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Research Article

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Tuber Yield, Water Productivity and Post-harvest Quality of Sprinkler-irrigated Chip Potato (*solanum tuberosum* L.) Under a Semiarid Climate

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Abstract
The potato chip industry has critical requirements regarding tuber physical and chemical aspects and these requirements are the characteristics targeted by chip potato breeding programs. This study aimed to evaluate 33 chip potato cultivars for the tuber yield and some physical and chemical characteristics of the tuber and potato chips at harvest and during cold storage period. Field experiments were conducted during the 2017 and 2018 growing seasons under sprinkler irrigation. Twenty-one cultivars were evaluated in 2017 and 22 cultivars were evaluated in 2018 using a randomized complete block design with four replications. The target traits under this study were tuber yield, tuber size, internal and external defects, sucrose and glucose content of the tuber and the chip color at harvest and during storage time. Fresh potato tuber yield varied with cultivar and ranged from 44.7 to 72.1 t/ha, averaging 58.5t/ha in 2017 and 60.8 t/ha in 2018. In 2017, cultivar NDTX081648CB-13W obtained the highest tuber yield and TX09396-1W obtained the lowest, while in 2018, Lamoka obtained the highest tuber yield and MSW044-1obtained the lowest. Cultivars NDTX081648CB-13W, MSW485-2, Atlantic, ACO1144-1W, and WANETA were the highest yielding cultivars in 2017, and Lamoka, HODAG, NICOLET, DAKOTA PEARL, and AF5429-3 were the highest yielding cultivars in 2018. Potato tuber size class of 4.7-8.75 cm was the most dominant and accounted for 93% in 2017 and 89% in 2018, respectively. Potato tuber specific gravity varied from 1.08-1.11 during both growing seasons and the dry matter content of the tubers ranged from 17.2 to 22.2% W9968-5 and MSV030-4 showed the highest internal defects of 47.2% and 33.7%, respectively, at harvest. W9968-5 still showed the highest external defects during the storage period. CO07070-13W, NDA081453CAB-2C and NY157 showed some internal defects during storage time in 2017. In 2018, NDA081453CAB-2C presented very high undesirable chip color (71.1%) followed by ND7519-1 (33.1%). In 2018, NDTX081648CB-13W, NY152 Niagara, and MSV313-2 showed relatively high internal defects (>15%) while Atlantic, MSV313-2, MSV358-3 and W9968-5 showed the highest external defects. During eight months of cold storage, NY162 showed 44.5% of external defects followed by MSV358-3 (24.6%), MSV313-2 (24%) and W9968-5 (20%). NY162 showed the highest total defects of 44.5% followed by MSV358-3, MSV313-2 and W9968-5 with total defects greater than 20%. Overall, there was a decrease in sucrose contents in the tubers after six months of cold storage except for the cultivars AF5040-8 and NDA081453CAB-2C. It increased thereafter during eight months in cold storage. However, sucrose content of the tubers at the end of the storage period was lower than the sucrose content at harvest except for B2727-2, NDA081453CAB-2C, NDTX081648CB-13W, and CO07070-13W. Significantly 100% increase in sucrose content in tubers of AF5040-8, DAKOTA PEARL, MSW485-2 Huron, MSX540-4 Mackinaw, NDA081453CAB-2C, and NDTX081648CB-13W was observed during the storage period. Glucose content of tubers changed during the storage period and was more noticeable in AF5040-8, AF5040-8, DAKOTA PEARL, MSW485-2 Huron, MSX540-4 Mackinaw, ND7519-1, NDA081453CAB-2C, and NDTX081648CB-13W. There was considerable increase in glucose content in ACO1144-1W, NDA081453CAB-2C, NDTX081648CB-13W, CO07070-13W, and W9968-5 tubers. At nine-month storage period, only Lamoka, ACO1144-1W, AF5040-8, MSX540-4, and CO02321-4W, HODAG, MSV030-4, MSW044-1, NY152 Niagara, NY162, and WANETA HODAG showed nice chip color. NDA081453CAB-2C, NDTX081648CB-13W, ND7519-1, and NDA081453CAB-2C presented the least desirable chip color with score "5". Cultivars with consistent scores of "1" constitute promising lines for chip potato producers across the dry and hot environment of the southwest region of the United States.

Introduction
Potato (*Solanum tuberosum L.*) is the fourth largest produced crop worldwide after maize, paddy rice and wheat with 487.4 million tons of tuber produced in 2017 and is widely used in different diets and animal feed [1]. Potatoes are a very popular food source worldwide in the form of french fries, chips, snacks, baked potatoes, boiled and

mashed potatoes. Chip potato is particularly produced for different types of snacks and french fries and there are different requirements for the potato processing industry. Nacheva and Pevicharova indicated that round-oval tubers are appropriate for potato chips and the long-oval tuber are preferable for french fries with other qualitative characteristics [2]. Variation in potato chips color is 90% attributed to reducing sugar while 98% of the color variation may be attributed to both reducing sugar and amino acids [3, 4]. It is therefore customary to use chip color as the main breeding trait beyond the internal and external defects and the agronomic traits which are also very important for production system profitability. Dale and Mackay and Haase indicated that the dry matter content of potato tuber linked with specific gravity is a main determinant of potato quality [5,6]. Potato dry matter content has been grouped as high dry matter content (≥20%), intermediate (between 18 and 19.9%), and low (≤17.9%) [7]. Dry matter content ≥ 20% and a specific gravity ≥ 1.08 are standard references of the processing industries [6,8]. Soil characteristics impact tuber yield and the characteristics of the potato tubers [9,10]. Abebe et al. reported that whenever potato yield was significantly dependent on genotype, the production site influenced the yield with significant genotype-environment interaction [11]. Po et al. reported that soil physical and chemical properties, and spectral reflectance induced more than 60% of tuber yield variability [12]. Fertilizer management, planting date and harvesting date affect potato specific gravity and dry matter content [13]. Zotarelli et al. and Nyiraneza et al. found that chip potato tuber yield was influenced by cropping system and source, rate, and timing of nitrogen fertilizer applied [14,15]. Rak et al. evaluated 47 breeding lines and 6 checks under 8 different storage environments and found that genotypes responded differently to the storage environment in terms of chip color, and the breeding clones W5840-4, W6484-5 and W6929-1 showed better performance compared to the checks in terms of chip quality and stability [16]. The stability of potato chip color during a long cold storage period is commercially preferred by processors. Paget et al. reported genotypes and environment interaction and concluded that newly developed potato varieties showed higher yield stability compared to the commercially established varieties in New Zealand [17]. From the evaluation of 18 potato cultivars in São Manuel (Brazil), Feltran et al. concluded that potato technological characteristics were influenced by cultivars [18]. Cari et al. investigated genetic covariance of 337 potato clones across 10 US states from 2011 to 2016 for genetic covariance and found that the genetic correlation between locations was 0.50 for vine maturity, 0.54 for tuber yield, and 0.72 for specific gravity [19]. Among their results, Florida showed up to 88% of genetic variance for vine maturity, and Texas was separated out for tuber yield; as such, their study is instrumental in documenting multi-location trial and breeding programs for the US potato industry.

Therefore, the chip potato breeding program targets these traits and the evaluation of breeding lines is very important for their adaptability and quality requirements. Tuber content in reducing sugars (glucose and fructose) impacts the flavor and the color of the processed products [20]. The objective of this study was to identify better fresh chip cultivars for direct field harvest than the standard Atlantic and better storage varieties than the current standards Lamoka and Snowden used as references for storage quality.

Materials and Methods

Study Area

The field experiment was conducted at the New Mexico State University (NMSU) Agricultural Science Center at Farmington (Latitude 36.69' North, Longitude 108.31' West, Elevation: 1720m) during the 2017 and 2018 growing seasons. The study area is dominated by a semiarid to arid climate with average annual precipitation of about 200 mm with large inter-annual variability. Minimum air temperature (Tmin), maximum air temperature (Tmax), average air temperature (Tmean), mean relative humidity (RHmean), wind speed (u2), solar radiation (Rs) and precipitation were collected on a daily basis from an automated weather station installed at the site by the New Mexico Climate Center. Trends in daily average weather conditions for the 2017-2018 period are presented in Figure 1. The soil at the study site is a fine sandy loam with pH higher than 8.

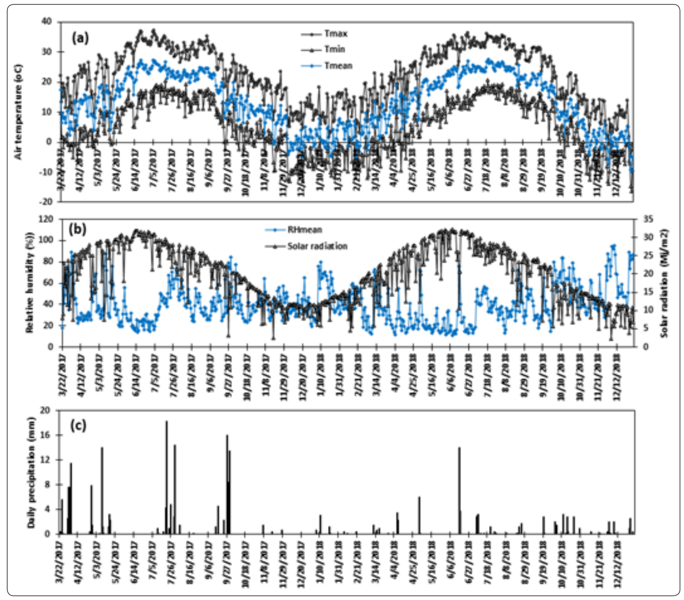

Figure 1: Variation in the (a)maximum and minimum air temperature, (b) relative humidity anddaily solar radiation, and (c)precipitation, from March 22, 2017 to December 31, 2018.

Experimental Design and Crop Management

Twenty-one and twenty-two potato cultivars were evaluated during the 2017 and 2018 growing seasons respectively [21,22]. Seed pieces were cut to 71g average size and planted at ten-inch (25 cm) seed spacingon April 13 and 18 in 2017 and 2018, respectively, and harvested on September 26 and 18 in 2017 and 2018, respectively. Plot size was four rows of twelve potato seeds and the experiments were set up with four replications in a randomized complete block design. The 2017 plots were fallow in 2014-2016 and the 2018 plots were sown with Sudan sorghum grass and fallow in 2014-2016. Applied fertilizer rates were 269 kg/ha Nitrogen (N), 136 kg/ha Phosphorus (P_2O_5), and 336 kg/ha Potassium (K_2O). In 2018, fertilizer was applied based on soil test results: 202 kg/ha Nitrogen (N), 135 kg/ha Phosphorus (P_2O_5), and 336 kg/ha Potassium (K_2O). Potato plants were treated in 2017 and 2018 with different pesticides as summarized in Tables 1 and 2. For each plot, the central two rows were harvested, the total fresh tuber weights were measured, and the tubers were counted and sized with reference to potato grading scale. Tubers were checked for external and internal physiological defects (discoloration, hollow heart, internal necrosis, brown spots, Presence of stem). Specific gravity was determined for each cultivar.

Postharvest Analysis

For postharvest quality examination in terms of bruise simulation, internal and external defects, and fry chip color, two bags of about

25 kg of each cultivar were stored in a cold room and kept over progressive stage periods (3, 6 and 9 months). Ten tubers of each cultivar were also sliced longitudinally for external and internal defects. Tubers in storage were periodically collected (25 tubers per cultivar), peeled and fried at 185ºC and chip color was evaluated and scored [21]. Sucrose and glucose contents of the tubers were determined. The fries were rated on the visual subjective scale from 1 to 5, with 1 representing a white flesh color and 5 the dark gray color. Potato varieties Lamoka and Snowden were used as controls. Potato crop water use and water productivity Potato actual crop evapotranspiration was estimated according to the equation proposed by Jenson and Allen et al. [22,23].

$$ETa = Kc \times ETo \quad (1)$$

where *ETa* = daily actual evapotranspiration (mm), *Kc* = daily crop coefficient, and *ETo* = Penman-Monteith grass reference evapotranspiration (mm).

Daily grass-reference ET was computed using the standardized ASCE form of the Penman-Monteith (PM-ETo) equation [23].

$$ETo = \frac{0.408\Delta(Rn - G) + (\gamma Cn\, u2/(T + 273))(es - ea)}{\Delta + \gamma(1 + Cd\, u2)} \quad (2)$$

where *ETo* is the reference evapotranspiration (mm day^{-1}), Δ is the slope of saturation vapor pressure versus air temperature curve (kPa °C^{-1}), Rn is the net radiation at the crop surface (MJ m^{-2} d^{-1}), G is the soil heat flux density at the soil surface (MJ m^{-2} d^{-1}), T is the mean daily air temperature at 1.5-2.5 m height (°C), *u*2 is the mean daily wind speed at 2 m height (m s^{-1}), es is the saturation vapor pressure at 1.5-2.5 m height (kPa), ea is the actual vapor pressure at 1.5-2.5 m height (kPa), *es* - *ea* is the saturation vapor pressure deficit (kPa), *γ* is the psychrometric constant (kPa °C^{-1}), *Cn* and *Cd* are constants with values of 900 °C mm s^{3} Mg^{-1} d^{-1} and 0.34 s m^{-1}. The procedure developed by Allen et al. was used to compute the needed parameters [23].

Potatoes were grown under non-limiting water and fertilizer conditions, and the standard FAO crop coefficient values were used [23]. Potato crop coefficients developed under a standard climatic condition, as 0.5, 1.15 and 0.75 for the initial, mid-season and late-season were also used to estimate potato ETa for the study period [23].

Crop water productivity was defined as the ratio of crop tuber yield to seasonal crop evapotranspiration (CWUE) and was estimated by the ratio of crop tuber yield to seasonal irrigation [24,25]:

$$CWUE = \frac{Tuber\ Yield}{Potato\ seasonal\ ETa} \quad (3)$$

Statistical Analysis

Potato tuber yields were analyzed using the analysis of variance in SAS and the least significant difference was used for pairwise tuber yields comparisons [26].

Table 1: Pesticide program used during the 2017 potato growing season at NMSU Farmington

Chemical		EPA	AI	Rate/	Unit	Date
Name	Type †	(No.)	(%)	acre		
Glory	herbicide	66222-106	75	0.5	lbs.	1-May
Tifluex HFP	herbicide	66222-46	42.7	0.66	pt.	1-May
Dual Mag	herbicide	100-816	83.7	1.5	pt.	1-May
Matrix SG	herbicide	352-768	25	1.5	oz.	20-May
Quadris Top	fungicide	100-1313	29.6	12	oz.	25-Jun
Bravo Weather Stik	fungicide	50534-188-100	54	8	pt.	25-Jun
Actara	insecticide	100-938	25	3	oz.	6-Jun
Bravo Weather Stik	fungicide	50534-188-100	54	8	pt.	2-Jul
Actara	insecticide	100-938	25	3	oz.	2-Jul
Revus Top	fungicide	100-1278	43.6	7	oz.	9-Jul
Sivanto Prime	insecticide	264-1141	17.1	14	oz.	9-Jul
Status	fungicide	7969-242	61.1	10	oz.	22-Jul
High Load	S-CO	N/A	N/A	6.4	oz.	22-Jul
Minecto Pro	insecticide	100-1592	15.4	10	oz.	6-Aug
Scala SC	fungicide	264-788	54.6	7	oz.	6-Aug
Bravo Weather Stik	fungicide	50534-188-100	54	8	pt.	6-Aug
Tanos	fungicide	352-604	50	8	oz.	13-Aug
Bravo Weather Stik	fungicide	50534-188-100	54	8	pt.	13-Aug
Sivanto Prime	insecticide	264-1141	17.1	14	oz.	13-Aug
Tanos	fungicide	352-604	50	8	oz.	19-Aug
Bravo Weather Stik	fungicide	50534-188-100	54	8	pt.	19-Aug
Movento	nematicide	264-1050	22.4	5	oz.	19-Aug

Tanos	fungicide	352-604	50	8	oz.	26-Aug
Bravo Weather Stik	fungicide	50534-188-100	54	8	pt.	26-Aug
Mustang Max	insecticide	279-3426	9.15	4	oz.	26-Aug
Reglone	desiccant	100-1061	37.3	32	oz.	1-Sep
Brimstone	herbicide	N/A	N/A	12	oz.	1-Sep
Super Tim 4L	fungicide	70506-212	40	4	oz.	1-Sep
Ranier EA	desiccant	2935-50200	NA	6.4	oz.	1-Sep
Reglone	desiccant	100-1061	37.3	32	oz.	6-Sep
Brimstone	herbicide	N/A	N/A	12	oz.	6-Sep
Super Tim 4L	fungicide	70506-212	40	4	oz.	6-Sep
Ranier EA	desiccant	2935-50200	N/A	6.4	oz.	6-Sep

Table 2: Pesticide program used during the 2018 potato growing season at NMSU Farmington

Chemical		EPA	AI	Rate/	Unit	Date
Name	Type	(No)	(%)	acre		
Metribusin	herbicide	68222-106	75%	0.4	lbs.	5-May
Tuscany	herbicide	71368-102	51.00%	1	oz.	5-May
Parallel	herbicide	68222-87	84.40%	1.33	pt.	5-May
Quadris	fungicide	100-1098	23.00%	15.5	oz.	22-Jun
Bravo Weather Stik	fungicide	66222-276	54%	16	oz.	22-Jun
Sivanto Prime	insecticide	264-1141	17.09%	14	oz.	22-Jun
Actara	insecticide	100-938	25%	3	oz.	7-Jul
Bravo Weather Stik	fungicide	50534-188-100	54%	16	oz.	7-Jul
Quadris Top	fungicide	100-1313	30%	14	oz.	7-Jul
Ridomill Gold SL	fungicide	100-1202	45%	6.2	oz.	21-Jul
Bravo Weather Stik	fungicide	50534-188-100	54%	16	pt.	21-Jul
Movento	nematicide	264-1050	22.40%	5	oz.	21-Jul
Leverage	insecticide	254-770	17.00%	3.8	oz.	21-Jul
Endura	fungicide	7669-197	70	10	oz.	4-Aug
Bravo Weather Stik	fungicide	50534-188-100	54%	16	oz.	4-Aug
Agri-Mek SC	insecticide	100-1351	8%	3.5	oz.	4-Aug
Revus Top	fungicide	100-1278	43.60%	7	oz.	18-Aug
Bravo Weather Stik	fungicide	50534-188-100	54%	16	oz.	18-Aug
Sivanto Prime	insecticide	264-1141	17.09%	14	oz.	18-Aug
Leverage	insecticide	254-770	17.00%	3.8	oz.	18-Aug
Reglone	desiccant	100-1061	37.30%	32	oz.	24-Aug
Brimstone	surfactant oil	NA	NA	12	oz.	24-Aug
Ranier EA	surfactant oil	2935-50200	NA	6.4	oz.	24-Aug
Reglone	desiccant	100-1061	37.30%	32	oz.	31-Aug
Brimstone	surfactant oil	NA	NA	12	oz.	31-Aug
Ranier EA	surfactant oil	2935-50200	NA	6.4	oz.	31-Aug

Results and Discussion

Potato Actual Evapotranspiration

Daily crop evapotranspiration varied from 1.1 to 10.2 mm and averaged 5.6 mm/day during the 2017 growing season while it varied from 1.2 to 9.8 mm/day and averaged 5.8 mm/day during the 2018 growing season (Figure 2). Seasonal evapotranspiration was 857.6 mm in 2017 and 869.3 mm in 2018. Daily ETa increased with crop growth and development and was at its peak values from 66 DAP to 107 DAP in 2017 and 67 DAP to 113 DAP in 2018. The results of this study are slightly higher that the findings of other studies. Alva et al. reported potato seasonal ETa of 825 mm in Benton County, WA under a Quincy fine sand soil [27]. The high ETa might be the result of a very high water demanding climate in the semiarid environment where air relative humidity during the potato growing season from April to September was 43% in 2017 and 36% in 2018 and the average daily temperature was 18.8 and 20.2^{o}C in 2017 and 2018, respectively. However, ETa values were reported under similar semiarid environment where potatoes are produced.Kiziloglu et al. reported well irrigated potato seasonal evapotranspiration of 475.2 mm in Erzurum-Turkey with the highest tuber yield of 26.9 t/ha [28]. Much lower potato ETa values were reported elsewhere; potato seasonal evapotranspiration varied with irrigation method from 375.7 to 511.4 mm under arid climate in Iraq [29]. Under hot and dry climate in Spain, evapotranspiration values recorded for potato variety Desiréeranged from 150 to 550 mm relative to different irrigation rates [30]. Results of this study are quite higher than the findings of Kiziloglu et al. and Erdem et al. who reported seasonal potato ETa range of 445-683 mm in semiarid climatic conditions of Turkey [28,31].

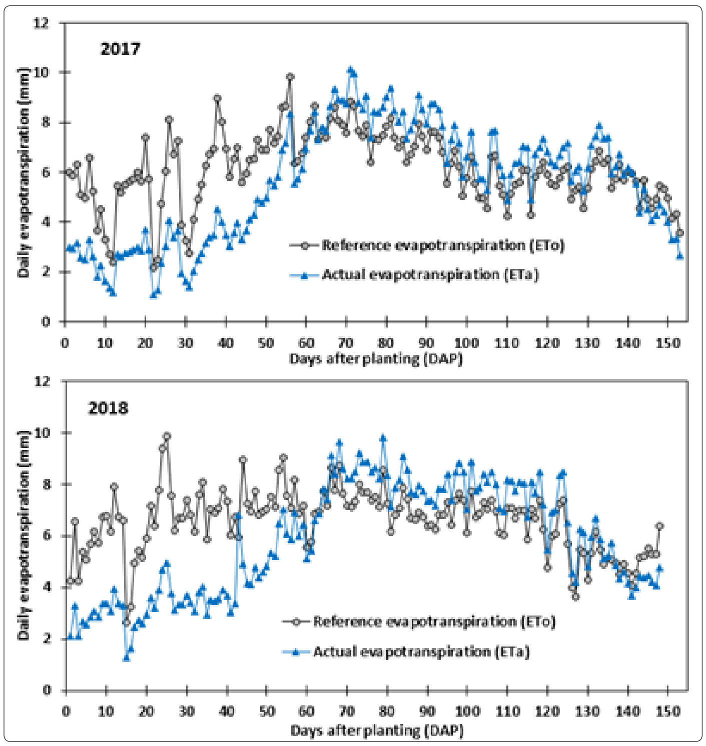

Figure 2: Trends in the daily grass reference evapotranspiration and potato actual evapotranspiration during the 2017 and 2018 growing seasons

Potato Tuber Yield and Yield Components

Tuber yield was a function of potato cultivar and varied from 44.7 to 71.4 t/ha in 2017 and from 50.9 to 72.1 t/ha in 2018, and averaged 58.5t/ha and 60.8 t/ha in 2017 and 2018, respectively (Tables 3 and 4). In 2017, potato cultivar NDTX081648CB-13W obtained the highest tuber yield, and the lowest tuber yield was obtained by TX09396-1W; while in 2018, Lamoka obtained the highest tuber yield, and the lowest tuber yield was obtained by MSW044-1. The first five top yielding cultivars during the 2017 growing season were NDTX081648CB-13W, MSW485-2, Atlantic, ACO1144-1W, and WANETA. The best five cultivars in 2018 were Lamoka, HODAG, NICOLET, DAKOTA PEARL, and AF5429-3. However, all the cultivars used in this study performed better than the overall common average potato tuber yield of 42 t/ha, showing their yielding potential and adaptability to the study environment [32]. However, good agricultural management practices should be adopted for the production sustainability and yield stability. Variation in potato tuber yield was observed for the same potato cultivars between 2017 and 2018. These finding are in agreement with Trifonov et al., who reported potato tuber yield that varied from 44.9 to 70.96 t/ha under dry desert climate in Israel [33]. Tuber yield of the potato variety Folva under coarse sand soil ranged between 60 and 66 t ha^{-1} in 2005 and between 42.4 and 41.7tha^{-1} in 2006 in Denmark [34,35]. Similar tuber yield was reported by Ahmadi et al.[36]. Radouani and Lauer reported potato variety Nicola tuber yield range of 50.16-57.98 t/ha and the variety Russet Burbank yield range of 15.63-49.07 t/ha as a function of seed weight under light sandy soil conditions in Morocco [37].

Tuber yield components varied with potato cultivars and production year. The average number of tubers per plant varied from 4.1 to 12.4 in 2017 and from7.6 to 17.5 in 2018. Average tuber weight varied from 121.9 to 226.8 g in 2017 and from 96.4 to 187.1 g in 2018. The number of tubers was negatively correlated with the weight of the tuber, and the tuber diameter size of 4.7-8.75 cm was the most dominant (about 93% and 89% in 2017 and 2018, respectively), while the small size tuber below 4.7 cm represented 4.3% in 2017 and 5.2% in 2018, respectively. The larger tuber size (>8.8 cm) represented 3.0% in 2017 and 6.1% in 2018. These yield characteristics are in accordance for making potato chips. Potato tuber specific gravity was clustered within the range of 1.08-1.11 during both growing seasons, and the dry matter content of the tubers ranged from 17.2 to 21.3% in 2017 and from 18.3 to 22.2% in 2018. Specific gravity is a major characteristic of interest in the processing value chain. The lower the specific gravity is, the higher the water content is and the costlier it is to process the potato.

Potato Water Productivity

Average water productivity was estimated as the ratio of tuber fresh yield to the average seasonal ETa. CWUE varied from 52.1 to 83.2 kg/ha/mm in 2017 and from 58.5 to 83 kg/ha/mm in 2018. CWUE averaged 68.2 and 70.0 kg/ha/mm in 2017 and 2018, respectively. The estimated CWUE is a little subjective as crop water use estimation did not consider cultivar specificity (in terms of plant architecture, biomass development, leaf area index, canopy coverage, growth stages duration, optimum fertilizer recommendation, etc.), and some cultivars might with better above ground development have had higher ETa compared to cultivars with reduced above ground biomass and lower canopy coverage or a shorter growing season. Wolfe et al. reported differences in crop actual ETa of two potato cultivars [38]. On the basis of average seasonal ETa, NDTX081648CB-13W and Lamoka obtained the highest CWUE in 2017 and 2018, respectively. These results are in agreement with Ati et al., who reported potato water productivity range of 51.3 – 102.6 kg/ha/mm under drip and furrow irrigation under semiarid climate in Iraq [29]. The CWUE values in the current study are lower than potato water productivity values reported under similar climatic conditions in other locales.

Impact of Storage Duration on Potato Tuber and Chip Quality

Traits like tissue color, external and internal defects, sucrose and glucose contents, and chip color and bruising were evaluated at harvest and during storage time. The sucrose and glucose contents of the cold-stored tubers were quantified using high-performance liquid chromatography. Potato tuber defects varied with cultivar.

At harvest, the cultivar W9968-5 showed the highest rate of undesirable color (10%) followed by NDTX081648CB-13W (2%), while NDA081453CAB-2C showed 10% of undesirable color after six months in storage and NDTX081648CB-13W showed the highest undesirable color after eight months in storage, for the 2017 harvest (Table 3). Overall, almost all cultivars had good internal quality without major defects, however, the internal defects were pronounced at up to 47.2% for W9968-5 and 33.7% for MSV030-4 at harvest. W9968-5 still showed the highest external defects during the storage period, after showing the highest total defects at harvest. Some internal defects appeared during storage period in CO07070-13W, NDA081453CAB-2C and NY 157. For the 2018 harvest, NDA081453CAB-2C presented very high undesirable chip color (71.1%) followed by ND7519-1 (33.1%), and the majority of cultivars had minor undesirable color (<2%). NDTX081648CB-13W, NY152 Niagara, and MSV313-2 showed relatively high internal defects (>15%) while Atlantic, MSV313-2, MSV358-3 and W9968-5 showed the highest external defects, between 10 and 18%. MSV313-2, MSX540-4 Mackinaw, NDTX081648CB-13W, NY152, and Niagara, NY162 showed internal defects higher than 10% and the cultivars MSV313-2, NDTX081648CB-13W, and NY152 Niagara showed total defect levels of greater than 20%, and may not be desirable for the commercial chip potato firm. Overall, MSV313-2 presented the highest total defects (32%) for the 2018 harvest. During eight months of cold storage, the internal quality of the potato tubers was improved and the external defects were worsening. The cultivar NY162 showed 44.5% of external defects followed by MSV358-3 (24.6%), MSV313-2 (24%) and W9968-5 (20%). Potato cultivar NY162 showed the highest total defects of 44.5% followed by MSV358-3, MSV313-2 and W9968-5 with total defects greater than 20% (Table 4).

Table 3: Tuber yield of potato cultivars planted in 2017 and chip quality of stored harvest

Cultivars	Tuber Yield (t/ha)	#tuber /plant	Tuber weight g	Tuber seize < 4.7 cm %	4.7-8.75cm %	>8.75cm %	culls %	specific gravity	solids %	27-Oct-17 undesirable color	internal defect	external defect	Total defects	sucrose mg/g	glucose mg/g	chip color	16-Mar-18 undesirable color	internal defect	external defect	Total defects	sucrose mg/g	glucose mg/g	chip color	2-May-18 undesirable color	internal defect	external defect	Total defects	sucrose mg/g	glucose mg/g	chip color
ACO1144-1W	66.4	9.8	167.3	4.5%	94.0%	1.5%	0.0%	1.088	18.3%	0.0%	0.0%	4.9%	4.9%	0.300	0.000	1.0	0.0%	0.0%	9.5%	9.5%	0.174	0.001	1.5	3.2%	0.0%	0.0%	3.2%	0.275	0.015	1.0
AF 5040-8	59.5	8.2	170.1	3.9%	94.9%	1.3%	0.0%	1.105	21.2%	0.0%	0.0%	19.4%	19.4%	0.601	0.000	1.5	0.0%	0.0%	1.5%	1.5%	0.197	0.011	1.5	0.0%	0.0%	4.9%	4.9%	0.619	0.008	1.0
B 2727-2	50.3	7.1	170.1	4.7%	94.3%	1.0%	0.0%	1.090	18.7%	0.0%	0.0%	21.4%	21.4%	0.473	0.026	1.0	0.0%	0.0%	6.3%	6.3%	0.576	0.012	1.0	1.0%	0.0%	2.6%	3.6%	0.605	0.003	1.5
LAMOKA	56.2	6.7	198.4	1.4%	96.1%	2.6%	0.3%	1.094	19.3%	0.0%	0.0%	11.7%	11.7%	0.516	0.000	1.0	0.0%	0.0%	6.8%	6.8%	0.400	0.012	1.0	0.0%	1.0%	1.1%	2.1%	0.316	0.001	1.0
MRS 127-2	53.6	6.5	161.6	6.0%	93.5%	0.5%	0.0%	1.092	18.9%	1.7%	0.0%	28.7%	30.4%	0.263	0.010	1.5	0.0%	5.3%	5.3%	10.6%	0.298	0.004	1.5	0.0%	1.0%	8.9%	9.9%	0.353	0.017	2.0
MSV 358-3	55.0	6.8	175.8	3.1%	94.8%	2.1%	0.3%	1.091	18.8%	0.0%	0.0%	18.8%	18.8%	0.622	0.034	1.0	0.0%	2.2%	11.2%	13.4%	0.265	0.003	1.0	4.5%	4.8%	0.0%	9.3%	0.457	0.023	2.0
MSW 485-2	69.3	8.2	164.4	3.8%	94.6%	1.5%	0.0%	1.100	20.4%	0.0%	0.0%	29.4%	29.4%	0.447	0.006	1.0	0.0%	0.0%	3.4%	3.4%	0.385	0.007	1.5	2.1%	0.0%	6.4%	8.5%	0.484	0.008	1.5
MSX540-4	54.1	7.4	158.8	4.3%	93.7%	2.1%	0.0%	1.100	20.4%	0.0%	0.0%	10.4%	10.4%	0.813	0.007	1.0	0.0%	0.0%	3.6%	3.6%	0.452	0.001	1.5	0.0%	0.0%	4.8%	4.8%	0.440	0.000	1.0
NDA081453CAB-2C	56.3	7.0	164.4	6.5%	91.0%	2.5%	0.0%	1.088	18.1%	0.0%	0.0%	22.9%	22.9%	0.716	0.004	1.0	10.0%	0.0%	10.1%	20.1%	1.011	0.198	2.0	4.7%	10.0%	10.1%	24.8%	1.227	0.201	5.0
NDTX081648CB-13W	71.4	9.4	170.1	3.3%	93.9%	2.8%	0.3%	1.094	19.2%	2.0%	0.0%	6.4%	8.4%	0.392	0.018	1.0	5.0%	0.0%	3.7%	8.7%	0.293	0.018	1.5	6.5%	5.0%	8.0%	19.5%	0.602	0.089	5.0
NY 152 (Niagara)	62.2	12.4	121.9	9.5%	90.5%	0.0%	0.0%	1.105	21.2%	0.0%	0.0%	3.1%	3.1%	0.682	0.001	1.0	0.0%	0.0%	8.1%	8.1%	0.279	0.000	1.0	0.0%	0.0%	6.4%	6.4%	0.329	0.006	1.5
SNOWDEN	59.2	8.9	158.8	3.4%	95.6%	1.0%	0.0%	1.088	18.3%	0.0%	0.0%	22.9%	22.9%	0.628	0.043	1.5	0.0%	0.0%	9.0%	9.0%	0.268	0.015	1.0	0.0%	1.0%	4.2%	5.2%	0.400	0.000	1.5
ATLANTIC	67.2	7.2	184.3	3.5%	95.8%	0.7%	0.0%	1.100	20.4%	0.0%	0.0%	25.2%	25.2%	0.517	0.110	1.0														
CO 07070--13W	57.6	7.3	121.9	6.9%	93.1%	0.0%	0.0%	1.082	17.2%	0.0%	0.0%	12.8%	12.8%	0.521	0.005	1.0	0.0%	9.4%	3.8%	13.2%	0.205	0.048	1.5	6.0%	2.0%	9.6%	17.6%	1.118	0.499	2.0
MSV030-4	51.4	6.2	175.8	5.0%	88.6%	6.4%	0.0%	1.105	21.3%	0.0%	0.0%	33.7%	33.7%	0.414	0.004	1.0	0.0%	0.0%	6.0%	6.0%	0.250	0.001	1.5	0.0%	0.0%	9.7%	9.7%	0.459	0.003	2.0
NC 0349-3	57.6	7.8	181.4	5.3%	91.7%	3.0%	0.0%	1.087	18.1%	0.0%	0.0%	4.9%	4.9%	0.448	0.011	1.0														
TX09396-1W	44.7	4.1	226.8	2.8%	83.8%	13.1%	0.3%	1.089	18.4%	0.0%	0.0%	21.6%	21.6%	0.415	0.022	1.0														
WANETA	66.7	5.5	181.4	1.9%	95.9%	2.2%	0.0%	1.089	18.3%	0.0%	0.0%	9.2%	9.2%	0.419	0.001	1.0	0.0%	0.0%	4.3%	4.3%	0.293	0.004	1.0	0.0%	0.0%	2.6%	2.6%	0.237	0.001	1.0
HODAG (W5955-1)	55.3	5.8	221.1	3.1%	80.9%	16.0%	0.0%	1.092	19.0%	1.4%	4.2%	16.0%	21.6%	0.396	0.006	1.0	0.0%	0.0%	16.8%	16.8%	0.208	0.003	1.5	0.0%	24.2%	0.0%	24.2%	0.389	0.008	1.0
W 9968-5	53.7	6.8	178.6	3.3%	96.2%	0.5%	0.0%	1.094	19.2%	10.0%	0.0%	47.2%	57.2%	0.594	0.004	1.0	0.0%	0.0%	40.9%	40.9%	0.408	0.007	1.0	0.0%	0.0%	24.2%	24.2%	0.443	0.043	2.0
NY 157	61.1	8.2	172.9	3.5%	93.7%	2.8%	0.0%	1.084	17.6%	0.0%	0.0%	18.2%	18.2%	0.353	0.004	1.0	0.0%	0.0%	5.3%	5.3%	0.235	0.000	1.0	0.0%	10.2%	0.0%	10.2%	0.311	0.003	2.0
Average	58.5	7.5	172.7	4.3%	92.7%	3.0%	0.06%	1.093	19.2%	0.007	0.002	0.185	0.194	0.501	0.015	1.071	0.8%	0.9%	8.6%	10.4%	0.344	0.019	1.3	1.6%	3.3%	5.8%	10.6%	0.504	0.052	1.9

key=SUCROSE green=<0.600, yellow=> 0.600, red/yellow= > 1.000 / GLUCOSE= green= <0.010, yellow= > 0.035, red/yellow= > 0.100

Table 4: Tuber yield of potato cultivars planted in 2018 and chip quality of stored harvest

Cultivars	Tuber Yield (t/ha)	# tuber /plant	Tuber weight g	Tuber size < 4.7 cm %	4.7-8.75cm %	>8.75cm %	culls %	specific gravity	solids %	undesirable color (%)	19-Sep-18 undesirable color %	internal defect %	external defect %	Total defects	sucrose mg/g	glucose mg/g	chip color	28-Nov-18 sucrose mg/g	glucose mg/g	25-Jan-19 sucrose mg/g	glucose mg/g	8-Apr-19 internal defect %	external defect %	Total defects	sucrose mg/g	glucose mg/g	chip color	6-May-19 sucrose mg/g	glucose mg/g	Total defects	chip color
AF5040-8	67.1	10.3	161.6	1.6%	89.7%	8.7%	0.0	1.094	20.7%	11.4%	0.0%	9.6%	0.0%	9.6%	0.582	0.004	1.0	0.487	0	0.589	0.01	0.0%	6.8%	6.8%	0.637	0.322	2.0	1.499	0.381	0.156	3
AF5429-3	64.0	11.6	153.0874	2.80%	83.40%	13.80%	0.0	1.092	19.4%	0.0%	0.0%	9.7%	0.0%	9.7%	0.727	0.004	1.5	0.65	0.008	0.529	0.015	0.0%	7.9%	7.9%	0.491	0.006	1.0	0.976	0.021	0.138	1.5
ATLANTIC	55.7	10.6	133.2	4.0%	94.8%	1.1%	0.0	1.094			0.0%	0.0%	10.0%	10.0%	0.316	0.000	1.0														
CO02321-4W	63.1	12.7	121.9	5.6%	85.7%	8.7%	0.0	1.099	22.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.417	0.000	1.0	0.93	0.004	0.727	0.012	0.0%	11.7%	11.7%	0.393	0.073	1.5	0.381	0.062	0.08	1
DAKOTA PEARL	64.6	7.6	153.1	4.0%	81.5%	14.5%	0.0	1.092	18.5%	10.3%	0.0%	1.0%	3.9%	4.9%	0.474	0.007	1.0	0.435	0	0.452	0.019	0.0%	14.4%	14.4%	1.066	0.263	1.5	1.066	0.263	0.247	1.5
HODAG	66.4	13.9	158.8	5.9%	89.9%	4.2%	0.0	1.084	19.9%	0.0%	0.0%	4.3%	0.0%	4.3%	0.503	0.004	1.0	0.435	0	0.417	0.021	0.0%	18.9%	18.9%	0.158	0.008	1.0	0.487	0.017	0.059	1
LAMOKA	72.1	12.6	150.3	4.3%	86.1%	9.7%	0.0	1.095	20.3%	0.0%	0.0%	4.5%	0.0%	4.5%	0.718	0.006	1.0	0.509	0.004	0.664	0.007	0.0%	12.7%	12.7%	0.413	0.004	1.0	0.894	0.063	0.13	1
MSV030-4	62.4	10.5	119.1	5.2%	85.6%	9.2%	0.0	1.096	20.8%	1.0%	0.0%	0.0%	0.0%	0.0%	0.726	0.004	1.0	0.804	0.001	0.569	0.083	0.0%	3.5%	3.5%	0.748	0.067	1.0	0.866	0.023	0.049	1
MSV313-2	61.6	9.7	150.3	4.5%	85.5%	9.7%	0.0	1.100	20.4%	2.8%	0.0%	17.1%	15.0%	32.1%	0.644	0.003	1.0	0.473	0.041	0.645	0.003	0.0%	24.1%	24.1%	0.281	0.083	2.0			0.269	2
MSV358-3	51.6	8.8	119.1	4.9%	95.1%	0.0%	0.0	1.086	18.9%	0.0%	0.0%	0.0%	10.9%	10.9%	0.649	0.001	1.0	0.589	0.018	0.507	0.011	0.0%	24.6%	24.6%	0.484	0.037	1.5			0.246	1.5
MSW044-1	50.9	12.0	104.9	9.4%	85.3%	5.3%	0.0	1.097	18.3%	2.0%	0.0%	0.0%	7.3%	7.3%	0.580	0.004	1.0	0.293	0.001	0.205	0.003	1.4%	11.1%	12.5%	0.485	0.062	1.5	0.451	0.003	0.05	1
MSW485-2 Huron	53.5	12.1	107.7	9.1%	86.3%	4.6%	0.0	1.099	20.7%	9.2%	0.0%	6.5%	0.0%	6.5%	0.371	0.000	1.0	0.458	0.001	0.38	0.006	0.0%	13.8%	13.8%	0.796	0.106	2.0	1.206	0.177	0.167	2
MSX540-4 Mackinaw	53.6	9.3	121.9	5.0%	94.2%	0.9%	0.0	1.100	20.1%	0.0%	0.0%	10.3%	0.0%	10.3%	0.649	0.001	1.5	0.501	0	0.373	0.003	0.0%	10.4%	10.4%	0.668	0.001	1.5	1.499	0.106	0.242	2
NICOLET	65.6	17.5	124.7	4.3%	89.1%	6.6%	0.0	1.099	20.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.479	0.000	1.5	0.433	0	0.439	0.022	0.0%	2.7%	2.7%	0.032	0.006	1.0	0.336	0.008	0.106	1.5
ND7519-1	61.8	10.7	127.6	5.1%	92.9%	2.0%	0.0	1.086	21.5%	33.1%	0.0%	0.0%	0.0%	0.0%	0.616	0.000	1.0	0.419	0.003	0.7	0.109	0.0%	3.4%	3.4%	1.148	0.557	5.0	1.148	0.557	0.365	5
NDA081453CAB-2C	57.1	12.8	133.2	4.7%	89.6%	5.7%	0.0	1.092	19.5%	71.1%	0.0%	0.0%	3.5%	3.5%	0.556	0.001	1.0	0.58	0.077	1.356	0.276	0.0%	7.1%	7.1%	1.128	1.540	5.0	2.379	1.147	0.203	5
NDTX081648CB-13W	59.9	10.7	127.6	4.4%	90.1%	5.4%	0.0	1.088	18.8%	8.7%	0.0%	25.0%	0.0%	25.0%	0.388	0.001	1.5	0.579	0.094	0.472	0.028	0.0%	7.1%	7.1%	0.463	0.484	2.0	1.953	0.67	0.246	3
NY152 Niagara	63.2	15.0	96.4	12.1%	86.5%	1.4%	0.0	1.110	21.5%	0.0%	0.0%	21.0%	0.0%	21.0%	0.708	0.000	1.0	0.62	0	0.7	0.021	0.0%	11.9%	11.9%	0.536	0.004	1.0	0.488	0.012	0.101	1
NY162	64.3	10.3	147.4	5.1%	91.8%	3.1%	0.0	1.099	19.1%	0.0%	0.0%	12.5%	0.0%	12.5%	0.341	0.000	1.0	0.543	0.012	0.498	0.015	0.0%	44.5%	44.5%	0.391	0.059	1.5			0.157	1
SNOWDEN	54.7	10.8	102.1	6.2%	93.8%	0.0%	0.0	1.093	18.6%	0.0%	0.0%	8.3%	0.0%	8.3%	0.600	0.003	1.0	0.362	0.015	0.356	0.019	0.0%	13.9%	13.9%	0.347	0.069	1.5	0.547	0.003	0.06	1.5
W9968-5	61.1	11.7	127.6	4.2%	93.6%	2.2%	0.0	1.094	19.2%	0.0%	0.0%	0.0%	10.0%	10.0%	0.535	0.000	1.5	0.762	0.036	0.468	0.048	1.5%	20.0%	21.5%	0.171	0.018	2.0			0.215	2
WANETA	63.8	8.3	187.1	1.8%	90.0%	17.4%	0.0	1.085	18.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.293	0.000	1.0	0.518	0	0.417	0.001	0.0%	7.4%	7.4%	0.103	0.000	1.0	0.433	0	0.074	1
Averages	60.8	11.3	133.1	5.2%	89.1%	6.1%	0.0%	1.094	19.9%	7.1%	0.0%	5.7%	2.9%	8.6%	0.540	0.002		0.542	0.015	0.546	0.003	0.1%	13.2%	13.4%	0.521	0.018		0.791	0.017	0.160	

key=SUCROSE green=<0.600, yellow=> 0.600, red/yellow= > 1.000 / GLUCOSE= green= <0.010, yellow= > 0.035, red/yellow= > 0.100

Sucrose and Glucose contents of potato tubers varied by cultivar during the cold storage period following the 2017 harvest (Table 3). Overall, there was a decrease in sucrose content in the tubers after six months in cold storage (except in AF5040-8 and NDA081453CAB-2C), but these levels increased thereafter at eight months in cold storage. However, the sucrose content of the tubers at the end of the storage period was lower than the sucrose content at harvest except for B2727-2, NDA081453CAB-2C, NDTX081648CB-13W, and CO07070-13W (Figure 3a). There was considerable increase in glucose content in ACO1144-1W, NDA081453CAB-2C, NDTX081648CB-13W, CO07070-13W, and W9968-5 tubers (Figure 3b). For the 2018 season, sucrose content of tubers at harvest varied from 0.295mg/g to 0.727 mg/g. During the subsequent storage period, sucrose content changed from 0.205 mg/g to 1.356 mg/g after five months in cold storage and increased from 0.336 mg/g to 2.379 mg/g after nine months in cold storage (Figure 3c). Significantly,a 100% increase in sucrose content of tubers was observed in AF5040-8, DAKOTA PEARL, MSW485-2 Huron, MSX540-4 Mackinaw, NDA081453CAB-2C, and NDTX081648CB-13W during the storage period. The glucose content of potato tubers also changed during the storage period. More hydrolysis of complex sugar into glucose was more noticeable in AF5040-8, AF5040-8, DAKOTA PEARL, MSW485-2 Huron, MSX540-4 Mackinaw, ND7519-1, NDA081453CAB-2C, and NDTX081648CB-13W (Figure 3d). The increase in sucrose content is associated with an increase in glucose content of potato tuber during cold storage period. This reaction produces amino acids, causing darkening and off-flavors of potato chips during frying process [3,39]. Sugar content of potato tuber is one of the main characteristics on which chip color depends, as a reducing sugar (fructose and/or glucose) content higher than 2% induces a non-enzymatic browning reaction (Maillard reaction) during the frying process, causing the potato chip to turn dark in color [40].

At harvest, all potato cultivars presented nice and non-bruise chip color; after six months' storage time, some cultivars presented nice color with stem end except NDA081453CAB-2C, which had the highest sucrose and glucose contents among all the cultivars and the highest chip color score of 2 (Tables 3 and 4). At nine-month storage period, only Lamoka, ACO1144-1W, AF 5040-8, MSX540-4, and HODAG (W5955-1) showed nice and bruise chip color among the 21 cultivars, with a chip color score of 1, thus showing their benefits as preferred cultivars to be produced and stored in a cool room for nine months. The rest of the cultivars presented some internal defects and stem ends. NDA081453CAB-2C and NDTX081648CB-13W presented the worst chip color with a chip color score of 5. For the 2018 harvest, all cultivars presented nice chip color with scores of 1 and 1.5 (Table 4). Chip color degraded with storage time and at 8 and 9-month storage time, ND7519-1 and NDA081453CAB-2C presented undesirable chip color with color score of 5, while CO02321-4W, HODAG, Lamoka, MSV030-4, MSW044-1, NY152 Niagara, NY162, and WANETA presented nice, bruise and desirable chip color. The rest of the cultivars presented intermediate chip color with some stem ends and internal defects (Table 4). Lamoka and Snowden, already known for excellent chip color retention during storage time, confirmed their quality in the current study [41]. The results of this study are in agreement with Wayumba et al. and Meena et al., who reported nice and light color of potato chip right after harvest when the tubers have low sugar content [42,43]. Increase of glucose content in tubers during cold storage period is also reported by Datir, who indicated reduction in starch and accumulation of reducing sugars during cold storage [44]. Similar findings were also reported by Wayumba et al. [42]. As the chip color score "1" is always the target of chip potato breeding, cultivars with a consistent score of "1" constitute good candidates to be released and made available for commercial potato producers and small farmers across the dry and hot environment of the southwest region of the United States.

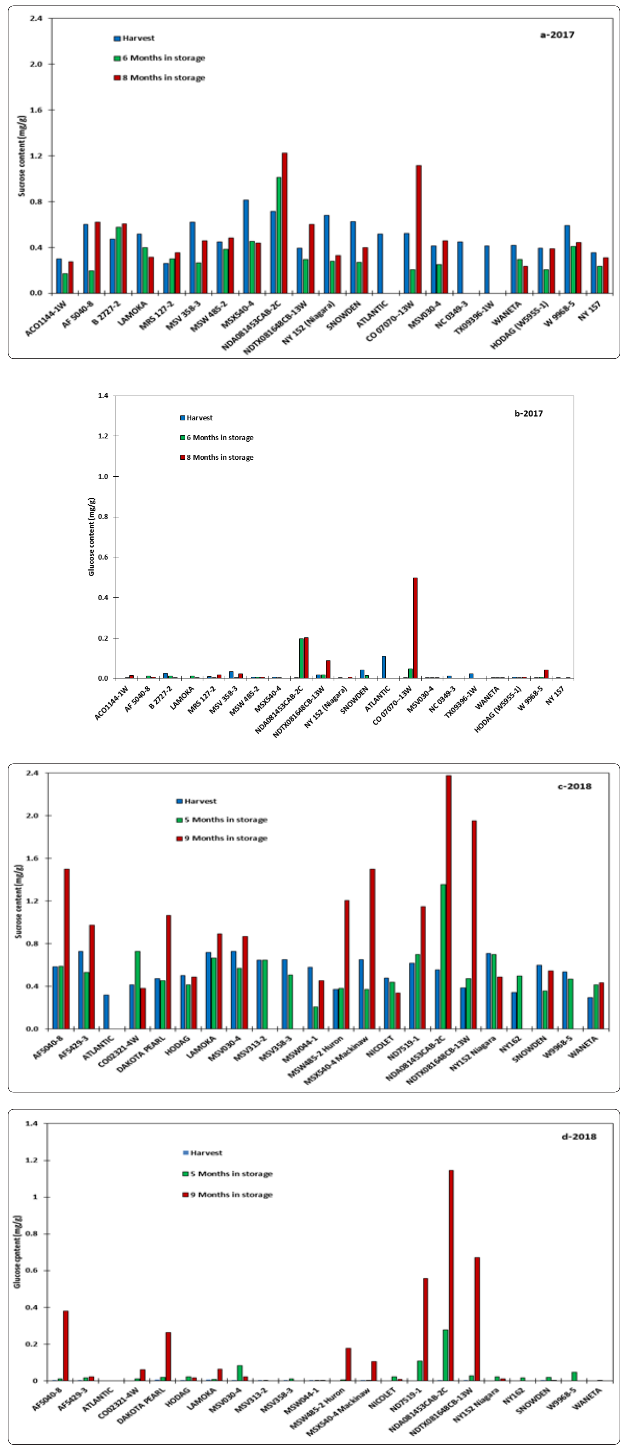

Figure 3: Variation in sucrose and glucose contents in potato tubers during the storage periods of the 2017 and 2018 harvests

Conclusion

Chip potato cultivars were evaluated for tuber yield, tuber quality and postharvest qualities in storage during the 2017 and 2018 growing seasons. Tuber yield varied with cultivar and ranged from 44.7 to 72.1 t/ha with 91% of tubers sized between 4.7 and 8.75cm and 5% above 8.75 cm. While some cultivars did not present good physical and chemical qualities after 9-month storage time, others showed reasonable negligible external and internal defects, desirable sucrose and glucose content and consequently showed nice color and bruise potato chip quality and should be considered for chip potato production. However, more research should be conducted on fertilizer management and/or planting date and density to optimize use efficiency for more profitability of the chip potato production value chain across the hot and dry environment of the southwest United States.

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