Harvest Interval Has Greater Effect on Periderm Maturity and Storage Quality of Early-maturing, Tablestock Potato than Nitrogen Rate

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Abstract. Early-maturing potato cultivars (*Solanum tuberosum* L.) grown in many subtropical and tropical regions are typically packed and shipped without curing. The objective of this study was to evaluate two early-maturing potato cultivars ('Fabula' and 'Red LaSoda') grown under four nitrogen fertilizer (NF) rates and harvested at three intervals after vine kill for effects on tuber physical and compositional quality at harvest and during storage. NF was applied through fertigation (0, 112, 224, or 336 kg·ha⁻¹) and compared with granular NF application (224 kg·ha⁻¹). The tubers were harvested weekly after vine kill (H1, H2, and H3) then evaluated for quality at 7 and 14 days during storage at 10 °C/80% to 85% relative humidity (RH). 'Fabula' tubers from H1 had the highest cumulative weight loss (3.6%) after 14 days of storage (season 1), while those from both H1 and H2 were highest (4.4%) in season 2, regardless of NF application method or rate. Tuber firmness increased by 1.5 newtons (N) for tubers from H1 after 7 days storage, and again by 0.76 N after 14 days for tubers from H2 and H3. Periderm dry matter content (DMC) for H1 tubers increased to 13.9% after 7 days, regardless of fertilizer treatment, in contrast to those from H2 or H3 where DMC remained constant throughout storage (10.6% and 11.4%, respectively). For 'Red LaSoda', cumulative weight loss in season 1 for H1 tubers was 2.2% after 14 days storage, whereas that for H2 and H3 tubers averaged 0.7%; this trend was similar for season 2. Periderm DMC significantly increased with increased storage time; that for H2 tubers was highest (19.6%) after 14 days. In both cultivars, tuber ascorbic acid content (AAC), soluble solids content (SSC), and total titratable acidity (TTA) remained constant throughout the 14-day storage period. Periderm maturity of 'Fabula' and 'Red LaSoda' potatoes had a greater effect on tuber physical and compositional quality during storage than the fertilizer rates or application methods. Fertigation at NF rates of 112, 224 or 336 kg·ha⁻¹ was comparable with conventional granular NF application for growing high-quality tubers with acceptable postharvest life. Growing tubers at 112 kg·ha⁻¹ nitrogen via fertigation has the potential to reduce both irrigation water usage and fertilizer runoff during the production cycle.

Potato (*Solanum tuberosum* L.) tubers continue active metabolism after harvest and require appropriate storage conditions to minimize losses that can arise from these

physiological processes (Kumar et al., 2004). One key factor determining storability of tubers is harvest maturity, classified as physical, physiological, and chemical maturity (Bussan, 2003). Tablestock potatoes reach harvest maturity when the tuber periderm adheres firmly to the underlying cell layers, the point known as skin-set (Lulai and Orr, 1993). Early-season tablestock cultivars are often grown as a spring crop to meet an early market window with high prices; however, they are typically harvested 90–120 d after planting (DAP) at which point the periderm is minimally mature and easily removed (UNECE Standard FFV-52, 2011). Greater quantitative and qualitative losses are associated with storage of immature tubers (Burton,

1989) whereas tubers harvested from senescent plants are physically more mature (Braue et al., 1983). For this reason, tablestock potato vines are killed before harvest to promote periderm physical maturity ("skin-set"), thereby reducing skinning or scuffing during mechanical harvest and subsequent handling operations (Zotarelli et al., 2016b).

Water and nitrogen availability during plant growth can affect leaf growth and carbon partitioning, and subsequently the biochemical process involved in tuber skin-set (Tyner et al., 1997). Northeast Florida accounts for the majority of the state's spring potato production, characterized by fine sandy soils with low water-holding capacity and low organic matter content (Manrique, 1993). Heavy and erratic rainfalls commonly experienced in such subtropical growing regions can cause nutrient leaching from the root zone, further decreasing available nitrogen (Papadopoulos, 1988). Acceptable tuber yields and quality are also dependent on the placement and timing of NF (Westermann et al., 1988).

The current grower practice in northeast Florida is band application of granular NF at preplant (≈30 d before planting), at plant emergence (25 DAP), and at the onset of tuber initiation (Rens et al., 2015). There is rapid nitrogen uptake 45–65 DAP (Zotarelli et al., 2014, 2015b), during which time the risk of leaching is also high. Seepage irrigation is the primary method used in this region and requires maintenance of a high water table. This method also has the potential for increased nutrient leaching and runoff, and has raised important ecological and human-health concerns in this growing region, where groundwater is the source of drinking water for most of the residents. By contrast, fertigation delivers dissolved fertilizer through drip tapes that increases water and nutrient use efficiency by precisely applying water and nutrients to the plant root zone. Reyes-Cabrera et al. (2014) also reported significant decreases in tuber physiological disorders for early-maturing potatoes grown using fertigation.

A companion study of early-maturing, tablestock potatoes grown in sandy soils found that fertigation obtained maximum yields by applying nitrogen at rates 224–273 kg·ha⁻¹ (Makani et al., 2015). However, excess NF negatively affects plant and tuber growth by promoting excessive vine growth and by delaying tuber periderm maturation in the field, leading to higher weight loss (Dahlenburg et al., 1990), higher disease incidence (Jablonski, 2006), decreased phytochemical content (Zhang et al., 1997), and low or elevated starch content (Bombik et al., 2002). It is important to note that these studies were conducted using medium-to-late season cultivars that have more mature tuber periderm at harvest because of a longer growing season (up to 180 d). Consequently, adoption of NF recommendations based on these cultivars could potentially cause significant storage losses to the more perishable, early-maturing potato cultivars.

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Table 1. Effects of nitrogen fertilizer method of application, rate, and harvest interval on initial pulp dry matter content of 'Fabula' tubers (season 2).

Harvest interval ²	Pulp dry matter content (%)				
	Fertilizer treatment ³				
	F-0	F-112	F-224	F-336	G-224
H1	16.8 aA ^x	14.7 aAB	13.8 aB	14.2 aAB	14.6 aAB
H2	13.3 bA	14.3 aA	14.1 aA	14.1 aA	14.6 aA
H3	13.1 bA	14.3 aA	14.7 aA	14.5 aA	15.0 aA

²Harvest intervals: H1, H2, H3 = 1, 2, or 3 weeks after vine kill, respectively.

³Fertilizer rates of F-0, F-112, F-224, and F-336 = fertigation rates of 0, 112, 224, or 336 kg·ha⁻¹, respectively. G-224 = granular application at 224 kg·ha⁻¹.

^xMeans within a column (fertilizer treatment) followed by the same small letter, or by the same capital letter within a row (harvest interval) do not differ significantly according to Tukey's range probability test ($P < 0.05$).

Table 2. Effects of nitrogen fertilizer method of application and rate on initial soluble solids content (SSC), total titratable acidity (TTA), and pH content of 'Fabula' tubers (seasons 1 and 2 combined).

Fertilizer treatment ²	SSC (%)	TTA (%)	pH
F-0	2.73 b ^y	0.12 b	2.70 c
F-112	3.35 b	0.13 ab	3.47 b
F-224	3.85 ab	0.15 a	3.88 ab
F-336	4.13 a	0.14 a	4.02 a
G-224	4.15 a	0.15 a	4.13 a

²Fertilizer rates of F-0, F-112, F-224, and F-336 = fertigation rates of 0, 112, 224, or 336 kg·ha⁻¹, respectively. G-224 = granular application at 224 kg·ha⁻¹.

^yMeans within each column followed by the same small letter do not differ significantly according to Tukey's range probability test ($P < 0.05$).

The objective of this present work was to determine the effect of growing two commercially important, early-maturing potato cultivars using two NF application methods, four NF rates, and three harvest intervals after vine killing on selected tuber quality and nutritional value parameters at harvest and during simulated commercial storage.

Materials and Methods

Experimental site and field layout. Field trials were conducted at the UF/IFAS Hastings Agricultural Extension Center, Cowpen Branch Facility, Hastings, FL (29.7167° N, 81.5083° W) during Spring 2013 (season 1) and 2014 (season 2). The experiment was laid out as a completely randomized design with treatments in a split-plot design; NF rates were assigned to the main plots and potato cultivars to the sub-plots. The field (79 m by 18 m) was configured with row spacing = 1.04 m and hill height = 0.35 m, then subdivided into 32 plots (7.3 m each; four plots/treatment).

Two widely grown, early-maturing table-stock potato cultivars, 'Fabula' and 'Red LaSoda', were selected for this study (Source: Maine Farmer's Exchange, Presque Isle, ME). Both cultivars have potential for high yields and are well suited for production in the southeastern United States. 'Fabula' has a light-tan, smooth periderm, oblong shape and yellow pulp; it is vine killed about 87 d from planting (Mwatuwa, et al., 2017). 'Red LaSoda' has deep-red periderm, deep eyes and white pulp; it is vine killed from 86 to 100 DAP (Zotarelli et al., 2016a). Each cultivar was hand-planted (20-cm in-row

spacing and 15-cm depth) over two spring seasons, on 28 Jan. 2013 and on 29 Jan. 2014. The crop was irrigated using surface drip irrigation, where drip lines (16-mm inner diameter, 8-mm thickness, and 20-cm emitter spacing) with a flow rate of 500 L·h⁻¹ 100-m⁻¹ (RO-DRIP; John Deere Water, Moline, IL) were placed 5 cm above the seed piece after planting. Irrigation commenced 38 and 30 DAP in seasons 1 and 2, respectively; daily irrigation volume, based on calculated crop evapotranspiration, was split into three to four irrigation events, and adjusted according to precipitation received.

For the fertigation treatments, granular ammonium nitrate fertilizer (34-0-0) was completely dissolved in water and injected into the drip system, at four rates (0, 112, 224, and 336 kg·ha⁻¹; F-0, F-112, F-224, and F-336, respectively). Total NF for each fertigation treatment was split and applied over 5 weeks starting 45 DAP. NF amount at each split application corresponded to projected crop nitrogen requirements, which were based on crop growth stage. The granular NF treatment was based on the recommended rate of 224 kg·ha⁻¹ (G-224) and banded and incorporated into the soil at plant emergence and again when plants were 15–20 cm long. Both treatment methods received phosphorus (112 kg·ha⁻¹) and potassium (168 kg·ha⁻¹) fertilizers applied in granular form at preplant; an additional side-dress of potassium (140 kg·ha⁻¹) was applied at plant emergence. In addition, weeds, insects, and diseases were managed using standard practices for the region (Zotarelli et al., 2015a).

Plant vine kill and tuber harvest intervals. Irrigation was stopped 2 weeks before vine kill (91 and 98 DAP in 2013 and 2014, respectively) which involved a single application of the chemical desiccant glufosinate ammonium (Rely® 280 Herbicide; Bayer Crop Science, Research Triangle Park, NC) applied at a rate of 1535 mL·ha⁻¹. Plots were manually harvested weekly for 3 weeks after vine kill (H1, H2, and H3); tubers were placed in mesh poly bags and transported about 90 min to the Postharvest Horticulture Laboratory at the University of Florida, Gainesville, for storage and analysis.

Storage test quality analysis. Average-sized tubers (150–200 g) from each NF treatment and field plot replicate ($n = 4$) were carefully sorted to remove defects, hand-washed under flowing tap water, fan-dried (about 30 min), and stored in mesh poly bags ($n = \approx 50$ tubers/bag) under simulated

commercial conditions of 10 °C, 80% to 85% RH. Tuber ($n = 56$) quality from each fertilizer treatment and each harvest interval was evaluated at harvest and after 7 and 14 d of storage.

Weight loss was determined at each evaluation on a fresh weight basis. Firmness measurements were made on longitudinal slices derived from central tuber region (20-mm thick, 1 slice/tuber), using a TA HD Plus Texture Analyzer Machine (Texture Technologies Corp, Scarsdale, NY) equipped with a 50-N load cell. Each slice was laid flat and punctured at the center (pith) to 4-mm depth using a convex-tip probe (4-mm diameter) at a loading rate of 2 mm·s⁻¹ and bioyield force was recorded. Dry matter content (wet weight basis) was determined from a 20-mm thick longitudinal slice, separated into periderm and pulp tissue, and dried at 65 °C for 48 h.

Three, 20-mm thick, longitudinal slices (one per replicate tuber per plot), were separated into periderm and pulp tissue. Pulp tissue was pureed in a Waring blender for 1 min, the slurry centrifuged (20 min; 15,000 × g_n ; 4 °C) using a Beckman model J2-21 centrifuge (Beckman Coulter Inc., Fullerton, CA), filtered through cheesecloth and the supernatant used for chemical analyses.

Soluble solids content was measured using a temperature-compensated digital refractometer (model ABBE Mark II; Cambridge Instruments Inc., Depew, NY) and expressed as percent fresh weight basis. Total titratable acidity and pH were determined from 3 mL of the supernatant, diluted with 50 mL deionized water. The mixture was filtered and titrated with 0.1 N sodium hydroxide solution to an endpoint of pH 8.2. Total titratable acidity was calculated using the amount of 0.1 N sodium hydroxide (in mL) multiplied by the conversion factor for malic acid (0.067), the predominant acid in potato (Ranganna, 1986). Ascorbic acid content was measured from 2 g of separated periderm and pulp tissues, using the AOAC (1984) procedure for the spectrophotometric determination of AAC (absorbance at $\lambda = 540$ nm). For more details, see Makani (2014).

Statistical analysis. Statistical analysis of each variable collected was performed using the general linear mixed model (PROC GLIMMIX) of SAS 9.3 (SAS Institute Inc., Cary, NC). An analysis of variance was performed separately for each cultivar to determine significant treatment effects for growing season, NF method of application and rate,

Fig. 1. Effects of N fertilizer method of application, rate, harvest interval, and storage period on fresh weight loss of 'Fabula' tubers during 14 d storage at 10 °C, 80% to 85% relative humidity (season 1). Fertilizer treatments: F-0, F-112, F-224, F-336 = 0, 112, 224, or 336 kg·ha⁻¹ of N applied as fertigation, respectively; G-224 = 224 kg·ha⁻¹ of N applied in granular form. Harvest intervals: H1, H2, H3 = 1, 2, or 3 weeks after vine kill, respectively. Error bars represent standard error at the 95% confidence interval.

and harvest interval. Treatment means were separated using Tukey's range probability test with 95% confidence limits.

Results and Discussion

Potato quality at harvest

There were dramatic differences in rainfall amount and timing between the two seasons. Season 1 had a cumulative rainfall of 454 mm; however, 56% (254 mm) of the total seasonal rainfall fell during the 3-week harvest period, with the majority falling just before H1. Rainfall in season 2 was significantly lower (394 mm), and the harvest period was quite dry, with only 9% (35 mm) falling during that time.

'Fabula'. At harvest, tuber firmness (11.9 N) and periderm DMC (10.9%) were unaffected by fertilizer treatment, harvest interval, or growing season (data not shown). A previous study using the same NF rate (224 kg·ha⁻¹) with drip irrigation reported higher pulp firmness for 'Fabula' and 'Red LaSoda' potatoes at H1 (18–24 N), but lower values for H2 and H3 (13–14 N), similar to those in this study; periderm DMC was also similar to the present study (Makani et al., 2015). With regard to pulp DMC, in season 1 the average for all harvest intervals was 14.1% (data not shown). However, in the drier season 2 and only for H1, pulp DMC from the F-0 treatment was higher (16.8%) than that from the F-224 treatment (13.8%) (Table 1). Porter and Sisson (1993), studying late-maturing cultivars, reported that increased NF rate negatively affected tuber dry matter accumulation (periderm and pulp tissues were combined). These authors attributed this difference to the plant diverting more nitrogen to vegetative growth than to tuber growth and development. However, in the current study, there was no clear correlation between fertilizer rate and DMC other than that observed for the single occurrence for tubers grown with F-0 or F-224 rates at H1.

Tuber SSC, TTA, and pH generally increased with increased fertilizer rate, independent of harvest interval or growing season (Table 2). Tubers grown under the fertigation treatments F-0 or F-112 had a significantly lower SSC (3.04%) than under F-336 or the granular treatment G-224 (average 4.14%). Tuber TTA followed a similar pattern; tubers from the fertigation treatment F-0 had a significantly lower content of 0.12%, compared with 0.15% with F224, F-336, or G-224. The lowest pH of 2.7 was for tubers grown with F-0, whereas that for tubers from the other fertilizer treatments ranged from pH 3.47–4.13.

NF supply affects the concentration of sucrose, which is the primary component of SSC in potato tubers (Halford et al., 2012) and the major transport form of photoassimilates from source to sink organs (Zrenner et al., 1995). In the current study, delayed periderm development under high N rates likely accounted for higher SSC, similar to findings in late-maturing cultivars (Iritani and Weller, 1973). The pH index determines deterioration potential by fermentation and enzymatic activity; maximum activity of invertase (sucrose breakdown) and phosphorylase (starch breakdown) enzymes occurs at pH 4.7 and 5.5, respectively (Pressey, 1966). Therefore, the higher pH for tubers from F-224, F-336, and G-224 (average 4.04) was indicative of a higher tendency to accumulate sugar over starch.

Harvest interval had the greatest effect on tuber AAC, which generally decreased as harvest interval increased; there was no effect because of fertilizer treatment or growing season. Tubers harvested at H1 had the highest periderm AAC (17.4 mg/100 g), decreasing to 13.2 mg/100 g at H2 and H3. Similarly, pulp AAC was 24.4 mg/100 g at H1 and 18.1 mg/100 g at H2 and H3 (data not shown). Previous results showed a similar trend for 'Fabula' and 'Red LaSoda' potatoes, although actual values were higher for the

Fig. 2. Effects of harvest interval and storage period on firmness of 'Fabula' tubers during 14 d storage at 10 °C, 80% to 85% relative humidity (seasons 1 and 2 combined). Harvest intervals: H1, H2, H3 = 1, 2, or 3 weeks after vine kill, respectively. Error bars represent standard error at the 95% confidence interval.

respective harvest intervals (Makani et al., 2015). The literature is replete with studies showing a decline in tuber AAC of medium-to-late-maturing cultivars when harvest is delayed (Perkins, 1993; Shekhar et al., 1978). This reduction in biosynthesis of AAC was attributed to vine death and natural senescence.

'Red LaSoda'. In season 1, tuber firmness at harvest was unaffected by NF treatment; at H1 and H2 firmness was 13.1 N, decreasing slightly but significantly to 11.8 N at H3 (data not shown). In season 2, the drier harvest period, tuber firmness was unaffected by fertilizer treatment or harvest interval and averaged 13.1 N (data not shown).

In season 1 only, pulp DMC at harvest was higher in tubers grown under F-0 (15.3%), compared with those from the other fertilizer treatments (13.7%) (data not shown); for 'Fabula', pulp DMC was higher for F-0 tubers

Table 3. Effects of N fertilizer method of application and rate, harvest interval and storage period on tuber periderm dry matter content of 'Fabula' during 14 d storage at 10 °C, 80% to 85% relative humidity (seasons 1 and 2 combined).

Harvest interval ^z	Storage period (d)	Periderm dry matter content (%)				
		Fertilizer treatment ^y				
		F-0	F-112	F-224	F-336	G-224
H1	0	10.9 bA ^x	11.1 bA	10.4 bA	10.8 bA	11.3 bA
	7	13.6 aA	13.6 aA	13.9 aA	13.9 aA	14.7 aA
	14	14.4 aA	14.3 aA	11.4 bB	14.1 aA	11.1 bB
H2	0	10.3 aA	10.8 aA	11.3 aA	10.1 aA	10.2 aA
	7	10.0 aA	11.6 aA	11.9 aA	11.5 aA	10.6 aA
	14	10.7 aA	11.4 aA	11.7 aA	10.6 aA	10.1 aA
H3	0	10.7 aA	11.4 aA	11.3 aA	11.7 aA	11.5 aA
	7	11.1 aA	10.5 aA	11.3 aA	12.1 aA	11.8 aA
	14	11.7 aA	11.0 aA	11.5 aA	12.4 aA	11.7 aA

^zHarvest intervals: H1, H2, H3 = 1, 2, or 3 weeks after vine kill, respectively.

^yFertilizer rates of F-0, F-112, F-224, and F-336 = fertigation rates of 0, 112, 224, or 336 kg·ha⁻¹, respectively. G-224 = granular application at 224 kg·ha⁻¹.

^xMeans within a column (fertilizer treatment) followed by the same small letter at each harvest interval, or by the same capital letter within a row (storage time), do not differ significantly according to Tukey's probability test ($P < 0.05$).

Fig. 3. Effects of harvest interval and storage period on cumulative fresh weight loss of 'Red LaSoda' tubers during 14 d storage at 10 °C, 80% to 85% relative humidity by season. Harvest intervals: H1, H2, H3 = 1, 2, or 3 weeks after vine kill, respectively. Error bars represent standard error at the 95% confidence interval.

Table 4. Effects of harvest interval and storage period on tuber periderm dry matter content of 'Red LaSoda' tubers during 14 d storage at 10 °C, 80% to 85% relative humidity (season 1).

Storage period (d)	Periderm dry matter content (%)		
	Harvest interval ^z		
	H1	H2	H3
0	14.9 bB ^y	14.9 cB	17.5 aA
7	17.5 aA	17.1 bA	16.4 aA
14	16.6 aB	19.6 aA	16.4 aB

^zHarvest intervals: H1, H2, H3 = 1, 2, or 3 weeks after vine kill, respectively.

^yMeans within a column (harvest interval) followed by the same small letter at each harvest interval, or by the same capital letter within a row (storage time), do not differ significantly according to Tukey's probability test ($P < 0.05$).

in season 2. Stress on these early-season cultivars grown under F-0 treatment may have been sufficient to interfere with tuber bulking, albeit for different seasons for each cultivar tested (Westermann et al., 1988). Yields were lowest for 'Fabula' and 'Red LaSoda' potatoes grown in F-0 (Makani et al., 2015). Potatoes grown at higher N rates synthesize and translocate more photosynthates to the tubers, resulting in higher yields (Kumar et al., 2007). Previous studies, where the peel and

pulp have not been separated, have shown increased DMC with increased N rate, up to the point of "overfertilization," with no significant increase thereafter (Kumar et al., 2007; Westermann et al., 1994) or a marked decline (Bombik et al., 2002). Findings from this study suggest that 224 kg·ha⁻¹ might have been the point of overfertilization, resulting in a decreased rate of dry matter translocation to the tubers during growth. However, weather conditions could have played a greater role in this as this was observed only during the drier season 2. The extremely heavy rainfall in season 1 likely caused more water uptake into the immature tuber periderm tissue, accounting for the lower periderm DMC at H1 and H2 (14.9%) than at H3 (17.5%), regardless of NF treatment (data not shown). In the drier season 2, fertilizer treatment and harvest interval had no significant effect on DMC for periderm (15.0%) or pulp (15.8%) for 'Red LaSoda' potatoes.

In both seasons, SSC was significantly lower at H1 in tubers grown under F-0 (2.98%) compared with the other fertilizer treatments (3.84%); SSC was 3.39% for tubers from H2 or H3 (data not shown). As mentioned previously, 'Fabula' tubers grown under F-0 had lower

SSC, regardless of harvest interval. Fertilizer treatment, harvest interval or season did not affect tuber AAC (13.6 and 18.1 mg/100 g for periderm and pulp, respectively), TTA (0.1%), or pH (3.9%) (data not shown). This may be attributed to an inherent early tuber development and maturation in 'Red LaSoda' tubers, as reported by Zotarelli et al. (2016a).

Potato quality during storage

'Fabula'. In season 1, cumulative weight loss in H1 tubers after 14 d of storage ranged from 3.0% to 4.4%, compared with 1.2% to 3.4% for those from H2 or H3 (Fig. 1). The significantly higher weight loss in H1 tubers, regardless of fertilizer treatment, was likely due to poor barrier properties of immature skin to water vapor loss from the pulp (Sabba and Lula, 2002). Suberin, a complex biopolymer embedded with soluble waxes, is deposited on the periderm during tuber growth and after harvest, minimizing cellular desiccation of the tuber inner tissues (Burton, 1989); suberization occurs at a higher rate with delayed harvest (Tyner et al., 1997). Tubers grown under F-0 had similar cumulative weight loss during storage for the three harvest intervals; however, those from H2 and H3 lost more weight during storage (3.2%) compared with the other fertilizer treatments (1.3%), an indication that the rate of suberin deposition during storage was negatively affected by N deprivation during growth.

In season 2, cumulative weight loss was higher for tubers from H1 and H2 (4.4%) than those from H3 (2.5%) (data not shown). The generally drier weather conditions during this growing season may have favored more uniform periderm maturation, regardless of fertilizer treatment. In both growing seasons, tubers had the highest fresh weight loss during the first 7 d of storage for all harvest intervals, further supporting the negative relationship between weight loss and periderm suberization.

There was no effect of fertilizer treatment or growing season on tuber firmness during storage; tubers from H1 increased in firmness from an initial of 11.8–13.3 N at 7 d, then decreased to 12.8 N at 14 d (Fig. 2). Gamea

et al. (2009) attributed the increase in firmness at the beginning of storage to high pulp elasticity resulting from high weight loss. This short-term effect may have been overlooked in other previously published studies with late-maturing potatoes, where firmness decreased during much longer storage periods of 6 to 9 months (Jablonski, 2006). Lower rate of weight loss in the more mature H2 tubers likely accounted for a significant increase in firmness at 14 d; firmness for H3 tubers increased slightly after 7 d storage.

Periderm DMC was initially 10.9% for tubers from H1, the least mature tubers, increasing to 13.9% after 7 d storage, irrespective of NF treatment or rate, or season (Table 3). Only the F-224 and G-224 treatments decreased after 14 d. Water loss may have concentrated the starch content in cells, which typically constitutes 70% to 75% of the DMC (Lisinska and Leszczynski, 1989). There was no effect on periderm DMC for tubers from H2 or H3 because of NF treatment or rate, or storage time, similar to results for 'Fabula'. Tuber pulp DMC remained constant during storage (14.6%; data not shown). Because periderm and pulp tissues comprised very different types of cells, it is likely they reacted differently to the same treatment.

There was no interaction between fertilizer treatments, harvest interval, and storage time on the selected compositional qualities of 'Fabula'; tuber SSC, TTA, and pH averaged 3.59%, 0.14%, and 3.86%, respectively (data not shown). AAC was 14.6 and 20.1 mg/100 g for periderm and pulp tissues, respectively. These results suggest that storage at 10 °C, 80% to 85% minimized the conversion of starch to sugars during the storage period.

'Red LaSoda'. In season 1, H1 tubers lost the most weight during storage, irrespective of the fertilizer treatment; cumulative weight loss was 2.2% after 14 d, whereas that for H2 and H3 averaged 0.7% (Fig. 3). There was a similar trend in season 2, although both H1 and H2 tubers lost 2.7%, compared with 1.2% for tubers from H3. Similar to studies with other potato cultivars, delayed harvest permitted increased deposition of suberin waxes in the tuber periderm, thereby minimizing weight loss for tubers from the later harvest intervals. Late-maturing cultivars, however, show increasing weight loss with higher NF rates (Jablonski, 2006).

Tuber firmness in 'Red LaSoda' tubers averaged 12.7 N throughout storage regardless of fertilizer treatment, harvest interval, or growing season (data not shown). The likely reason was that cumulative weight loss remained <3%, in contrast to 'Fabula' tubers, which generally experienced higher weight loss and changes in firmness.

In season 1, periderm DMC for H1 tubers increased after 7 d storage and remained constant (17.1%), whereas that for tubers from H2 increased to 19.6% after 14 d (Table 4). Tubers from H3 were initially highest in periderm DMC and remained

constant during storage (16.8%), an indication of greater periderm maturity at harvest. In the less rainy season 2, periderm DMC remained constant during storage, averaging 15.4%. This is consistent with the report that less mature tubers transpired more water via the periderm, resulting in higher periderm DMC (Lisinska and Leszczynski, 1989). By contrast, pulp DMC remained constant during storage (16.8%) for both seasons, indicating that storage conditions limited weight loss due to transpiration (data not shown).

There were no significant changes in tuber composition during 14 d storage, for SSC (3.8%), TTA (0.2%), pH (4.2), and AAC (13.6 and 18.1 mg/100 g for periderm and pulp tissues, respectively (data not shown). This suggests that storage of tubers at 10 °C, 85% to 85% RH minimized oxidative and enzymatic degradation, supporting previous findings for long-term storage studies of late-maturing cultivars (Augustin et al., 1975).

Conclusions

NF application method and rate, and harvest interval affected the tuber harvest quality of early-maturing cultivars 'Fabula' and 'Red LaSoda' grown in spring seasons. Tubers grown with NF rates of 224 kg·ha⁻¹ or 336 kg·ha⁻¹ (fertigation only) were generally less compositionally mature at harvest (higher SSC, TTA, and pH) than those grown under 112 kg·ha⁻¹. Both cultivars harvested 1 week after vine kill were less physically mature (less-developed periderm) than those harvested 2 or 3 weeks later. Tuber physical maturity at harvest was a key determinant of storability; tubers harvested 1 week after vine kill had higher losses in tuber quality during 14 d storage at 10 °C, 80% to 85% RH (higher cumulative weight loss and higher pericarp DMC) than tubers harvested later. Tubers from both cultivars grown with NF rates of 112, 224, or 336 kg·ha⁻¹ had physical and compositional quality equivalent to those grown with the granular treatment of 224 kg·ha⁻¹ NF during storage; best storage quality resulted from tubers harvested 2 or 3 weeks after vine kill.

These results also show the potential to use a lower nitrogen rate (112 kg·ha⁻¹) with fertigation as a means of improving water and nitrogen-use efficiency, whereas minimizing storage quality losses for these early-maturing potato cultivars grown in subtropical areas.

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