Onion Cultivars Differ in Pungency and Bulb Quality Changes during Storage

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Abstract. Pungency and bulb quality changes during storage were evaluated using onion (*Allium cepa* L.) cultivars representing different storage abilities, pungency, and soluble solids content. Bulbs were harvested from greenhouse-grown plants, cured, and stored for 3 or 6 months at 5 ± 3 °C, $80\% \pm 5\%$ relative humidity (0.8 to 1.1 kPa vapor pressure deficit). Prior to storage, and after each month of storage, bulbs were evaluated for pungency by measuring enzymatically formed pyruvic acid (EPY), soluble solids content (SSC), percent loss in mass (%ML), and loss of dormancy. Pungency differed among cultivars prior to and during storage. Among short-day (SD) cultivars, EPY either decreased or increased linearly with increased storage duration. Among intermediate (ID)- and long-day (LD) cultivars, EPY decreased linearly or quadratically during storage. Short-day cultivar SSC increased, then decreased quadratically during storage, while ID and LD cultivar SSC decreased linearly over time. Percent loss in mass increased linearly during storage among all cultivars, although SD cultivars exhibited greater %ML than did ID or LD cultivars.

Commercially grown onions are routinely marketed out of storage for fresh consumption and for use in food processing. Onions, however, vary in their ability to store, which can influence product usage. O'Connor (1979) attributed differences in storage duration to variations in pre- and postharvest environmental conditions or to the cultivar.

Environmental conditions during growth or during the handling of harvested bulbs influence storage duration within onion cultivars. Heavy N applications during growth or N applied during bulb maturation decreased storage duration and bulb quality (Gamiely et al., 1991; Uzo and Currah, 1990). In dry seasons, supplemental irrigation increased storage duration (Drinkwater and Janes, 1955); however, high irrigation levels just prior to harvest increased storage losses (Uzo and Currah, 1990). Cutting roots too soon at harvest or breaking the necks prior to physiological maturity decreased bulb storage duration (Jones and Mann, 1963). Harvest time as related to physiological maturity also influenced bulb storage duration. Harvesting onions when the foliage had lodged on 50% to 80% of the plants resulted in the longest bulb storage (Komochi, 1990). Leaving the bulbs in the field after foliar lodging also decreased bulb storage life and quality (Tucker and Drew, 1982). Likewise, bulbs cured for 3 d at 37 °C and 75% relative humidity (RH) stored longer with bet-

ter quality than did uncured bulbs (Komochi, 1990).

Onion cultivars differ in their ability to store. Storage differences are due mainly to length of bulb dormancy, water loss (Corgan and Kedar, 1990), or disease susceptibility (Maude, 1990). Onions that store well are generally long-day (LD) cultivars with a long dormancy period, small bulb necks, and low water loss. Poor storing onions are generally short-day (SD) cultivars with a short dormancy period, large bulb necks, and high water loss after harvest (Woodman and Barnell, 1937). However, some recently developed SD cultivars have improved storage characteristics (Madisa, 1994; Peters et al., 1989) and some LD cultivars store poorly (oral communication, M. Havey, Univ. of Wisconsin).

Because onions are primarily consumed for their unique flavors, and because pungency and flavor may change over time, flavor

and quality problems may arise during storage. Poor-storing 'Granex'-type onions (SD) grown for low pungency and fresh, raw consumption increased in pungency during short-term storage (Smittle, 1988). 'Sweet Sandwich' (LD), which stores well, decreased in pungency during storage (Peterson et al., 1986), while poor-storing 'Southport White Globe' (LD) increased in flavor precursor concentration at the end of storage (Lancaster and Shaw, 1991). Because these cultivars were grown in different environments and stored under different conditions, among-cultivar flavor changes cannot be easily compared. Our study was conducted to evaluate flavor changes that occur during the storage of several onion cultivars that were grown and stored under similar environmental conditions.

Materials and Methods

Eight cultivars that represented a wide range of storage characteristics, flavor intensity, usage types, and photoperiodic responses were selected (Table 1). In Jan. 1994, each cultivar was seeded into 400 growing cubes (Grodan A/S, DK-2640 Hedehusene, Denmark). Seeds were covered with fine vermiculite, watered as needed with a 20N–20P–20K nutrient solution (Grace-Sierra Co., Milpitas, Calif.), and thinned to one plant per cube 2 weeks after planting. Seedlings were greenhouse-grown (lat. 34°N) at 25 °C day/20 °C night temperatures for 9.5 weeks prior to transplanting into greenhouse growing beds. To control damping off, Bravo 720 (Fermenta Plant Protection Co., Mentor, Ohio) was applied as needed.

Five growing beds (5.47 × 1.22 × 0.31 m) were lined with two layers of black plastic (6 mil = 152 µm), and filled with 2000 L of a modified half-strength Hoagland's (1950) solution. Total dissolved salts were maintained at ≈ 1000 mg·L⁻¹ throughout the experiment. Solutions were amended every 2 weeks by adding additional nutrient salts to replace those absorbed by the plants. Because sulfur fertility is closely associated with onion pungency (Randle, 1992a), sulfur content was monitored weekly (Gaines and Mitchell, 1979) and maintained at 60 mg·L⁻¹ throughout the experiment. The nutrient solution was aerated

Table 1. Enzymatic pyruvic acid (EPY), percent bulb sulfur (%S), and soluble solids content (SSC) of onion cultivars prior to storage. Cultivars were harvested 9 June 1994 except for 'Zenith', which was harvested 23 June 1994.

Cultivar ^a	Type ^b	Characteristics	EPY ^a	%S ^w	SSC
Dehydrator #3	SD	Processing, white, pungent	12.8 a ^v	0.57 c	13.7 a
Rio Unico	SD	Nonstorage, white, pungent	7.5 cd	0.54 c	8.7 d
Granex 33	SD	Nonstorage, yellow, mild	6.3 d	0.66 ab	7.6 e
Walla Walla Sweet	ID	Nonstorage, yellow, mild	9.5 bc	0.58 c	8.1 de
Candy	ID	Moderate storage, yellow, pungent	6.9 d	0.60 bc	8.2 de
Pukekohe	LD	Storage, yellow, very pungent	11.0 ab	0.69 a	11.4 b
Zenith	LD	Sweet Spanish, yellow, pungent	12.4 a	0.70 a	10.5 c
Sweet Sandwich	LD	Storage, yellow, mild	6.6 d	0.46 d	10.7 c

^aSeed Sources: 'Dehydrator #3', 'Walla Walla Sweet', and 'Zenith'—SunSeed Inc., Hollister, Calif.; 'Rio Unico'—Rio Colorado Seeds, Yuma, Ariz.; 'Granex 33' and 'Sweet Sandwich'—Asgrow, Kalamazoo, Mich.; 'Candy'—PetoSeed, Saticoy, Calif.; 'Pukekohe'—Yates Seed, Auckland, New Zealand.

^bShort-day (SD), intermediate-day (ID), and long-day (LD) types.

^cµmol pyruvic acid per mL of onion juice.

^dDry-mass basis.

^eMean separation within columns by Duncan's multiple range test, $P = 0.05$.

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and circulated four times per hour using a Teel pedestal pump (model 3P611E; Dayton Electric Manufacturing Co., Chicago) attached to polyvinyl chloride (PVC) pipe running the length of the bed. The nutrient solution volume of each bed was maintained using a mechanical float connected to a deionized water source. Styrofoam boards, with 2.2-cm-diameter holes 10.2 cm on center, were placed in the beds and suspended over the nutrient solution using PVC supports.

On 15 Mar., the plants were inserted into the holes in the styrofoam boards. Onions were grouped according to cultivar and photo-periodic response in a randomized complete-block design with four replications. Wire fencing with 2.5-cm openings was suspended 15.2 cm over each bed to support the foliage.

Between 21 Apr. (photoperiod 13 h, 14 min) and 18 May, SD cultivars were covered each morning with black plastic to maintain an 11-h photoperiod to prevent premature bulbing. On 18 May, the SD cultivars were left uncovered and bulbs were allowed to mature under natural photoperiods (14 h, 2 min). To induce bulbing in ID and LD cultivars, on 1 May the natural photoperiod (13 h, 35 min) was extended 1 h at the end of the day with 150-W incandescent lights ($18 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) suspended 1.5 m over the beds. The natural photoperiod was extended on 15 May (13 h, 56 min) by 2 h, and on 27 May (14 h, 15 min) by 3 h. Mature bulbs were similar in size and appearance to field-grown onions.

Each cultivar was harvested when 50% of the bulbs had soft pseudostems (Table 1). At harvest, the roots were severed, and the onions were laid out in the greenhouse (25 °C day/20 °C night temperatures) for 7 d to allow the leaves to dry and turn brown. During this time, the plants were covered with burlap to prevent sun scald. The leaves were then cut from the bulbs, and the bulbs were placed into mesh bags and cured in the greenhouse for 7 d.

Bulbs were graded within cultivars according to size, and seven to 10 small (<5 cm in diameter), medium (5 to 8 cm), and large (>8 cm) bulbs were placed into each bag and weighed using a digital scale (model I-10; Ohaus, Florham Park, N.J.). Prior to storage, four replications of seven to 10 bulbs of each cultivar were analyzed for pungency, as indicated by enzymatically formed pyruvic acid (EPY), soluble solids content (SSC), and percent bulb sulfur (%S). Enzymatically formed pyruvic acid was determined using the method

of Randle and Bussard (1993). SSC was determined with a hand-held refractometer (Kernco, Tokyo) as described by Mann and Hoyle (1945), and %S was determined according to Jones and Issac (1972). The remaining bagged bulbs were held in a cooler, set at 5 ± 3 °C, and $80\% \pm 5\%$ RH (0.8 to 1.1 kPa vapor pressure deficit), in a split-block design with four replications. Blocks were the four quadrants of the cooler. Cultivars were the main plots and months of storage were the subplots. Every 30 d thereafter, bulbs were removed from storage according to cultivar and replication, acclimated to 27 ± 3 °C for 24 h, inspected for disease and root elongation at the bulb's base, weighed, and analyzed for EPY and SSC. Only intact bulbs were used for EPY and SSC determinations.

Data from SD cultivars, which were stored for 3 months, were analyzed separately from the ID and LD cultivars, which were stored for 6 months because of their greater storability. Data were analyzed using the GLM procedures of SAS (Cary, N.C.) and Duncan's means separation (Steel and Torrie, 1981). The relationships between storage duration (independent variable) and EPY, SSC, and %WL (dependent variables) were determined by regression analysis. Differences among the slope and y intercept of the regression equations were tested using *t* tests ($\alpha = 0.05$).

Results and Discussion

Pungency and bulb quality prior to storage. Enzymatically formed pyruvic acid, SSC, and %S differed among cultivars prior to storage (Table 1). 'Dehydrator #3', 'Pukekohe', and 'Zenith' had the highest EPY, while 'Rio Unico', 'Granex 33', 'Sweet Sandwich', and 'Candy' had the lowest. These EPY and bulb %S values were within the range of onions from a broad genetic background (Randle, 1992a). However, the value for 'Sweet Sandwich' EPY was substantially lower than previously reported (Peterson et al., 1986). Bulb %S was highest for 'Zenith', 'Pukekohe', and 'Granex 33' and lowest for 'Sweet Sandwich' (Table 1). Although onion pungency and other flavors arise from sulfur compounds (Block, 1992), previous reports had indicated that bulb %S correlated poorly with EPY (Randle and Bussard, 1993) and total volatile organosulfur concentrations (Randle et al., 1994). Bulb %S also correlated poorly with EPY in our study ($r = 0.26$; NS). SSC ranged from a high of 13.7%

for 'Dehydrator #3' to lows of 7.6% for 'Granex 33', 8.1% for 'Walla Walla Sweet', and 8.2% for 'Candy' (Table 1). These SSC values were in the range of those previously reported (Randle, 1992b). Rutherford and Whittle (1984) found that total soluble and reducing sugars were significantly correlated with SSC in onion.

Enzymatically formed pyruvic acid changes during storage. Among the SD group, EPY differed among cultivars ($P = 0.01$) and storage dates ($P = 0.05$), but the interaction between cultivars and storage dates was not significant. In addition, the EPY regression trend during storage differed among cultivars (Table 2). 'Rio Unico' EPY displayed no significant trend during storage, values for 'Dehydrator #3' decreased linearly [EPY = $13.08 - 0.68$ (month); $P = 0.05$], while those for 'Granex 33' increased linearly [EPY = $5.87 + 0.47$ (month); $P = 0.03$; Table 2]. Smittle (1988) reported that the EPY of 'Granex 33' increased during storage. Because 'Granex 33' is typically grown for the mild, sweet onion market, and because mild sweet onions are now marketed out of storage, increases in pungency during storage can have a negative impact on this industry. The fact that 'Dehydrator #3' decreased in pungency during storage suggests that the same may be true for other SD cultivars, some of which may be suitable for mild, sweet onion production and marketed out of storage.

Among the ID and LD group, EPY also differed among cultivars ($P = 0.01$) and storage dates ($P = 0.01$), but the interaction between cultivars and storage dates again was nonsignificant. In this group, regressions were either linear or quadratic during storage (Table 3). 'Pukekohe' [EPY = $12.16 - 0.28$ (month); $P = 0.10$], 'Candy' [EPY = $7.47 - 0.51$ (month); $P = 0.01$], and 'Walla Walla Sweet' [EPY = $10.39 - 0.47$ (month); $P = 0.01$] all displayed significant negative linear regressions of EPY vs. time during 6 months of storage. While there were no differences among these cultivars in slope of the regression, 'Candy' differed ($P = 0.05$) from 'Walla Walla Sweet' and 'Pukekohe', and 'Pukekohe' differed ($P = 0.05$) from 'Walla Walla Sweet' in intercept. 'Zenith' EPY decreased, then increased quadratically [EPY = $14.07 - 2.22$ (month) + 0.22 (month)²; $P = 0.03$]. 'Sweet Sandwich' EPY exhibited no significant change, although its EPY was previously reported to decrease during storage (Peterson et al., 1986). The pun-

Table 2. Effects of storage time at 5 ± 3 °C, and $80\% \pm 5\%$ relative humidity on bulb enzymatically formed pyruvic acid (EPY), soluble solids content (SSC), and accumulated loss in mass (MLOSS) of the short-day onion cultivars Rio Unico (RU), Dehydrator #3 (D3), and Granex 33 (G33).

Months	EPY ($\mu\text{mol}\cdot\text{mL}^{-1}$ fresh mass)			SSC (%)			MLOSS ($\text{g}\cdot\text{kg}^{-1}$)		
	RU	D3	G33	RU	D3	G33	RU	D3	G33
0	7.5 $\pm$ 0.9 ^a	12.8 $\pm$ 1.8	6.3 $\pm$ 0.7	8.7 $\pm$ 0.3	13.7 $\pm$ 0.3	7.6 $\pm$ 0.4	NA ^b	NA	NA
1	7.8 $\pm$ 1.3	11.1 $\pm$ 0.6	6.3 $\pm$ 0.7	9.3 $\pm$ 0.7	16.5 $\pm$ 0.8	8.0 $\pm$ 0.6	46 $\pm$ 13	21 $\pm$ 1	41 $\pm$ 6
2	6.5 $\pm$ 0.7	11.1 $\pm$ 0.7	7.1 $\pm$ 0.7	8.5 $\pm$ 0.3	15.5 $\pm$ 0.1	8.2 $\pm$ 0.2	119 $\pm$ 32	62 $\pm$ 23	70 $\pm$ 8
3	7.0 $\pm$ 1.8	10.6 $\pm$ 0.2	7.8 $\pm$ 1.0	8.4 $\pm$ 0.5	13.7 $\pm$ 0.4	7.8 $\pm$ 0.4	154 $\pm$ 24	103 $\pm$ 41	88 $\pm$ 10
Regression significance									
Linear	NS	$P = 0.05$	$P = 0.03$	$P = 0.19$			$P = 0.01$	$P = 0.01$	$P = 0.01$
Quadratic					$P = 0.01$	$P = 0.05$			$P = 0.01$

^aMean $\pm$ standard error.

^bNot available.

gency of ID and LD onions in storage, therefore, was a function of the cultivar stored and storage duration. Consumers of stored onions, such as food processors, need to be aware that these differences occur so appropriate action may be taken to ensure processed product uniformity.

Dormancy and EPY changes during storage. Onion pungency changes during storage have been associated with the breaking of bulb dormancy. Although 'Southport White Globe' flavor precursor concentrations increased during storage, concentrations decreased as the bulbs broke dormancy and sprouted (Lancaster and Shaw, 1991). Enzymatically formed pyruvic acid, measured in our study, is a stable product from flavor precursor decomposition, and is a bulb pungency indicator (Randle and Bussard, 1993). Loss of dormancy, as indicated by root sprouting, differed among cultivars (Table 4). All SD cultivars broke dormancy within 3 months of storage, while the LD cultivars Pukekohe, Zenith, and Sweet Sandwich remained dormant for 6 months. No associations, however, could be made between EPY changes during storage and bulb dormancy. 'Dehydrator #3' and 'Granex 33' both broke dormancy, but had opposite EPY linear regression trends. 'Zenith' and 'Pukekohe' both remained dormant, yet differed in EPY regression trends. However, 'Dehydrator #3' broke dormancy while 'Pukekohe' remained dormant, but both displayed significant linear decreases in EPY. Changes in EPY during storage, therefore, cannot be associated with dormancy in these cultivars.

Soluble solid changes and loss in mass during storage. Among the SD group, SSC differed among cultivars ($P=0.01$) and among storage dates ($P=0.01$), and the interaction between cultivars and storage dates was significant ($P=0.01$). 'Rio Unico' displayed no significant trend in SSC during storage, while quadratic equations for SSC were found for 'Dehydrator #3' [$SSC=9.21+5.77(\text{month})-1.18(\text{month}^2)$; $P=0.01$] and 'Granex 33' [$SSC=6.70+1.09(\text{month})-0.20(\text{month}^2)$; $P=0.05$], levels increasing, then decreasing (Table 2). The regression equation for 'Dehydrator #3', however, differed from that for 'Granex 33' for the intercept ($P=0.05$) and for the linear (month; $P=0.05$) and quadratic components (month²; $P=0.05$). The initial SSC increase in the SD cultivars may have been the result of the high loss in mass that occurred during the first month of storage. Loss in mass is primarily due to water loss from the bulb through the neck (Komochi, 1990), and SD, nonstorage-type onions exhibited greater losses than storage-type onions (Woodman and Barnell, 1937). Loss in mass continued linearly over the storage period for all SD cultivars in our study (Table 2). In the first storage month, 'Dehydrator #3' lost 2.1% of its prestorage mass while 'Granex 33' lost 4.2%. Soluble solids increases also may have resulted from the conversion of nonsoluble highly polymerized fructans to soluble sugars during this time. Darbyshire and Steer (1990) proposed that onions, in general, first synthesize fructans, which are then converted to simpler

Table 3. Effects of storage time at $5 \pm 3^\circ\text{C}$, and $80\% \pm 5\%$ relative humidity on bulb enzymatically formed pyruvic acid (EPY), soluble solids content (SSC), and accumulated loss in mass (MLOSS) of the long-day onion cultivars Sweet Sandwich (SS), Pukekohe (PLK), Zenith (Ze) and intermediate-day Candy (Ca), and Walla Walla Sweet (WWS) during storage. Month 4 EPY data unavailable.

Months ²	Cultivar				
	SS	PLK	Ze	Ca	WWS
EPY ($\mu\text{mol}\cdot\text{mL}^{-1}$ fresh mass)					
0	6.6 $\pm$ 0.5	11.0 $\pm$ 2.1	12.4 $\pm$ 2.3	6.9 $\pm$ 1.4	9.5 $\pm$ 1.3
1	7.8 $\pm$ 1.7	12.8 $\pm$ 2.2	9.9 $\pm$ 1.6	6.7 $\pm$ 1.1	10.8 $\pm$ 0.7
2	7.6 $\pm$ 1.0	11.7 $\pm$ 0.9	9.5 $\pm$ 2.0	7.1 $\pm$ 1.6	9.0 $\pm$ 0.9
3	6.6 $\pm$ 0.9	10.3 $\pm$ 1.6	8.9 $\pm$ 1.7	4.7 $\pm$ 0.4	7.3 $\pm$ 2.2
5	7.0 $\pm$ 2.4	10.9 $\pm$ 1.8	8.8 $\pm$ 1.1	5.9 $\pm$ 0.7	7.1 $\pm$ 1.8
6	5.0 $\pm$ 0.4	10.0 $\pm$ 0.9	9.3 $\pm$ 2.0	4.2 $\pm$ 0.8	7.9 $\pm$ 2.5
Regression significance					
Linear	$P=0.11$	$P=0.10$	$P=0.04$	$P=0.01$	$P=0.01$
Quadratic	$P=0.13$		$P=0.03$		
SSC (%)					
0	10.7 $\pm$ 0.1	11.4 $\pm$ 0.4	10.4 $\pm$ 0.4	8.1 $\pm$ 0.6	8.1 $\pm$ 0.4
1	10.9 $\pm$ 0.2	10.7 $\pm$ 0.4	10.0 $\pm$ 0.3	8.2 $\pm$ 0.5	8.2 $\pm$ 0.5
2	10.8 $\pm$ 0.4	11.2 $\pm$ 0.5	9.8 $\pm$ 0.4	8.7 $\pm$ 0.5	9.8 $\pm$ 0.4
3	10.3 $\pm$ 0.4	10.3 $\pm$ 0.5	9.7 $\pm$ 0.5	7.5 $\pm$ 0.3	7.2 $\pm$ 0.6
4	10.2 $\pm$ 0.4	10.4 $\pm$ 0.5	9.6 $\pm$ 0.4	7.2 $\pm$ 0.5	7.6 $\pm$ 0.4
5	9.5 $\pm$ 0.1	9.5 $\pm$ 0.2	9.4 $\pm$ 0.6	7.3 $\pm$ 0.3	7.0 $\pm$ 0.4
6	10.0 $\pm$ 0.1	10.1 $\pm$ 0.5	9.8 $\pm$ 0.2	7.1 $\pm$ 0.7	7.0 $\pm$ 0.2
Regression significance					
Linear	$P=0.01$	$P=0.01$	$P=0.01$	$P=0.01$	$P=0.01$
MLOSS ($\text{g}\cdot\text{kg}^{-1}$)					
1	11 $\pm$ 3	15 $\pm$ 6	3 $\pm$ 0.1	11 $\pm$ 3	8 $\pm$ 1
2	23 $\pm$ 7	27 $\pm$ 1	11 $\pm$ 3	16 $\pm$ 2	16 $\pm$ 2
3	34 $\pm$ 5	35 $\pm$ 1	16 $\pm$ 3	23 $\pm$ 3	25 $\pm$ 2
4	41 $\pm$ 11	35 $\pm$ 2	24 $\pm$ 2	28 $\pm$ 4	33 $\pm$ 3
5	51 $\pm$ 2	45 $\pm$ 5	29 $\pm$ 5	36 $\pm$ 4	48 $\pm$ 4
6	49 $\pm$ 3	57 $\pm$ 6	19 $\pm$ 5	42 $\pm$ 5	65 $\pm$ 6
Regression significance					
Linear	$P=0.001$	$P=0.001$	$P=0.001$	$P=0.001$	$P=0.001$

Table 4. Rooting (%) of bulbs of short-day (SD), intermediate-day (ID), and long-day (LD) onion cultivars during storage at $5 \pm 3^\circ\text{C}$, $80\% \pm 5\%$ relative humidity.

Cultivar ²	Months of storage						
	0	1	2	3	4	5	6
Rio Unico (SD)	0	100	100	NA ³	NA	NA	NA
Dehydrator #3 (SD)	0	100	100	NA	NA	NA	NA
Granex 33 (SD)	0	0	0	75	NA	NA	NA
Walla Walla Sweet (ID)	0	0	58	100	95	88	100
Candy (ID)	0	0	0	0	8	72	100
Pukekohe (LD)	0	0	0	0	0	0	0
Zenith (LD)	0	0	0	0	0	0	0
Sweet Sandwich (LD)	0	0	0	0	0	0	0

²Percentage of bulbs with roots elongating from the base of the bulb was determined by dividing the number of bulbs rooting by the total number of bulbs per cultivar.

³Not applicable.

forms of sugars. The degradation of a highly polymerized fructan into its many fructose molecules would increase SSC.

Within the ID and LD group, SSC differed among cultivars ($P=0.01$) and storage dates ($P=0.01$), but the interaction was nonsignificant. SSC decreased linearly in all ID and LD cultivars (Table 3). The SSC regression equations were: 'Candy' $SSC=8.68-0.23(\text{month})$, $P=0.01$; 'Walla Walla Sweet' $SSC=8.40-0.21(\text{month})$, $P=0.01$; 'Sweet Sandwich' $SSC=11.09-0.19(\text{month})$, $P=0.01$; 'Pukekohe' $SSC=11.41-0.19(\text{month})$, $P=0.01$; 'Zenith' $SSC=10.55-0.21(\text{month})$, $P=0.01$. These results are similar to previously reported SSC changes in onions. During LD onion storage, total soluble sugars decreased due to respiration (Bennett, 1941; Rutherford and Whittle, 1982). Loss in mass increased linearly or quadratically in all ID and LD

cultivars (Table 3). Decreases in mass due to water loss are characteristic of onions in long-term storage (Woodman and Barnell, 1937).

All onion cultivars, whether SD, ID, or LD, differed in pungency (EPY), SSC, and %ML changes during storage. Pungency changes during storage were not associated with day-length bulbing response or with dormancy loss during storage. Because the cultivars were grown, stored, and evaluated under similar environmental conditions, the pungency differences during storage were due to metabolic dissimilarities in the S-alk(en)yl cysteine sulfoxides associated with individual phenotypes. Understanding the fundamental differences in how pungency changes over time should allow for better product utilization when onions are brought out of storage and consumed fresh or processed. Moreover, establishing phenotypic differences in S-alk(en)yl cysteine sul-

foxide metabolism during storage may allow breeders to determine heritability estimates and develop breeding strategies for this character in order to meet the specific flavor needs of the onion industry.

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