, and ascorbic acid content of Yukon Gold as influenced by in-row spacing.

	In-row spacing (cm)			
	15	20	25	
Soluble protein (mg/g dry wt)	43.3 b	45.9 a	46.6 a	*
Ascorbic acid (mg/100 g d. wt)	84.9 a	84.6 a	85.2 a	NS
Dry weight (%)	20.5 a	20.5 a	20.6 a	NS
Specific gravity	1.085 a	1.085 a	1.085 a	NS

Mean separation within rows by Duncan's multiple range test at $p = 0.05$; *, ***, ^{NS}, significant at $p = 0.05$, 0.001, and not significant respectively.

Table 12. Yield (metric ton/ha), percent marketable yield and number of stems per plant of Yukon Gold as influenced by seed type.

	Seed type			
	Whole	Healed-cut	Fresh-cut	
US No. 1[z]	22.6 a	19.2 b	18.9 b	**
Small tubers	14.5 a	12.1 b	12.5 b	***
Medium tubers	8.1 a	7.1 a	6.4 a	NS
% marketable	69.0 a	66.0 a	64.0 a	NS
Stems/plant	3.5 a	2.8 b	3.3 a	***

Mean separation within rows by Duncan's multiple range test at $p = 0.05$; **, ***, NS, significant at $p = 0.01$, 0.001, and not significant, respectively.

[z]Tuber sizes are: US No. 1, > 4.8 cm; small tubers, 4.8 - 6.4 cm; medium tubers, 6.4 - 8.3 cm in diameter.

Table 13. Soluble protein, ascorbic acid, percent dry wt, and specific gravity of Yukon Gold as influenced by seed type.

	Seed type			
	Whole	Healed-cut	Fresh-cut	
Ascorbic acid (mg/100 g dry wt)	92.3 a	85.2 a	74.1 b	*
Specific gravity	1.086 a	1.086 a	1.084 b	***
% dry weight	20.8 a	20.1 a	20.7 a	NS
Soluble protein (mg/g dry wt)	45.6 a	44.9 a	45.2 a	NS

Mean separation within rows by Duncan's multiple range test at $p = 0.05$; *, ***, NS significant at $p = 0.05$, 0.001, and not significant, respectively.

Table 14. Percent dry weight, soluble protein, and ascorbic acid content of bud-end and stem-end of Yukon Gold tubers.

Tuber section	Dry weight (%)	Soluble protein (mg/g dry wt)	Ascorbic acid (mg/100g dry wt)
Bud-end	20.1 b	58.4 a	78.9 a
Stem-end	21.7 a	34.0 b	48.7 b
	*	***	**

Mean separation within columns by Duncan's multiple range test at $p = 0.05$; *, **, *** Significant at $p = 0.05$, 0.01 and 0.001, respectively.

Table 15. Soluble protein, ascorbic acid content, percent dry weight, and specific gravity of Yukon Gold at harvest and after cold storage[z].

	Harvest	Cured	Non-cured	
Soluble protein (mg/g dry wt)	50.0 b	58.1 a	56.4 a	***
Ascorbic acid (mg/100g dry wt)	97.0 a	17.3 b	9.3 c	***
Dry wt (%)	20.1 b	20.2 b	23.5 a	***
Specific gravity	1.075 b	1.092 a	1.092 a	***

Mean separation within rows by Duncan's multiple range test at $p = 0.05$; *** Significant at $p = 0.0001$.

[z]Potatoes were stored at 3 C for 12 weeks

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Appendix 1. Soil pH and fertilizer rates used for growing potato at six locations in southwest Virginia

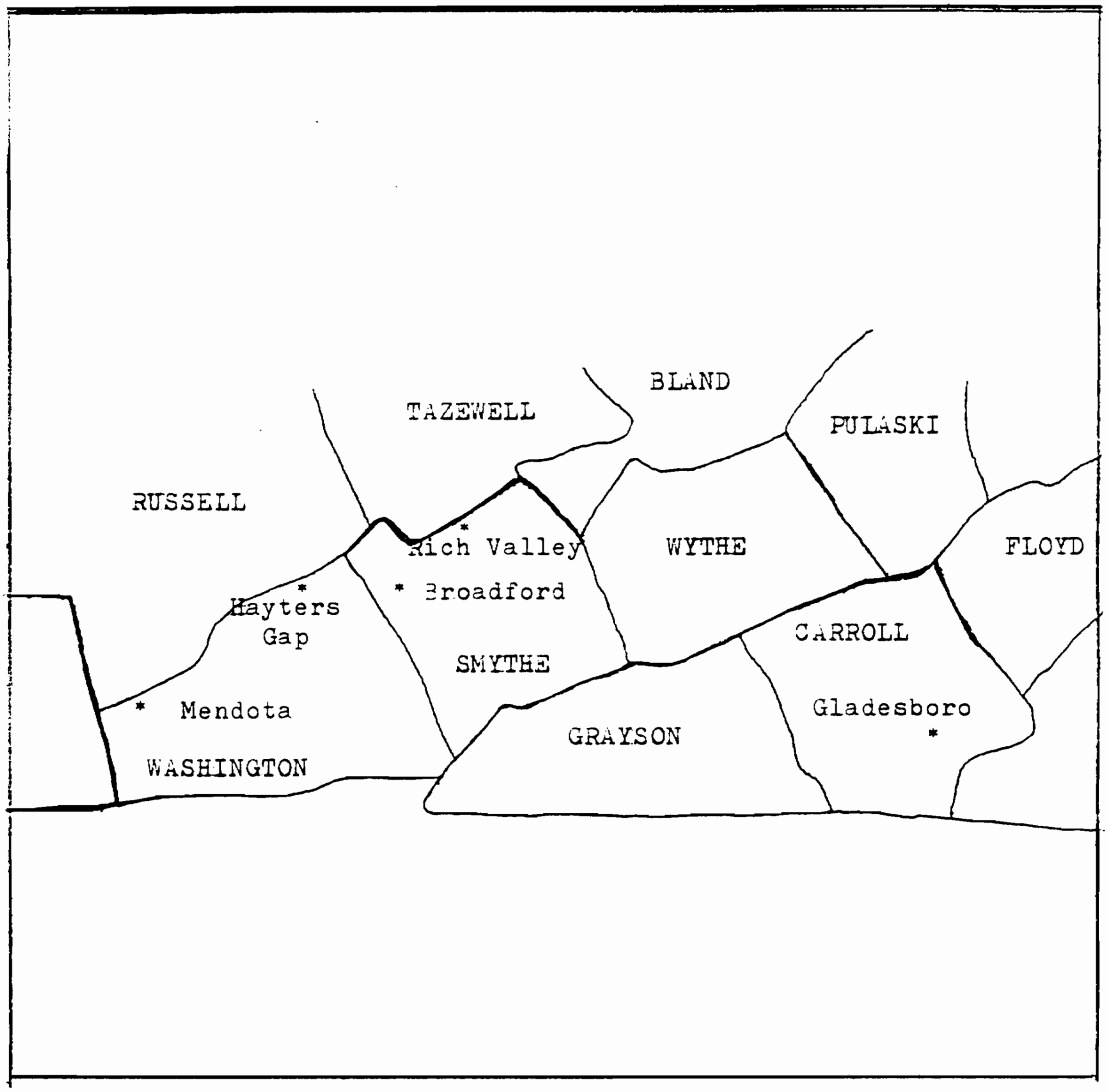
		Fertilizer (metric tons/ha)		
Location	pH	N	P_20_5	K_20
Broadford	5.2	150	150	200
Gladesboro	6.1	150	150	100
Hyters Gap 1	6.9	150	100	200
Hyters Gap 2	5.4	150	150	200
Mendota	7.8	150	100	300
Rich Valley	7.4	150	150	200

Appendix 2. Days from planting to harvest for five potato cultivars at six locations in southwest Virginia

Location	Cultivar	Days to harvest
Broadford	Atlantic, Belrus, Kennebec, Superior, Yukon Gold	93
Gladesboro	Atlantic, BelRus, Superior, Superior, Yukon Gold	107
Hyters Gap-1	BelRus, Superior, Yukon Gold,	73
	Atlantic, Kennebec	107
Hyters Gap-2	BelRus, Superior, Yukon Gold,	99
	Atlantic, Kennebec	115
Mendota	Superior, Yukon Gold	100
	BelRus	102
	Atlantic	114
	Kennebec	123
Rich Valley	BelRus, Superior, Yukon Gold, Kennebec, Atlantic	107

Differences in growing seasons among locations were caused by elevation (Appendix 3) and by rainfall distribution.

Appendix 3. Map of southwest Virginia showing the six locations where potato was grown and the elevations in meters.



Elevation of the six locations shown on the map
Broadford 600 m, Gladesboro 760 m, Hayters Gap 1 550 m, Hayters Gap 2 540 m, Mendota 600 m, Rich Valley 560 m.

Appendix 4. Soil type, soil texture, and drainage condition at the six locations

Location	Soil type	Soil drainage
Broadford	Wheeling, clay loam	good
Gladesboro	Sandy loam, rocky	very good
Hayters Gap 1	Westmoorland, silt loam and rocky	very good
Hayters Gap 2	Frederick silt loam	good
Mendota	Clay loam with hard pan	poor
Rich Valley	Wheeling, clay loam	good

Vita

Okeyo James Ajuoga was born on August 21, 1953 in Rusinga Island, South Nyanza district, Kenya. He received his primary education at Kamasengere school in Rusinga Island from 1964 to 1970. He then proceeded for secondary education at Mbita secondary from 1971 to 1974.

He attended Egerton College, Njoro, Kenya from 1975 to 1978 and graduated with a Diploma in Horticulture (with Distinction). Thereafter, he joined the Ministry of Agriculture in April, 1978 and worked at The National Horticultural Research Station, Thika, and The National Pyrethrum and Horticultural Research Station, Molo, Kenya, up until July, 1981.

He joined Egerton College and worked as a demonstrator from August, 1981 to September, 1985. From here, he continued his education at the University of Nairobi, Kenya in 1985 from where he received a Bachelor of Science degree in Agriculture in 1988. He rejoined Egerton University and worked as an Assistant lecturer in Horticulture from July, 1988 to December, 1989.

In January, 1990 he entered graduate school at Virginia Polytechnic Institute and State University. He earned a Master of Science in Horticulture in August, 1992.

He is married to Ruphina Nyawade. They have three children; Ogaya, Nyawade, and Bunge.