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Fresh Market Evaluation of Six Russet-Type Potato Varieties and Four Russet Norkotah Strains

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Abstract In 2016, Russet Norkotah was the second most widely grown potato variety in the US; however, recent research has identified alternatives with excellent production economics. During 2011–2013, fresh market variety research was conducted in the Columbia Basin of central Washington, a long-season production region. Russet Norkotah was compared to five varieties–Classic Russet, Mountain Gem Russet, Russet Burbank, Targhee Russet, and Teton Russet–and four sub-clonal strains–CO-3, CO-8, TX-278, and TX-296–derived from Russet Norkotah. Each variety was evaluated for early- (104 days between planting and vine kill) and late- (150 days between planting and vine kill) harvest tuber size profile, grade, and yield, grower economic value, susceptibility to blackspot bruise and shatter bruise, emergence, stem and at-harvest tuber numbers, tuber length-to-width ratios, and quality. When harvested early, Classic Russet and Mountain Gem Russet produced 30% and 15% more gross revenue than Russet Norkotah, respectively. All other varieties and Russet Norkotah strains except CO-3 produced as much early-harvest gross revenue as Russet Norkotah. CO-3 early-harvest revenue was close to 50% lower than that of Russet Norkotah. All varieties and Russet Norkotah strains produced significantly greater late-harvest yields and gross returns than Russet Norkotah. Late-harvest gross revenue for Targhee Russet and Mountain Gem Russet was 38% and 34% higher than Russet Norkotah, respectively. Classic Russet, Mountain Gem Russet, Targhee Russet, and Teton Russet had significantly more shatter bruise following the late harvest than Russet Norkotah and all Russet Norkotah strains. Russet Burbank was among the most susceptible to blackspot and Targhee Russet the least, with 32% and 2.1%, respectively. If bruising is mitigated, Mountain Gem Russet, Classic Russet, and Teton Russet may be suitable alternatives to Russet Norkotah and Russet Norkotah strains for both early and late harvests.

Resumen En el 2016, la variedad de papa Russet Norkotah fue la segunda más cultivada en los EUA; no obstante, investigaciones recientes han identificado alternativas con excelente producción económica. Durante 2011–2013, se condujo una investigación de variedades para el mercado fresco en la rivera del Columbia en el centro de Washington, una región de producción de ciclo largo. Se comparó a Russet Norkotah con cinco variedades: Classic Russet, Mountain Gem Russet, Russet Burbank, Targhee Russet, y Teton Russet, y cuatro variantes subclonales: CO-3, CO-8, TX-278, y TX-296-derivada de Russet Norkotah. Cada variedad se evaluó por precocidad (104 días entre la siembra y la quema de follaje) y por tardías (150 días entre la siembra y la quema de follaje), por perfil del tamaño de tubérculo a la cosecha, clasificación y rendimiento, por valor económico al productor, susceptibilidad a la mancha negra y cuarteaduras por daño mecánico, emergencia, número de tubérculos por tallo a la cosecha, relación largo-ancho de tubérculo, y calidad. En cosecha temprana, Classic Russet y Mountain Gem Russet produjeron 30% y 15% más ingreso bruto que Russet Norkotah, respectivamente. Las otras variedades y las variantes de Russet Norkotah, excepto CO-3, produjeron tanto ingreso bruto en cosecha temprana como Russet Norkotah. El ingreso de CO-3 en cosecha temprana fue cercano al 50% más bajo que el de Russet Norkotah. Todas las variedades y las

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variantes de Russet Norkotah produjeron significativamente mayores rendimientos e ingresos brutos que Russet Norkotah en cosecha tardía. El ingreso bruto en cosecha tardía de Targhee Russet y Mountain Gem Russet fue 38% y 34% más alto que el de Russet Norkotah, respectivamente. Classic Russet, Mountain Gem Russet, Targhee Russet, y Teton Russet tuvieron significativamente más daño mecánico después de la cosecha tardía que Russet Norkotah y que todas las variantes de Russet Norkotah. Russet Burbank estuvo entre las más susceptibles a la mancha negra y Targhee Russet la menos, con 32% y 2.1%, respectivamente. Si se mitiga el daño mecánico, Mountain Gem Russet, Classic Russet, y Teton Russet pudieran ser alternativas deseables a Russet Norkotah y sus variantes tanto para cosecha temprana como tardía.

Keywords Yield · Economics · Size profile · Shatter bruise · Blackspot bruise · Length to width

Introduction

Potato breeding programs in the US have developed many russet cultivars for fresh market. Russet Norkotah (R. Norkotah) and R. Norkotah strains were collectively planted on over 33,800 ha in WA, ID, and OR during 2015 (USDA-NASS 2016). Across the US, R. Norkotah was the second most widely grown potato variety in 2016, planted on over 443,000 ha (USDA-NASS 2017).

Prior to its release from North Dakota State University in 1987, R. Norkotah demonstrated yield and quality improvements over other fresh market russet-type varieties (Johansen et al. 1988; James et al. 1989). On a national basis, one of the primary reasons that R. Norkotah strains have been accepted is their greater and more consistent yields compared to standard R. Norkotah. Superior resistance to shatter (Novy et al. 2014) and blackspot bruising (Hane et al. 2003) relative to other russet varieties is another advantage of R. Norkotah and R. Norkotah strains. Both shatter and blackspot bruise reduce tuber quality. Shatter bruising creates open wounds allowing infection by fungal and bacterial pathogens. Bruising can reduce economic return and may cost the US potato industry over $298 M annually (Thornton and Bohl 1998). Visual appeal, uniform size and shape, an attractive russet skin, and low incidence of storage issues have likely contributed to the popularity of R. Norkotah and R. Norkotah strains.

Despite these positive traits, R. Norkotah has several serious drawbacks. R. Norkotah and R. Norkotah strains are susceptible to Potato Virus Y (PVY). R. Norkotah is very susceptible to *Verticillium* wilt, which often contributes to early plant death (Jansky and Miller 2010). PVY infection of R. Norkotah seed has led to yield reductions of up to 58% (Mondjana et al. 1993; Hane and Hamm 1999). In addition to causing yield reductions, PVY infection can make it difficult to certify seed, resulting in reduced seed availability and higher seed prices (Rykbost et al. 1999). R. Norkotah often produces yields inferior to other varieties (Novy et al. 2014; Stark et al. 2016). These relatively low yields may be due to early maturity and genetic susceptibility to PVY and *Verticillium* infection.

Susceptibility to PVY and *Verticillium* wilt, inadequate yields, and seed lot certification difficulties have created a need to replace R. Norkotah, with varieties that produce greater economic return with the same or lower inputs. The objectives of the research reported here are: 1) to assess the agronomic and economic performance of newer, russet-type varieties relative to industry standard varieties and strains following an early and late harvest, 2) to identify strengths and weaknesses of the assessed varieties and, 3) to evaluate these varieties for production merit following an early and late harvest.

Methods and Materials

Unless otherwise specified, strains and varieties are referred to as "varieties" from this point forward to simplify discussion. The fresh market potential of four recently released potato varieties–Classic Russet (Classic R.), Mountain Gem Russet (Mountain Gem R.), Targhee Russet (Targhee R.), and Teton Russet (Teton R.)–as well as Russet Burbank (R. Burbank), R. Norkotah, and four sub-clonal strains of R. Norkotah (CO-3, TX-278, CO-8, and TX-296) was evaluated during three years (2011–13) under early and late harvest production (104 and 150 days between planting and vine kill, respectively). The newer varieties were chosen following positive evaluation by the Northwest Potato Variety Development Program (Stark et al. 2010, 2016; Novy et al. 2014; Whitworth et al. 2016). R. Norkotah and R. Burbank were selected as standard reference varieties due to their popularity among growers (USDA-NASS 2017). The R. Norkotah strains were selected for evaluation of their adaptation to the long-production environment in the Columbia Basin of central Washington.

Field experiments were located at the Washington State University Research Unit near Othello, WA, and planted into a Shano silt loam. Standard management practices for this region were used for all varieties in order to control for differences that might result from variation in fertilization, irrigation, or other management. Early harvest plots were fertilized with approximately 225–160-150 kg ha-1 of N, P2O5, and K2O, respectively, (soil residual + applied). Late harvest plots received approximately 400–250-450 N, P2O5, and K2O, respectively, (soil residual + applied) (Lang et al. 1999). Pesticide and herbicide applications to control pests were consistent with commercial production within the Columbia Basin region. For most of the season, soil within the trials

was kept at or above 65% available soil moisture using center pivot irrigation. Plant emergence, stem and at-harvest tuber numbers, weight, tuber length-to-width ratios, size distribution, yield, specific gravity, and internal and external defects were assessed. Research plots were 6.1 m long and arranged in a split plot design with harvest timing main plots and variety sub-plots. Data were collected from the center row of three-row plots that were replicated four times.

Seed tubers were hand cut into 43–85 g pieces and planted using a two-row assist-feed small-plot planter. Seed pieces were placed at a depth of 20 cm from the top of the seed piece to the top of the hill and were spaced 30.5 cm apart within rows for the early harvest and 25.4 cm apart for the late harvest. Row width was 86 cm, which is typical of commercial potato fields in the Columbia Basin. One plant of the purple-skinned variety All Blue was planted at the end of each plot to provide end plants with competition and serve as a harvest marker.

Early-harvest plots were planted April 7, 4, and 9 of 2011, 2012, and 2013, respectively. Late-harvest plots were planted April 14, 17, and 15 of 2011, 2012, and 2013, respectively. Thus, seed pieces for the early harvest were planted 6–13 days prior to those planted for late harvest. Vines of early- and late-harvest plots were flailed and treated with a desiccant (diquat) 104 and 150 days after planting, respectively. Fourteen days after vine kill, tubers were mechanically harvested with a custom one-row plot harvester. Each tuber was washed, weighed, and counted via a wash-table and electronic sizer. Tuber yield was calculated for three categories: US No. 1, US No 2, and cull grade. Cull grade included tubers with external defects such as knobs and other malformations, green color, growth cracks, rot, or small size (< 113 g). Ten 170–454 g tubers from each plot were assessed for shatter bruise (including air checks/thumbnail cracks), internal brown spot, brown center, and hollow heart defects. Approximately 15 tubers weighing 227–340 g from each plot were used to calculate length-to-width ratios and specific gravity using the weight-in-air/weight-in-water method.

Economic Value

Gross income ($/hectare) was calculated for each variety using a regional four-year price average for fresh market russet potatoes during the 2007–10 seasons (USDA-Market News 2007–2010). Early-harvest prices were determined for July to mid-August, and late-harvest prices were determined for October using USDA market news F.O.B. shipping point prices for the Columbia Basin (Table 1). From the income generated from each 1000 kg of potatoes, $88.20 was subtracted to reflect typical packaging fees charged by fresh-pack sheds (Table 1). Final gross return values were converted to a percentage of R. Norkotah's value for ease of presentation.

Controlled Impact to Evaluate Blackspot Bruising

Per the methods outlined in (Kunkel et al. 1986), twelve late-harvest tubers from three replications of each variety, were warmed to room temperature (approximately 23 °C) for 24 h. Each tuber was then subjected to impact by a 113-g weight from a height of 58.4 cm. Each tuber received four impacts, two on the stem end and two on the bud end. After 24 h, each tuber was peeled in the area of impact and evaluated to determine the percent of impacts that had developed into blackspot bruise. All light brown to black discoloration found in the impact location was recorded as blackspot bruise and the percent calculated.

Statistical Analysis

For each clone or variety, early and late harvest data were analyzed across years (2011–13) and subjected to analysis of variance. The resulting means were statistically separated using Fisher's Protected Least Significant Difference (LSD) Test at the 0.05 level of significance. Lacking interactions, tuber and stem number per plant, length to width ratio, culls, and internal defects were combined and analyzed across harvest timing. All other data were analyzed and reported within harvest timing due to interactions between early and late-harvest production. Regression analysis was used to assess the relationship between tuber specific gravity and incidence of shatter bruising.

Results

Early Harvest Economic Return, Tuber Yield, Size, and Grade

Following an early harvest, the economic performance of all varieties except CO-3 was as good as or better than R. Norkotah (Fig. 1). Gross return was 48% lower for CO-3 than for R. Norkotah. Only two varieties produced higher gross return than R. Norkotah: Classic R. and Mountain Gem R. Moreover, the early harvest return for Classic R. was significantly greater than for all other varieties across the three years of the study. Six varieties produced economic returns similar to that of R. Norkotah: TX-278, Teton R., Targhee R., TX-296, CO-8, and R. Burbank (Fig. 1).

The two highest grossing varieties, Classic R. and Mountain Gem R., produced the highest early-harvest carton yields (30 and 28 t ha^{-1}, respectively) (Table 2). Mountain Gem R. produced a total yield of 56 t ha^{-1}, which was significantly greater than all other varieties except Targhee R. (53 t ha^{-1}). Although the economic value and carton yield of Mountain Gem R. were among the highest, it also produced many undersized tubers (Table 2). All varieties produced less

Table 1 Potato fresh market packaging, grade, and size classifications, and four-year average shipping point prices in the Columbia Basin of Washington. Prices are listed by tuber size and grade with associated packing fees

	Grade and Tuber Size Range		Four-Year WA State Columbia Basin Average Prices[c]		Pack-Shed Packaging and Handling Fee	Adjusted Value[d]	
Markets/Packaging[a]	US No. 1	US No. 2	$/1000 kg				
Carton Count	g	g	Early	Late		Early	Late
100 Count	199 to 241		428.43	355.67	88.20	340.23	267.47
90 Count	242 to 269		468.78	385.43	88.20	380.58	297.23
80 Count	270 to 298		565.36	420.71	88.20	477.16	332.51
70 Count	299 to 354		607.70	466.58	88.20	519.50	378.38
60 Count	355 to 397		608.36	466.58	88.20	520.16	378.38
50 Count	398 to 510		601.08	455.11	88.20	512.88	366.91
4.5 kg Film Bags							
Non-size A	113 to 198		188.96	243.87	88.20	100.77	155.67
45 kg Burlap Sacks							
170 g minimum size US No. 2	511 to 567[b]	170 to 567	213.67	282.02	88.20	125.46	193.82
Bulk							
Process culls	<113	<170	88.20	88.20	88.20	0	0
Process culls	>567	>567	88.20	88.20	88.20	0	0

[a] Count = tuber number per 22.7-kg carton

[b] 511–567-g US No. 1 tubers were priced at US No. 2170-g minimum size

[c] Sales F.O.B. Shipping Point, market periods 2007–2010 (USDA Federal-State Market News Service 2007–2010)

[d] Adjusted value = Four-year average price minus pack-shed fee

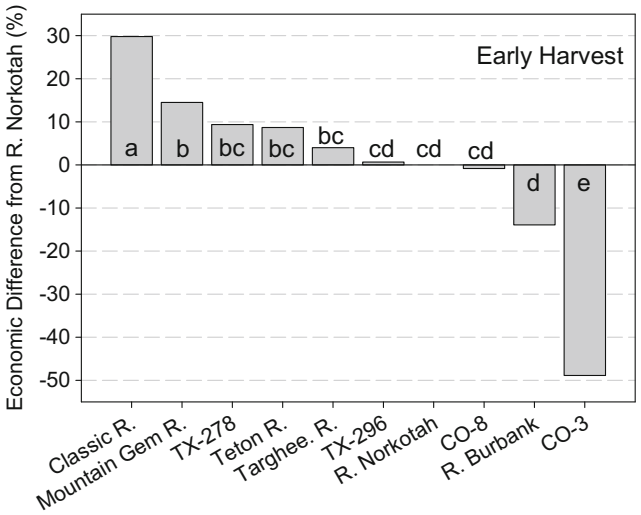

Fig. 1 Percent difference in early fresh market gross economic return from Russet (R.) Norkotah for each variety averaged across 2011–13. Means of columns underscored by the same letter are not significantly different according to Fisher's Protected LSD Test ($P \leq 0.05$)

than 0.5 t ha^{-1} of oversized tubers when harvested early, except Classic R., which produced 2.2 t ha^{-1}; the differences, however, were not significant (Table 2). Carton yields for Targhee R., Teton R., R. Norkotah, TX-278, TX296, and CO-8 ranged from 19 to 21 t ha^{-1} and were not significantly different from each other. CO-3 was the least productive and profitable, producing only 12 t ha^{-1} of carton-sized tubers and 36 t ha^{-1} of total early-harvest yield (Table 2, Fig. 1). R. Burbank and CO-3 produced approximately half the early-carton yield of the top two yielding varieties (Table 2).

Across all varieties, the percent of US No. 1 tubers >113 g at early harvest ranged from 68% (R. Burbank) to 88% (Classic R.) (Table 2). Classic R. produced the highest percentage of US No. 1 tubers >113 g and was followed closely by Targhee R. (83%), TX-278 (80%), and Mountain Gem R. (79%). Varieties with the lowest percentage of US No. 1 tubers >113 g at early harvest were R. Burbank (68%) and CO-3 (73%).

Late-Harvest Economic Return, Tuber Yield, Size, and Grade

All varieties produced higher economic returns than R. Norkotah when harvested late (Fig. 2). Only one variety, Targhee R., produced higher economic returns than all R. Norkotah strains. Targhee R. produced 38% more economic return than R. Norkotah at the late harvest); this value was not significantly different from Mountain Gem R., which produced 34% more gross return than R. Norkotah. TX-278, Classic R., CO-3, CO-8, and R. Burbank produced between 19% and 28% more gross return than R. Norkotah (Fig. 2). The R. Norkotah strains, TX-278, CO-3, CO-8, and TX-296, produced gross returns that were 28%, 27%, 22%, and 15% higher than R. Norkotah, respectively. Near, or at the bottom, for economic value were Teton R., TX-296, and R. Norkotah (Fig. 2).

The varieties with the best late-harvest economic value, Targhee R. and Mountain Gem R., produced the highest total yields (91 and 89 t ha^{-1}, respectively) and had some of the highest carton yields (49 and 51 t ha^{-1}, respectively) (Table 2). Three other varieties also produced total yields above 79 t ha^{-1}: CO-3 (82 t ha^{-1}), Classic R., and R. Burbank (80 t ha^{-1} each) (Table 2). Classic R. and TX-278 also had relatively high carton yields (44 and 43 t ha^{-1}, respectively). R. Norkotah produced the lowest total yield (63 t ha^{-1}, Table 2). Classic R. produced the highest yield of oversized tubers (19 t ha^{-1}) and few undersized and non-sized A tubers (Table 2). CO-3 produced 10 t ha^{-1} of oversized tubers, while all other varieties produced <8 t ha^{-1}. Similar to the early harvest, Mountain Gem R. and R. Burbank produced the most undersized tubers (20 t ha^{-1}) (Table 2). All other varieties produced between 7 and 13 t ha^{-1} of undersized tubers.

All varieties except R. Burbank and R. Norkotah produced >80% US No. 1 tubers >113 g at the late harvest (Table 2). Classic R. produced the highest proportion of US No. 1 tubers at the late harvest (92%), as well as in the early harvest (88%). Targhee R., Mountain Gem R., and TX-278 all produced 86% US No. 1 tubers. Interestingly, the two more widely grown varieties, R. Burbank and R. Norkotah, produced the fewest US No. 1 tubers (75% and 78%, respectively) (Table 2). Although days from planting to vine kill played a role, differences in tuber profiles from early and late harvest may also have been affected by the differences in fertility and within-row spacing for these two treatments.

Characteristics of Tubers and Aboveground Plant Parts

For each variety, early- and late-harvest data were combined for stem and tuber number per plant, length-to-width ratios, and cull categories (growth cracks, greening, knobs, and malformations) because there were no significant interactions for these variables. The early- and late-harvest data for average tuber weight and specific gravity were not combined due to significant interactions between variety and harvest timing for these variables (Table 3).

Early-harvested plants produced more stems (2.2) than those harvested late (2.0) and fewer tubers per plant, 7.6 vs 8.3, respectively (Table 3). Because stem and tuber number are typically set early in the season, the differences are likely related to unique growing conditions between planting date and tuber initiation in the study region.

Throughout this study, most varieties produced an average of two or more stems (Table 3). From the most prolific stem-producing variety to the least, the difference among varieties was no greater the 0.6 stems per plant. One of varieties with less than 2 stems per plant, Classic R., produced significantly

Table 2 Early and late fresh market harvest total yield, market sizes, and percent US No. 1 tubers greater than 113 g for each variety averaged across years (2011–13)

	Total Yield		Undersized Tubers (US 1 & 2)		US No. 1 Tuber Yield by Size				Oversized Tubers (US 1 & 2)		Percent US No. 1	
					Non-size A		Carton Yield[a]					
			<113 g		113–198 g		>198–510 g		>510 g		>113 g[a]	
	(t ha^{-1})										% of Total Yield	
Entry	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late
Targhee R.[b]	53 ab[c]	91 a	11 ab	12 b	5 a	23 a	19 bc	49 ab	0.0a	3 cd	83 b	86 b
Mountain Gem R.	56 a	89 a	16 a	20 a	5 a	14 cd	30 a	51 a	0.1a	7 c	79 bc	86 b
Classic R.	45 de	80 bc	5 c	7 c	1 c	9 d	28 a	44 bc	2.2a	19 a	88 a	92 a
Teton R.	50 bc	72 d	12 ab	13 b	4 ab	15 bc	21 b	38 e	0.3a	4 cd	77 c	82 bc
R. Burbank	47 cd	80 bc	15 a	20 a	5 a	14 cd	16 c	37 e	0.0a	5 c	68 e	75 e
R. Norkotah	47 cd	63 e	10 b	12 b	4 ab	16 b	19 bc	29 f	0.1a	2 d	77 c	78 de
TX-278	49 cd	78 bcd	9 b	11 bc	3 bc	17 b	21 b	43 cd	0.2a	5 c	80 bc	86 b
TX-296	47 cd	73 d	10 b	13 b	4 ab	15 bc	19 bc	35 e	0.4a	6 c	77 c	81 cd
CO-3	36 e	82 b	9 b	13 b	4 ab	15 bc	12 d	41 cde	0.1a	10 b	73 d	84 bc
CO-8	46 cde	75 cd	10 b	13 b	4 ab	15 bc	19 bc	39 cde	0.3a	6 c	77 c	83 bc
Main Effect of Harvest Timing												
Early	48 b		11 b		4 b		20 b		0.4 b		78 b	
Late	78 a		13 a		15 a		41 a		6.7 a		83 a	

[a] Carton yield is comprised of US No. 1 grade tubers weighing between 198 g and 510 g

[b] R. = Russet

[c] Numbers within a column and followed by the same letter are not significantly different according to Fisher's Protected LSD Test ($P < 0.05$)

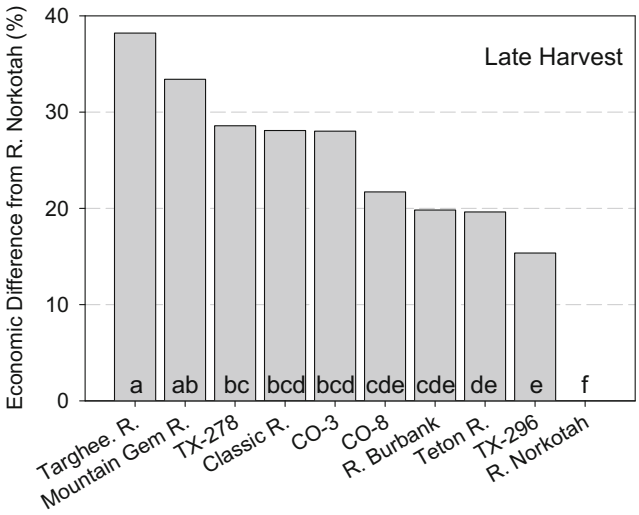

Fig. 2 Percent difference in late fresh market gross economic return from Russet (R.) Norkotah for each variety averaged across years 2011–13. Means of columns underscored by the same letter are not significantly different according to Fisher's Protected LSD Test ($P \leq 0.05$)

fewer tubers per plant (5.7) than all other varieties. With fewer tubers per plant to bulk during field production, Classic R. tubers were significantly heavier in both early (228 g) and late (288 g) harvests than the other varieties (Table 3). Targhee R. produced the highest number of tubers per plant (10.1) from a canopy composed of 2.2 stems per plant. Standard R. Norkotah produced 2.2 stems and 8.1 tubers per plant, while the R. Norkotah strains averaged 1.9 to 2.1 stems and 7.6 to 8.4 tubers-per plant. Among the R. Norkotah strains, CO-3 produced the fewest tubers per plant (7.6) and the lowest average tuber weight (140 g) at early harvest. Conversely, the late-harvest average tuber weight for CO-3 was higher than R. Norkotah and the other strains perhaps because CO-3 is a late-bulking variety.

Length-to-width ratios ranged from 1.58 to 1.88 (1.00 = round) across varieties (Table 3). The longest tubers belonged to R. Burbank, R. Norkotah, TX 296, CO-3, and CO-8.

Specific gravities ranged from 1.069 (Classic R.) to 1.076 (R. Norkotah) at the early harvest, but were not significantly different among varieties (Table 3). From the early- to the late-harvest, average tuber specific gravities increased (1.073 to 1.079) as did the range among varieties (1.074 to 1.085). Targhee R. (1.085) and Classic R. (1.082) had among the highest specific gravities of the group. Late-harvest specific gravities for R. Norkotah and the strains were among the lowest (1.074 to 1.079), with the exception of CO-3, with a specific gravity of 1.080 (Table 3).

Culls and Internal Defects

Overall, R. Burbank produced more culls (7.3%) than all other varieties (Table 4). Four percent of RB tubers had growth cracks, 1.3% knobs, 0.8% malformations, and 0.7% rot.

Table 3 Fresh market tuber and plant characteristics by variety and strain averaged across harvest timing and/or years (2011–13)

	Number per Plant		Length to Width Ratio[b]	Average Tuber Weight (g)		Specific Gravity	
Entry	Stems[a]	Tubers		Early	Late	Early	Late
Targhee R.[c]	2.2 ab[d]	10.1 a	1.61 d	154 b	189 c	1.075	1.085 a
Mountain Gem R.	2.0 ab	9.0 b	1.58 d	161 b	222 b	1.070	1.081 bc
Classic R.	1.9 b	5.7 g	1.68 cd	228 a	288 a	1.069	1.082 ab
Teton R.	2.5 a	8.2 c	1.65 cd	162 b	193 c	1.072	1.080 bc
R. Burbank	2.1 ab	8.6 bc	1.83 ab	153 b	200 c	1.075	1.081 bc
R. Norkotah	2.2 ab	8.1 cd	1.87 a	154 b	163 d	1.076	1.079 cd
TX-278	1.9 b	8.4 c	1.76 bc	156 b	196 c	1.073	1.074 d
TX-296	2.0 ab	8.1 cd	1.87 a	157 b	187 c	1.075	1.074 d
CO-3	2.1 ab	7.6 d	1.88 a	140 c	217 b	1.071	1.080 bc
CO-8	1.9 b	8.2 c	1.87 a	155 b	198 c	1.073	1.075 d
Main Effect of Harvest Timing							
Early	2.2 a	7.6 b	1.77	162 a		1.073 a	
Late	2.0 b	8.3 a	1.78	205 b		1.079 b	

[a] Aboveground stem counts per plant after full emergence

[b] Length to width data collected only during 2012 and 2013; value of 1.00 = round; values >1.00 indicate length > width

[c] R. = Russet

[d] Numbers within a column and followed by the same letter are not significantly different according to Fisher's Protected LSD Test ($P < 0.05$)

Table 4 Cull categories and internal defects as a percent of total yield for each variety and strain. Values were averaged across early- and late-harvest timings and years (2011–13)

Entry	Cull Type					Total Culls	Internal Defects		
							Hollow Heart	Brown Center	Internal Brown Spot
	Malformed[a]	Knobs	Green	Growth Cracks	Rot	% of Total Yield			
Targhee R.[a]	0.5 bc[b]	0.00 c	0.3	0.06 c	0.20 b	1.1 c	0.0 b	0.0 b	1.8
Mountain Gem R.	0.4 c	0.40 bc	0.4	1.60 b	0.20 b	3.0 b	4.7 a	0.7 b	0.7
Classic R.	0.2 c	0.60 b	1.0	1.40 b	0.04 b	3.3 b	0.4 b	0.0 b	0.4
Teton R.	1.1 ab	0.01 c	0.4	2.00 b	0.10 b	3.7 b	0.0 b	0.0 b	0.0
R. Burbank	0.8 ab	1.30 a	0.6	4.00 a	0.70 ab	7.3 a	6.5 a	20.0 a	3.0
R. Norkotah	0.4 c	0.07 c	0.7	0.20 c	0.90 a	2.5 bc	0.4 b	0.0 b	1.3
TX-278	0.3 c	0.02 c	0.5	0.04 c	0.40 b	1.2 d	0.0 b	0.0 b	0.5
TX-296	0.8 ab	0.04 c	0.7	0.09 c	0.70 ab	2.4 bc	0.0 b	0.0 b	0.4
CO-3	0.5 bc	0.20 bc	0.6	0.10 c	0.08 b	1.5 c	0.8 b	0.4 b	0.4
CO-8	0.8 ab	0.02 c	0.9	0.30 c	0.40 b	2.3 bc	0.0 b	0.4 b	1.8

[a] R. = Russet

[b] Numbers within a column and followed by the same letter are not significantly different according to Fisher's Protected LSD Test ($P < 0.05$)

Incidence of tuber malformation across all varieties was low, ranging from 0.2% (Classic R.) to 1.1% (Teton R.) (Table 4). R. Burbank (1.3%), Classic R. (0.6%), and Mountain Gem R. (0.4%) produced the highest numbers of knobby tubers; no more than 0.2% of tubers from each of the other varieties had knobs. Four varieties produced a significant amount of tubers with growth cracks: R. Burbank (4.0%), Teton R. (2.0%), Mountain Gem R. (1.6%), and Classic R. (1.4%); all remaining varieties had some tubers with growth cracks, but none exceeded 0.3%. R. Norkotah had the most tubers (0.9%) with rot at harvest. Less than 0.8% of tubers from the other varieties contained rot at harvest (Table 4). Anywhere from 0.3% to 1.0% of tubers from all varieties displayed some level of greening, but the differences were not significant. Varieties producing among the lowest level of total culls included Targhee R., TX-278, and CO-3 (Table 4).

R. Burbank (6.5%) and Mountain Gem R. (4.7%) had a greater incidence of hollow heart than all other varieties (Table 4). Less than 1% of the tubers from Classic R., R. Norkotah, and CO-3 developed hollow heart; the remaining five varieties lacked hollow heart (Table 4). Twenty percent of R. Burbank tubers developed brown center. Tubers from all other varieties contained less than 0.7% incidence of brown center. Internal brown spot did not significantly differ across varieties; however, it is important to note that all but one variety, Teton R., had some internal brown spot (Table 4).

Bruising

Thirty two percent of controlled bruise impacts to tubers resulted in blackspot bruise for R. Burbank (Fig. 3). Other varieties with significant blackspot included CO-3 (28%), Mountain Gem R. (24%), and Classic R. (22%) (Fig. 3). In contrast to this, only 2.1% of impacts to Targhee R. tubers resulted in bruising (Fig. 3). Blackspot bruising incidence on the remaining four varieties (CO-8, TX-278, Teton R., and TX-296) fell between 8% and 15%, and these varieties were not significantly different from R. Norkotah (12%). It is interesting to note that CO-3 showed higher susceptibility to blackspot bruising than R. Norkotah and the other R. Norkotah strains, despite the close genetic relationship among these varieties.

Shatter bruise incidence was greater, on average, when tubers were harvested later in the season (Fig. 4). The reason for this is not known; however, early-harvest temperatures were significantly warmer than those during the late harvest, and this might have resulted in less turgid early-harvest tubers. Moreover, larger average tuber sizes found at the late harvest were likely more prone to bruising than the smaller average tuber sizes from the early harvest. Nitrogen fertility rate was higher within the late-harvested plots and may have had some influence on shatter by delaying plant maturity. Genetic predisposition likely played a role in shatter susceptibility as five varieties consistently produced relatively high levels at both harvest dates. Targhee R., Classic R., R. Burbank, Teton R., and Mountain Gem R. developed shatter bruise in 13% to 36% of tubers when harvested early and 61% to 78% when harvested late (Fig. 4).

Shatter bruise for R. Norkotah and the R. Norkotah strains ranged from 17% to 27% of total yield (Fig. 4). Relative to the other varieties, R. Norkotah and all R. Norkotah strains tended to resist shatter bruising although these differences were not always significant. Because R. Norkotah and the R. Norkotah

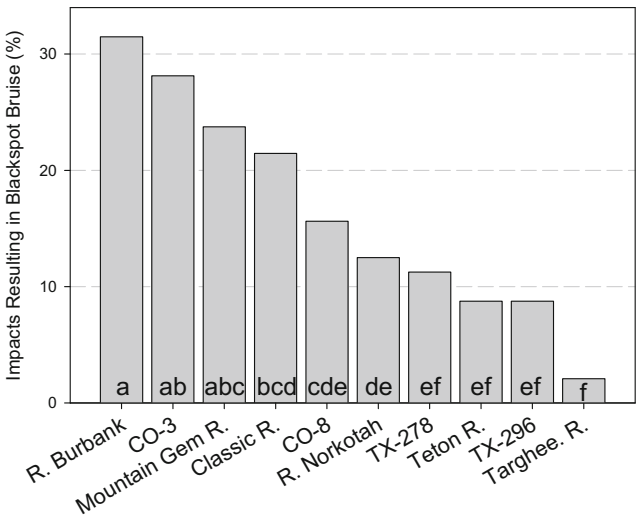

Fig. 3 Controlled blackspot bruise results averaged across 2012–13 (R. = Russet). Results are a percentage of controlled impacts that resulted in a blackspot bruise on the potato flesh. Letters indicate LSD ($p < 0.05$)

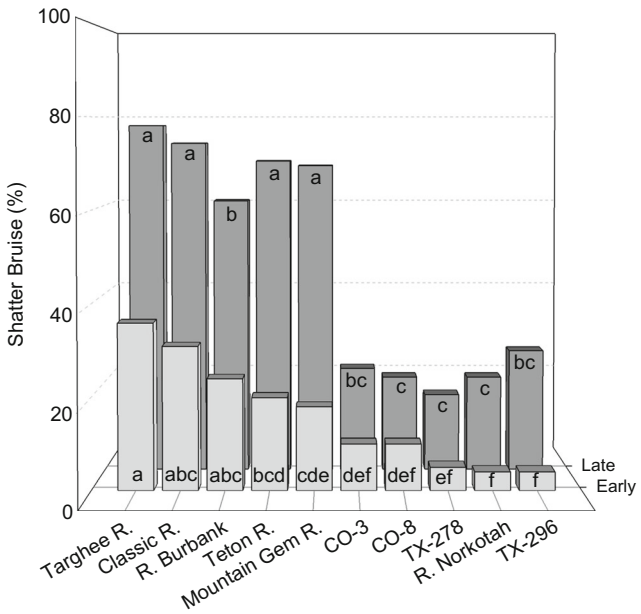

Fig. 4 Early and late fresh harvest incidence of shatter bruise (including air checks/thumbnail cracks) following routine harvest and grading during 2011–13 (R. = Russet); values indicate percent of 10 tubers × 4 replications × 3 years with visible shatter bruising. Letters indicate LSD ($p < 0.05$)

strains typically produced lower late-harvest specific gravities and shatter than the other varieties, the relationship between specific gravity and shatter bruising was further investigated. No link was found between tuber specific gravity and incidence of shatter bruising following regression analysis utilizing data from both harvest dates (data not shown).

White Spot

Swollen lenticels and associated white spots (USDA 1978; Johnson 2013) were often observed on the surfaces of Targhee R. tubers at harvest. Enlarged lenticels are typically associated with wet or moist soils (Timm and Flocker 1966; Adams and Lapwood 1978; Whitworth et al. 2016). This was seen in all three years of the trial, even though soil moisture levels were reasonable (65% available soil moisture, data not shown) throughout the season and low prior to and during harvest (data not shown). Tubers with enlarged lenticels may be less appealing to consumers and provide entry sites for pathogens (Mikitzel 2014).

Discussion

R. Norkotah and the R. Norkotah strains are popular among fresh pack growers because they have eye appeal, produce a high proportion of U.S No. 1 tubers and provide sustainable economic returns. Consumer acceptance and purchasing pull them through the market chain. Aside from obvious factors, one trait of this variety cannot be overlooked. R. Norkotah and most of the strains resist bruising, particularly shatter bruising. Low bruising helps minimize storage rot and in turn, grower risk. Shatter bruising creates an open wound for pathogens to follow and infect. The combination of high shatter bruise potential and susceptibility to soft rot in Classic R. and Teton R. or dry rot in Targhee R. (Table 5), could lead to economic loss or failure following long-term storage. Moreover, fresh market consumers likely appreciate tubers without bruise and may be more apt to make return purchases if their potatoes are issue-free.

All varieties in this trial produced high percentages of US No. 1 tubers, relative to R. Norkotah and the R. Norkotah strains. US No. 1 tubers typically have what might be considered eye appeal, but this is not guaranteed. Targhee R. produced a high percentage of US No. 1 tubers; however, the variety appears to be predisposed to a skin issue where exposed and enlarged lenticels were prevalent following harvest. Consumers may consider the dried post-harvest lenticel spots unsightly. Moreover, this condition may be difficult to manage for the commercial grower and the financial risk could be considerable. For this reason, Targhee R. may be better suited for an alternative market, such as french-fry processing.

Several of the newer varieties produced larger carton yields than R. Norkotah when harvested early (Classic R., Mountain Gem R.) and late (Targhee R., Mountain Gem R.), resulting in

Table 5 Disease susceptibilities and resistances of new and established varieties and strains

Entry	Scab	Vert Wilt	PVX	PVY[O]	PLRV	Net Necrosis	Late Blight		Dry Rot	Soft Rot	Early Blight		Corky Ringspot
							Foliar	Tuber			Foliar	Tuber	
Targhee R.[ab]	MR[c]	MR	MS	MS	S	MR	S	S	S/MS[i]	R	S	S	S
Mountain Gem R.[d]	R	MS	VS	VS	VS	MS	S	R	S/MR[i]	MR	S	S	MS
Classic R[e]	MR	S	VS	S	S	S	S	S	MR	S	MS	MS	MS
Teton R.[f]	R	S	MS	S	S	MR	S	S	R	S	S	ND	MS
R. Burbank[d]	R	S	VS	S	S	S	S	S	S/MS[i]	MS	MS	MS	S
R. Norkotah[cd]	MR	S	VS	VS	S	MR	S	VS	MR	MS	S	S	S
CO-3[g]	S	S-MS	S	S	S	R	S	ND	S	S	S-MS	MR	ND
CO-8[g]	S	S-MS	S	S	S	R	S	ND	S	S	S-MS	MR	ND
TX-278[h]	MR	M	S	S	S	S	S	ND	S	S	S	M	ND
TX-296 h	MR	M	S	S	S	S	S	ND	S	S	S	M	ND

[a] R. = Russet

[b] Whitworth et al. 2016

[c] VS-very susceptible, S-susceptible, MS-moderately susceptible, MR-moderately resistant, R-resistant, ND-no data

[d] Stark et al. 2016;

[e] Stark et al. 2010

[f] Novy et al. 2014

[g] Data obtained from Colorado State University

[h] Data obtained from Texas A&M Potato Breeding & Variety Development

[I] S for *Fusarium sambucinum*, MR or MS for *F. solani var. coerulea*

greater economic value than R. Norkotah and all R. Norkotah strains. Each of these newer varieties, Classic R., Mountain Gem R., Targhee R., and Teton R. were slightly shorter/rounder than R. Norkotah and the R. Norkotah strains. Although the differences were not extreme, consumers familiar with longer R. Norkotah tubers may view these newer variety tubers as being smaller, even though tubers may be of the same weight class. Moreover, fresh pack sheds using optical sizers need to be aware of the length to width differences of these varieties so tubers are sent to the right carton.

All of the newer varieties within this study have an important issue: susceptibility to bruising, especially shatter bruising. Classic R. and Teton R. are susceptible to both soft rot (Table 5) and shatter bruise. Growers used to handling the more shatter-resistant tubers of R. Norkotah, may experience a reduction in US No. 1 grade tubers and/or storage failure if unaware of the combined susceptibilities of these two varieties. Although bruising is a considerable issue with these varieties, growers can reduce bruising by using good management practices (Thornton et al. 1974). The most significant of these is to avoid and minimize impacts with equipment. It is also essential that growers of new varieties subscribe to management keen on observation throughout the harvest and post-harvest operations, looking for and preventing potential issues. If they are aware of these potential issues, they may find success with Classic R. and Teton R.

Mountain Gem R. was among the top economic performers in both early and late harvest trials and was more efficient in production than R. Norkotah, producing higher total and US No. 1 yields with inputs similar to other test varieties. It has some susceptibility to hollow heart, but even if the affected tubers were culled, Mountain Gem R. carton yields would be comparable to those of all other varieties in this trial. Mountain Gem R. appears to be less susceptible to *Verticillium* wilt than R. Norkotah or the R. Norkotah strains (Table 5). Although it is susceptible to shatter bruise, it is moderately resistant to soft rot (Stark et al. 2016). Mountain Gem R. is susceptible to one of the major dry rot pathogens, but moderately resistant to the other (Table 5). Blackspot bruising may be an issue, but bruising was no worse than it was for CO-3 and CO-8, which may be reduced with proper management.

Potato virus Y (PVY) infection is one reason seed lots are rejected for certification. Targhee R. appears to be less susceptible to PVY than the other test varieties. All other varieties are listed as either susceptible, or very susceptible (R. Norkotah and Mountain Gem R.; Table 5). Presumably, none of the varieties have greater PVY susceptibility than R. Norkotah.

We recommend that growers in the Columbia Basin and similar production regions avoid CO-3 in early-harvest production. CO-3 appears to bulk later in the season and may not produce adequate yields or economic return when harvested early. This contrasts with the other R. Norkotah strains that were tested, which produced early-harvest economic returns similar to R. Norkotah. In addition, CO-3 growers may see more blackspot bruise than those growing R. Norkotah or the other R. Norkotah strains.

Like all potato varieties, the more recently released varieties, Classic R., Mountain Gem R., Targhee R., and Teton R., have advantages and disadvantages relative to commercially established varieties. Many of the disadvantages can be managed if growers are aware of potential issues. We believe some of the more pressing issues with each of these varieties are as follows: Classic R.–shatter bruising and soft rot susceptibility, occasional growth cracks and hollow heart; Mountain Gem R.–very susceptible to PVY and can get some hollow heart, blackspot and shatter bruising; Targhee R.–enlarged lenticels which cause unsightly spots on tubers, and shatter bruising; Teton R.–relatively low yields late, possible shatter bruising and soft rot, growth cracks are possible. All of these varieties meet or exceed expectations in several key characteristics, especially economic return.

The performance of new varieties and clones may vary depending on location, environment, soil type, nutrient level (Atkinson et al. 2003), and planting configuration (King et al. 2010). Growers who choose to plant and harvest unfamiliar varieties should start small in an effort to avoid economic loss and allow time to identify unique management practices necessary to produce each variety.

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