Effects of Postharvest Curing, Ozone, Sulfur Dioxide, or Low Oxygen/High Carbon Dioxide Storage Atmospheres on Quality of Short-day Onions

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SUMMARY. Vidalia onions (*Allium cepa*) are a branded product of southeastern Georgia marketed under a federal marketing order. They are short-day, yellow onions with a Granex shape that are susceptible to a number of diseases postharvest, limiting the amount of time they can be marketed. Postharvest treatments and storage methods can help extend their marketability. Thus, the objective of this study was to evaluate these postharvest treatments and storage conditions on quality of three Vidalia onion varieties: 'WI-129', 'Sapelo Sweet', and 'Caramelo'. All varieties were undercut, then either harvested immediately (zero cure), field cured (2 days), or forced-air heat cured (3 days at $\approx 37^\circ\text{C}$) when judged mature. 'WI-129', 'Sapelo Sweet', and 'Caramelo' represent early, midseason, and late varieties, respectively. Bulbs were then sorted and stored in refrigerated storage [$0-1^\circ\text{C}$, 70% relative humidity (RH)], sulfur dioxide (SO_2) (1000 $\text{mg}\cdot\text{L}^{-1}$ in 2010 and 5000 $\text{mg}\cdot\text{L}^{-1}$ in 2011, one time fumigation) followed by refrigeration, ozone (O_3) (0.1–10 $\text{mg}\cdot\text{L}^{-1}$; continuous exposure, $0-1^\circ\text{C}$, 70% RH), or controlled-atmosphere storage [3% oxygen (O_2), 5% carbon dioxide (CO_2), $0-1^\circ\text{C}$, 70% RH]. After 2 and 4 months, bulbs were removed from storage, and evaluated after 1 and 14 days for quality and incidence of disorders. 'Caramelo' had the lowest percent marketable onions after curing in 2010, while 'WI-128' had the lowest percent marketable onions in 2011. There was a rain event immediately before harvesting 'Caramelo' that may have contributed to low marketability in 2010. Heat curing improved marketability for 'Sapelo Sweet' and 'WI-129' in 2010 compared with no curing. In 2011, heat curing resulted in more marketable onions for 'Sapelo Sweet' compared with no curing. Curing had no effect on 'Caramelo' in 2011 and field curing had the greatest percent marketable onions for 'WI-129' in 2011. In 2010, controlled-atmosphere storage had more marketable onions compared with SO_2 for 'Caramelo' and was better than simple refrigeration or O_3 with 'WI-129'. In 2011 refrigeration, controlled-atmosphere storage, and O_3 were all better than SO_2 with 'Caramelo'. 'Sapelo Sweet' and 'WI-129', on the other hand in 2011, had better storage with SO_2 compared with other storage methods. Onions stored for 2 months had 32% and 17% more marketable onions after removal compared with 4 months of storage regardless of storage conditions for 2010 and 2011, respectively. Poststorage shelf life was reduced by about one-third, 14 days after removal from storage regardless of the storage conditions.

Worldwide, the United States ranks third in the production of dry bulb onions after China and India (Food and Agriculture Organization of the United Nations, 2014). The Vidalia onion industry is an important component of Georgia's

agricultural economy, and is a significant portion of the U.S. onion market. Vidalia onions are a branded product protected by both state recognition and a federal marketing order. They are a short-day, yellow, high water content onion with a Granex shape. In 2010, almost 13,000 acres were

harvested in Georgia with an estimated farm gate value of \$139 million (Wolfe and Morgan, 2011). Onions ranked first among vegetables comprising $\approx 18.5\%$ of total vegetable farm gate value in Georgia (Wolfe and Morgan, 2011), which makes onions the state's most important vegetable crop.

Onions are divided into three categories based on the photoperiod length plants need to initiate bulb production, 1) short-day varieties that require 11–12 h of daylight, 2) intermediate-day varieties that will bulb when exposed to 13 h of daylight, and 3) long-day varieties that will bulb when exposed to photoperiods for 14–16 h (Brewster, 1990). Onions from different daylength classifications also have other significant differences, notably the degree of pungency and storability with short-day onions generally having the lowest pungency and the poorest storability. Due to the mild winter and early spring season in Georgia, short-day varieties are well suited for overwintering production in the state (Boyhan and Torrance, 2002).

Vidalia onions are relatively low in sulfur compounds, which makes them mild flavored (Boyhan and Torrance, 2002). However, having the characteristic of low sulfur content makes Vidalia onions more susceptible to infection from pathogens and diseases than high sulfur-containing onions (Maw et al., 1997b). Several fungal pathogens can attack sweet onions in Georgia. Botrytis neck rot (*Botrytis alli*) is one of the most common and damaging storage pathogens of short-day onions. In bad years, 70% of the total crop can be infected with botrytis neck rot rendering them unmarketable (Sanders et al., 2008). Under natural conditions, this pathogen infects the dead or dying tissue of the onion bulb, and then grows downward through the neck into the bulb proper (Pappelis et al., 1974).

The postharvest treatment required for long-term storage of onions is curing (Maw et al., 1997a). Curing

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
0.0283	ft ³	m ³	35.3147
2.54	inch(es)	cm	0.3937
1	ppm	mg·L ⁻¹	1
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

is a drying process intended to dry out the necks (Bayat et al., 2010) and outer scales of the bulbs (Maw et al., 2004) to reduce loss of moisture and prevent decay during storage. From harvesting to storage, curing can occur at any stage, whenever the conditions around the bulb become favorable to remove moisture from the bulb (Maw et al., 2004). There are two ways of curing onion bulbs: artificial and natural. Natural curing can take place in the field under the sun and wind after harvest. It is the least expensive way of curing and can be helpful in enhancing onion quality by allowing downward movement of nutrients from tops into the bulb (Maw et al., 1997a). Drying onions by forcing heated air around them is another way of curing. Standard conditions for this type of curing are blowing hot, dry air around the onions with temperatures up to 38 °C (Maw et al., 1998). Duration of heat curing varies according to the harvest maturity of the bulbs. For immature onions, the duration of heat curing required is more than for onions harvested at optimal maturity. Onions of early maturity are benefited when the duration of heat was 72 h, while for onions of optimal maturity required only 48 h of heat curing (Maw et al., 1997b).

Based on the market window, short-day onions can be handled in different ways: 1) fresh market, where the onions are sold directly without storage, 2) early-season markets, where the onions are stored in dry, well-ventilated sheds, 3) midseason markets, where onions can be stored under refrigeration, and 4) late season markets, where onions can be stored under refrigeration and controlled-atmosphere storage (Maw et al., 1997b). For successful long-term storage of short-day onions, they must be kept in a dormant state, which can be achieved with controlled-atmosphere storage. Controlled-atmosphere storage has been used widely with various fruits and vegetables like apples (*Malus × domestica*), pears (*Pyrus* sp.), kiwis (*Actinidia deliciosa*), blueberries (*Vaccinium* sp.), mango (*Mangifera indica*), bananas (*Musa* sp.), cabbage (*Brassica oleracea* var. *capitata*), chinese cabbage (*Brassica rapa*), etc. (Kader et al., 1989). In Georgia, Vidalia onions are stored in controlled-atmosphere storage (3% O₂, 5% CO₂) at 1–2 °C and RH of 75%, which helps in extending the market

availability of Vidalia onions from May to September (Boyhan et al., 2008). Sumner (2000) reported good quality Vidalia onions after 7 months of storage under controlled-atmosphere storage.

Sulfur dioxide is not used in onion storage in Georgia, but may offer an alternative to current long-term storage methods. In California, SO₂ has been used for the postharvest control of gray mold of table grapes (*Vitis vinifera*) caused by *Botrytis cinerea*, (Nelson, 1985). Marois et al. (1986) suggested that controlling gray mold on table grapes under commercial storage conditions was better when SO₂ application was at a concentration of 200 mg·L⁻¹ applied three times per week rather than the standard practice of 2500 mg·L⁻¹ once per week. SO₂ technology has been tested to control brown rot (*Monilinia fructicola*) in peaches [*Prunus persica* (Smith, 1930)], mold in raspberries [*Rubus* sp. (Spayd et al., 1984)], and postharvest decay and peel browning in longan fruit [*Diospyros longan* (Whangchai et al., 2005)]. SO₂ does have some drawbacks; it can corrode metal surfaces of the storage chamber and can cause product damage (Rahman, 2007).

Ozone can be helpful in postharvest treatment of fruits and vegetables and is currently used on a limited basis in some onion operations in southern Georgia. It can be applied as a gas or ozonized water either continuously or intermittently under controlled-atmosphere storage (Palou et al., 2001). Storage life of broccoli (*B. oleracea* var. *italica*) and cucumber (*Cucumis sativa*) can be extended with the help of O₃ (Skog and Chu, 2001). Song et al. (2000) reported that onion stored at low temperature when exposed to O₃ had half of the mold growth compared with the untreated onions.

Gubb and MacTavish (2002) observed that there are a number of factors that can affect the storage life of onions. This includes harvest time, temperature at the time of harvest, bulb composition, number of outer skin layers, and dry matter content. The objective of this study was to determine the influence of varieties, curing, storage atmosphere or fumigation, duration of storage, and poststorage time on marketability of Vidalia onions.

Materials and methods

This 2-year study evaluated varieties, curing method, storage

atmosphere or fumigation, time in storage, and poststorage time. In both years, three varieties, including ‘WI-129’, ‘Sapelo Sweet’, and ‘Caramelo’ were grown according to recommendations of the Georgia Cooperative Extension Service (Boyhan and Kelley, 2007) at the Vidalia Onion and Vegetable Research Center (VOVRC) in Lyons, GA. Eight-week-old seedlings were transplanted in mid-Nov. 2009 and 2010 for the Spring 2010 and 2011 harvests. Harvesting began when onions were judged mature, which is indicated when 20% to 50% of the tops have fallen over at the neck or there is significant weakness in the neck. Harvest began with undercutting the onions, ‘WI-129’, ‘Sapelo Sweet’, and ‘Caramelo’ on 26 Apr., 10 May, and 24 May 2010 and 14 Apr., 21 Apr., and 9 May 2011, respectively. During harvest and field curing, rain was recorded in 2010 at the nearby weather station (≈1 mile from the farm) with 0.05 inch on 25 May 2010. There were no rain events during harvest and field curing in 2011. After undercutting, two-thirds of the bulbs were harvested, and transported to the Vidalia Onion Research Laboratory (VORL) in Tifton, GA. The remaining one-third of the undercut bulbs was permitted to field cure for 48 h. In field curing, the soil is shaken from the roots, the tops are not removed, and the onions are placed on the soil surface. Average temperatures in 2010 during harvest and curing ranged from 63 to 75 °F and in 2011 ranged from 68 to 80 °F. On the same day, the bulbs arrived at VORL, they were cleaned, sorted, and graded manually to choose visually marketable onions of good size for the study. Onions with visual damage, disease, or were misshapen were discarded. Bulbs were segregated into 20-bulb lots and placed into poly mesh bags to insure good air circulation. Half the bags of each variety were then transported to the Black Shank Farm in Tifton, GA, where they were placed one layer deep inside a peanut drier for heat curing (37 °C) by forced air for 48 h. The remainder of the bags were maintained inside the VORL facility without curing (≈75 °F, 70% RH). After completion of the 48-h field cure treatment at VOVRC, bulbs were collected and transported to VORL

where they were also graded and sorted into 20-bulb lots.

All of the onions from the heat or field curing as well as the uncured onions were placed into one of four cold storage rooms (each having a volume of 12 m³) at 1–2 °C and 70% RH at VORL. The four storage rooms were 1) regular air storage [20.95% O₂, 0.03% CO₂, and 78% nitrogen gas (N₂)], 2) controlled-atmosphere storage (3% O₂, 5% CO₂, and 92% N₂), 3) one-time SO₂ fumigation followed by regular air storage, or 4) continuous O₃ (0.1–10 mg·L⁻¹ continuous exposure) under regular air storage. For the SO₂ fumigation treatment in 2010, 1000 mg·L⁻¹ of SO₂ was injected into a sealed cold storage room and remained at this concentration for 1 h, with fans running to help circulate the gas. The concentration was based on the weight of SO₂ to meet the concentration for the storage room volume. At the completion of the fumigation, the room was vented with air for 3 to 4 h until SO₂ levels were reduced below detectable levels (less than 1 mg·L⁻¹). In 2011, the SO₂ treatment used 5000 mg·L⁻¹ of SO₂. For the O₃ treatment, an O₃ generator (XT-4000; Air-Zone, Suffolk, VA) was programmed to inject O₃ into the room to maintain a continuous exposure between 0.1 and 10 mg·L⁻¹ of O₃. O₃ concentration was continuously monitored using an O₃ detector (A-21Z; Eco Sensors, Santa Fe, NM). Concentration of the gases, humidity, and temperature were detected by sensors, which were placed inside each storage room under computer control.

Bulb samples were removed after 2 and 4 months of storage, and warmed overnight to room temperature (22 °C) under controlled conditions. The following day, four bags (replications) of each treatment were removed randomly and weighed while a similar set of four bags were maintained at room temperature for 14 d to evaluate poststorage marketability. Bulbs were evaluated for botrytis neck rot, sour skin (*Burkholderia cepacia*), slippery skin (*Burkholderia gladioli* ssp. *allicola*), physical damage, sprouts, and other storage defects were noted. First, bulbs were evaluated visually for any significant damage or symptoms of diseases, which were considered unmarketable. If there were no defects

or disease symptoms observed from the outside, bulbs were then cut longitudinally to see any internal symptoms of disease. Only the bulbs passing both external and internal exams were considered marketable with the primary cause of rejecting bulbs, botrytis neck rot.

Bulbs held for 14 d under ambient conditions were evaluated in an identical manner as described above. These same procedures were used to evaluate onions stored for 4 months. This experiment was repeated in 2011.

The experiment was arranged with a full factorial arrangement with five factors as a randomized complete block design with four replications. Three of the five factors were categorical, which included variety, type of curing, and storage conditions, while the remaining two were numerical, months in storage and days after storage before evaluation. The analysis was conducted by splitting the factor model into two separate analyses: one consisting of two factors, varieties and curing methods; the second with storage conditions, months in storage, and poststorage time. This was done to facilitate ease of analyses and to have a more meaningful presentation of the data. Data were collected as percent marketable onions. Analysis of variance was performed on this data. Fisher's protected least significant difference at $P \leq 0.05$ was calculated.

Results and discussion

For all results, there was a by year interaction so results are presented for years individually. As seen in Table 1, in 2010, with 'Caramelo' both heat curing and no curing had greater percent marketable onions compared with field curing. For 'Sapelo Sweet' in 2010, heat curing had the greatest percent marketable onions with 78.3%, which was greater than no curing or field curing. 'WI-129' in the same year also had the greatest percent marketable onions with heat curing, which was significantly higher than no curing, but was similar to field curing.

In 2011, 'Caramelo', had no difference between curing methods (Table 1). 'Sapelo Sweet' in 2011 had similar amounts of marketable onions with either field or heat curing, both of which had more marketable onions compared with the no curing treatment. Finally in 2011,

with 'WI-129' field curing had the greatest amount of marketable onions with 58.2%, which was greater than heat or no curing.

In 2010, 'Sapelo Sweet' had the greatest amount of marketable onions with 70.1% marketable compared with either 'WI-129' or 'Caramelo' (Table 1). By contrast, in 2011 both 'Caramelo' and 'Sapelo Sweet' had similar amounts of marketable onions, which were significantly greater than 'WI-129'.

There were interaction effects for storage conditions, varieties, and years so these results are presented separately (Table 2). In both 2010 and 2011, 'Caramelo' had more marketable onions when stored under refrigerated controlled-atmosphere conditions or with refrigerated O₃ storage than when stored under refrigeration after SO₂ treatment (Table 2). There were no differences between storage conditions in 2010 for 'Sapelo Sweet'; however, in 2011 SO₂ treatment had the greatest percent marketable onions compared with controlled atmosphere, O₃, or refrigeration alone. In 2010, 'WI-129' had the greatest percent marketable onions with controlled atmosphere compared with O₃ or simple refrigeration. However, it did not differ from SO₂ treatment. In 2011, SO₂ treatment with 'WI-129' onions had the greatest percent marketable onions at 73.0%, which was significantly better than all other storage conditions. In addition, in 2011 'WI-129' onions stored under controlled-atmosphere conditions had more marketable onions than either refrigeration with O₃ or refrigeration alone.

Interactions between storage conditions and time in storage as well as storage conditions and poststorage time were significant. In addition, storage conditions by year and time in storage by year were also significant so these results are presented separately (Table 3). The longer onions were held in storage the lower the percent marketable onions. This was true in both 2010 and 2011. In 2010, there were ≈20% fewer marketable onions after 4 months in storage compared with 2 months in storage. In 2011, there were ≈10% fewer onions from 2 to 4 months in storage.

Onions stored for 2 months in 2010 had the greatest marketable onions with controlled-atmosphere storage, which was significantly better

Table 1. Percent marketable short-day onion for three varieties after three postharvest curing protocols in 2010–11.

	2010 ^z			2011		
	Caramelo	Sapelo Sweet	WI-129	Caramelo	Sapelo Sweet	WI-129
Curing method ^y	Marketable onions (%)			Marketable onions (%)		
Field curing	28.3 b ^x	68.5 b	55.9 a	59.2	67.7 a	58.2 a
Heat curing	40.5 a	78.3 a	59.4 a	55.0	62.9 a	48.6 b
No curing	41.8 a	63.4 b	35.1 b	59.8	40.4 b	41.5 b
Variety						
Caramelo		36.8 c			58.0 a	
Sapelo Sweet		70.1 a			56.5 a	
WI-129		49.8 b			49.4 b	
Probabilities						
Variety	0.000					
Curing method	0.000					
Variety × curing method	0.000					
Year	0.087					
Variety × year	0.000					
Curing method × year	0.000					
Variety × curing method × year	0.014					

^zOnions were evaluated for marketability after removal from 2 and 4 months of refrigerated [1–2 °C (33.8–35.6 °F), 70% relative humidity] storage.

^yField curing = harvested onions with soil removed from the roots and tops still attached are left on the soil surface in the field for 48 h.

^xMeans followed by the same letter in each column are not significantly different at $P \leq 0.05$, according to Fisher's protected least significant difference.

Heat curing = artificially drying onions at 37 °C (98.6 °F) for 48 h after tops and roots have been removed.

No curing = storing onion as such after harvest without drying with tops and roots removed.

Table 2. Percent marketable onions for three different short-day onion varieties stored under different postharvest environments, 2010–11.

	2010			2011		
	Caramelo	Sapelo Sweet	WI-129	Caramelo	Sapelo Sweet	WI-129
Storage conditions ^z	Marketable onions (%)			Marketable onions (%)		
Refrigeration	35.6 ab ^y	69.2	37.3 c	59.1 a	42.4 c	34.2 c
Controlled atmosphere	42.0 a	72.1	59.4 a	63.9 a	54.2 b	50.9 b
Ozone + refrigeration	42.7 a	65.1	47.5 b	64.5 a	56.5 b	39.5 c
Sulfur dioxide + refrigeration	27.2 b	73.8	55.0 ab	44.4 b	73.1 a	73.0 a
Probabilities						
Variety	0.000					
Year	0.084					
Storage conditions	0.000					
Variety × storage conditions	0.000					
Variety × year	0.000					
Storage conditions × year	0.002					
Variety × storage conditions × year	0.001					

^zRefrigeration = storage at 1–2 °C (33.8–35.6 °F) with 70% relative humidity.

^yMeans followed by the same letter in each column are not significantly different at $P \leq 0.05$, according to Fisher's protected least significant difference.

Controlled atmosphere = 3% oxygen, 5% carbon dioxide, and 92% nitrogen gas held at 1–2 °C with 70% relative humidity.

Ozone = 0.1–10 mg·L⁻¹ (ppm) continuous exposure with refrigeration.

Sulfur dioxide = 1000 mg·L⁻¹ in 2010 and 5000 mg·L⁻¹ in 2011 one-time injection with refrigeration.

than refrigeration alone or refrigeration after treatment with SO₂ (Table 3). However, controlled-atmosphere storage in 2010 after 2 months of storage did not differ from O₃ treatment. In 2011, after 2 months of controlled-atmosphere storage, O₃ storage, or SO₂ treatment all had more marketable onions than refrigeration alone. SO₂ treatment, in 2010 after 4 months in storage had the greatest percent marketable onions compared with refrigeration alone, but it did not differ from either controlled-atmosphere storage

or O₃ storage. In 2011, SO₂ again had the greatest percent marketable onions at 67.1%, which was significantly more than refrigeration alone, controlled-atmosphere storage, or O₃ storage.

Poststorage time also had a significant effect on marketable onions. The percentage of marketable onions was significantly greater immediately after removal from storage compared with 14 d later (Table 4).

A number of different conditions were used to determine unmarketable

onions (data not shown). These conditions included botrytis neck rot, sour skin, slippery skin, physical damage, shriveled onions, and from unknown causes. Of those onions judged as unmarketable 62.6% were due to botrytis neck rot, 20.9% to unknown causes, 6% to slippery skin, 5.4% to physical damage, 4.5% due to sour skin, and 0.6% were shriveled onions.

Botrytis neck rot's impact on onions varies from year to year and could be difficult to control because the pathogen can enter the bulb

below the soil line. It is also common for the pathogen to infect neck tissue thus the name. Once the pathogen enters the bulb it is not always obvious after curing. The pathogen in infected onions that are placed in controlled-atmosphere storage will continue to grow, although it is not capable of sporulating (Purvis et al., 2001). Because the pathogen cannot sporulate in controlled-atmosphere storage, bulb losses are primarily due to infections acquired in production. This has resulted in uneven results from this type of storage with the amount of marketable onions varying widely. Anecdotally, severe losses in stored onions occur about once every 4 years. It has been hypothesized that greater losses with stored onions occurs during years when winter temperatures remain low for extended periods of time resulting in slower growth allowing the pathogen to infect onions from below the soil line. Usually as onions are actively growing, particularly early growth, the outer bulb leaves are sloughed off or become the dry papery outer layer of the onion, which helps protect the onion (DeMason, 1990).

In this study, the number of parameters like variety, postharvest curing, storage conditions, duration of storage, and poststorage time were evaluated to assess the influence on percent marketable onions. The results demonstrated clearly that postharvest curing, storage conditions, storage duration, and poststorage time significantly affect the percent of marketable onions. This study documents that all three varieties were significantly different from each other in 2010, but in 2011 only 'WI-129' had significantly less marketable onions. The early harvested variety 'WI-129' had almost the same percentage of marketable onions for both years. Past studies also support our results that early maturing varieties do not perform as well in storage as mid and late maturing varieties (Boyhan et al., 2008). But there were large differences in the percent marketable onions for the other two varieties. In 2010, the midseason variety 'Sapelo Sweet' had the highest percent marketable onions. There was a rain event in 2010 during the 'Caramelo' harvest, which probably contributed to the poor performance of this variety that year. However, in 2011, this

Table 3. Effects of postharvest storage conditions, time in storage, and postharvest shelf life on percent marketable short-day onions.

	2010		2011	
	2 mo.	4 mo.	2 mo.	4 mo.
Storage conditions ^z	Marketable onions (%)			
Refrigeration	60.3 b ^y	34.0 b	50.9 b	39.6 b
Controlled atmosphere	69.2 a	47.0 a	66.0 a	46.8 b
Ozone + refrigeration	63.4 ab	40.5 ab	62.5 a	44.7 b
Sulfur dioxide + refrigeration	57.6 b	47.7 a	60.0 a	67.1 a
Probabilities				
Storage conditions	0.000			
Storage time (2 or 4 mo.)	0.000			
Poststorage time (1 or 14 d) ^x	0.000			
Year	0.128			
Storage conditions × storage time	0.000			
Storage conditions × poststorage time	0.009			
Storage time × poststorage time	0.162			
Storage conditions × storage time × poststorage time	0.270			
Storage conditions × year	0.002			
Storage time × year	0.001			
Poststorage time × year	0.116			

^zRefrigeration = storage at 1–2 °C (33.8–35.6 °F) with 70% relative humidity.

^yMeans followed by the same letter in each column are not significantly different at $P \leq 0.05$, according to Fisher's protected least significant difference.

^xPoststorage time = after removal from storage onions were evaluated immediately (day 1) or held under ambient conditions [≈ 24 °C (75.2 °F)] for 14 d before evaluating for marketability.

Controlled atmosphere = 3% oxygen, 5% carbon dioxide, and 92% nitrogen gas held at 1–2 °C with 70% relative humidity.

Ozone = 0.1–10 mg·L⁻¹ (ppm) continuous exposure with refrigeration.

Sulfur dioxide = 1000 mg·L⁻¹ in 2010 and 5000 mg·L⁻¹ in 2011 one-time injection with refrigeration.

variety did much better comparable to 'Sapelo Sweet' and better than 'WI-129'.

Botrytis neck rot is the primary storage disease of onions in the southeastern United States, with infection starting in the field. Cool, moist weather conditions before or at the time of harvest favors the disease and can cause more losses in storage (Johnson, 1986). Harvesting after rain events should be avoided to insure a quality product goes into storage. Similarly, if rain is in the 48- to 72-h forecast, heat curing of harvested onions may be advisable over field curing to reduce the risk of wet bulbs being placed into storage.

Curing in general helps onions store better and for longer periods (Maw et al., 2005). Our study also generally indicated that curing had a significant positive impact on percent marketable onions. However, this was not as clear-cut as in previous studies. The low percent marketable onions with 'Caramelo' in 2010 after field curing can be explained, we believe, by the rain event during field curing that year. Uncured 'Sapelo Sweet' onions did as well as field curing in 2010 and there was no difference

Table 4. Poststorage marketable onions after 1 or 14 d under ambient conditions [≈ 24 °C (75.2 °F)] from onions combined from various storage conditions and stored for both 2 and 4 months.

Poststorage time (d)	Marketable onions (%)
1	63.2
14	44.1
Probability ^z	0.000

^zFrom analysis of variance.

between cured and uncured 'Caramelo' onions in 2011. Finally in 2011, uncured 'WI-129' onions did as well as heat-cured onions, but not as well as field-cured onions.

Storing onions under different conditions had an impact on onion marketability. The greater percent marketable onions under SO₂ treatment in 2011 may be related to the higher treatment concentration of SO₂ in 2011, which was applied at 5000 mg·L⁻¹ in 2011 compared with 1000 mg·L⁻¹ in 2010. SO₂ may be a viable alternative to controlled-atmosphere storage, which is widely used in the industry, because it would be less expensive. In 2010, SO₂ was as good

as controlled-atmosphere storage with ‘Sapelo Sweet’ and ‘WI-129’ and in 2011, it was the best overall with ‘Sapelo Sweet’ and ‘WI-129’. There was no direct injury detected in the onions treated with SO₂.

Overall, no clear-cut onion storage condition appeared to consistently result in more percent marketable onions. Even if ‘Caramelo’ onions from 2010 are excluded due to the rain event during harvest and field curing, there were no differences with ‘Sapelo Sweet’ that year and storage conditions other than simple refrigeration were better for ‘WI-129’. In 2011, SO₂ was the best storage method for ‘Sapelo Sweet’ and ‘WI-129’; however, for ‘Caramelo’ it was the worst. Although not clear-cut, SO₂ may offer a viable alternative to current storage methods for short-day onions in Georgia.

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