

Controlled atmosphere and shelf life performance of a new late-maturing Japanese pear (*Pyrus pyrifolia* (Burm. F.) Nakai) cultivar 'Atago'

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Abstract

The aim of this research was to investigate the optimum storage condition, duration and shelf life performance of a new late-maturing Japanese pear cultivar 'Atago' under normal atmosphere, controlled atmosphere and shelf life conditions. For this purpose, fruits without injury or decay were divided into two groups. Group 1 (control) was stored in normal atmosphere; group 2 was stored in controlled atmosphere at 2.5% O₂ + 1.5% CO₂. The fruits were stored at 0 °C and 90-95% relative humidity for 32 weeks. 120 fruits were removed from normal atmosphere and controlled atmosphere every two months. Analyses were conducted on 60 fruits immediately after removal from storage, whereas remaining 60 fruits were transferred to the shelf life conditions (20 °C and 60-65% relative humidity), where they were kept for 5 d for shelf life performance evaluation. Fruits were analysed for weight loss, peel and flesh colour, flesh firmness, pH, titratable acidity, soluble solid content, respiration rate, ethylene production, peel, internal and core browning, rotting, superficial and senescent scald and sensorial evaluation. According to results of ethylene production 'Atago' was evaluated in the moderate range of the ethylene-generating group of Japanese pears and accepted as a climacteric fruit. Core browning was at higher levels in normal atmosphere than controlled atmosphere at the end of the storage. Results suggested that 'Atago' should be stored in controlled atmosphere at 2.5% O₂ + 1.5% CO₂ to prevent core browning and rotting and to maintain a high-quality extended marketing period.

Keywords: cold storage; nashi; organoleptic characteristics; physicochemical quality; postharvest

Introduction

In *Pyrus*, there are three major species, *P. communis* L. (pear or European pear), *P. bretschneideri* Rehd. or *P. ussuriensis* Maxim. (Chinese pear), and *P. pyrifolia* Nakai (Japanese pear: Nashi), which are commercially cultivated in temperate zones (Itai and Fujita, 2008). *Pyrus pyrifolia* (Burm. F.) Nakai (including 'Atago' cultivar) is the main species in Japan, Korea, and southern and central China (Li *et al.*, 2016). Asian pears are also called as salad pears, Nashi (Japanese for 'pear'), Oriental, Chinese or Japanese pears (Nihonnashi) (Beutel, 2019).

The pear production of the world is reported as 24,168,309 *t*. Turkey takes the fifth place with 503,004 *t* of pear production on 26,000 ha of land (FAO, 2017). In recent years, the cultivation of Asian pear cultivars has also begun to gain importance.

Pears are climacteric fruit that show increased ethylene production and respiration rates during ripening. Rapid ripening and softening make them sensitive to mechanical injury and pathogen infection (Cheng *et al.*, 2015). Since pome fruits respond best to storage at the lowest possible temperature compared to other fruit varieties, this offers great advantages for long-term trouble-free storage of such fruits (Kader, 2002). Rapid cooling and cold storage (-1 to 0 °C) at high humidity, at least 90-95%, is the most important tool for preserving the quality of pears (Kowalczyk *et al.*, 2017). Storage at low temperature delays fruit senescence and extends postharvest life of the fruit, however pears are susceptible to development of chilling injury associated disorders, including peel and core browning and decay (Cheng *et al.*, 2015). Some Asian pear varieties cannot be stored for a long time because they have very short shelf life, and early deterioration may occur. For this reason, it is possible to store Asian pears efficiently by controlled atmosphere storage (Imahori *et al.*, 2015). Controlled atmosphere storage can extend shelf life by using O₂ and CO₂ concentrations ranging between 1-2% and 0-2%, respectively, depending on pear cultivar (Kowalczyk *et al.*, 2017). Pears are generally less tolerant than apples to very low O₂ levels because low levels of O₂ in storage rooms change the energy status of pear fruit with detrimental consequences in membrane phospholipids and enhancement of internal disorders (Saquet and Almeida, 2017).

To our knowledge, no prior studies have investigated the postharvest life of a new fire-blight (*Erwinia amylovora*) resistant late-maturing Japanese pear (*Pyrus pyrifolia* (Burm. F.) Nakai) cultivar 'Atago'. Therefore, the present study aimed to determine the optimum storage condition, duration and shelf life performance of 'Atago'. To achieve these goals the physicochemical, physiological and sensory quality changes of the fruits were investigated during cold storage under normal and controlled atmosphere conditions and their subsequent shelf life.

Materials and Methods

Fruit material

The pear cultivar 'Atago' grafted on 4-year old *Pyrus betulafolia* rootstock was used as fruit material. 'Atago' is a new fire-blight (*Erwinia amylovora*) resistant late-maturing Japanese pear (*Pyrus pyrifolia* (Burm. F.) Nakai) cultivar. The medium sized fruits have yellow specks on the green ground. The fruit has long stem, flattened and swollen and white and very juicy flesh (Ekici, 2016). Its commercial harvest time under the ecological conditions of Turkey (Denizli) is approximately on late August or early September.

Storage conditions

Fruits were transported immediately to the laboratory at Isparta University of Applied Sciences, Faculty of Agriculture, and Department of Horticulture after the harvest. Fruits without injury or decay were selected and divided into two groups and placed to the controlled atmosphere (CA) (2.5% O₂ + 1.5% CO₂) and normal atmosphere (NA) (20.9% O₂ + 0.003% CO₂) conditions. The cold storage (CS) conditions for CA and NA were 0 °C and 90-95% relative humidity (RH). Analyses were conducted at harvest date and at two-month intervals during the CS. During the storage period, 120 fruits were removed from the NA and CA every two months and analyses were conducted on 60 fruits (30 CA, 30 NA) immediately after removal from storage, whereas remaining 60 fruits (30 CA, 30 NA) were transferred to the room temperature conditions (20 °C and 60-65% RH), where they were kept for 5 d for shelf life (SL) performance evaluation.

Physicochemical analyses

Flesh firmness was determined using a digital texture machine and measured via compression using a 100 N load cell and a stainless steel 7.9 mm diameter cylindrical probe. Fruit peel and flesh colour was determined by using a chroma meter. The CIE L^* (lightness) a^* (+ a^* : red, - a^* : green) b^* (+ b^* : yellow, - b^* : blue) colour space was used to measure the colour. Chroma (C^*) and hue angle (h°) were calculated as $C^* = (a^{*2} + b^{*2})^{1/2}$ and $h^\circ = \arctan b^*/a^*$, respectively. Weight loss was expressed as the percentage of weight loss with respect to the initial weight. The soluble solid content (SSC) was measured using a digital refractometer and was expressed as percentage of soluble solids per 100 g fresh weight. Titratable acidity (TA) was determined by a digital pH meter and titrimeter, and expressed as percentage of grams of malic acid equivalent per 100 g fresh weight and pH was measured by a digital pH meter. For respiration rate (RR) and ethylene production (EP) measurements, the static system described by Saltveit (2016) was used. RR and EP were determined by gas chromatography. Samples were put in a gas tight glass jars at room temperature. Gas sample was taken from the jars at the end of the 6 h. Measurements were made in split/split less (S/SL) of inlet in split mode with gas sampling valve with 1-mL gas sample by using fused silica capilar column, with thermal conductivity detector (TCD) for RR measurements and flame ionization detector (FID) for EP measurements by a gas chromatography and a software. Carrier gas flow was 1.7 mL/min in stable flow mode. The temperature of the oven, TCD and FID detectors were 40 °C (isothermal), 250 °C and 250 °C, respectively (Dilmaçunal, 2009). RR and EP were expressed as $\text{nmol kg}^{-1}\text{s}^{-1}$.

Peel, internal and core browning, superficial and senescent scald and rotting

Internal browning (IB) was evaluated according to Deuchande *et al.* (2016). Core browning (CB) was evaluated according to the browning severity of the core using a scale of 0-5: 0: no browning, 1: very light brown, 2: light brown, 3: medium, 4: dark brown 5: very dark brown. CB incidence and rotting were expressed as percentage of affected fruits. Peel browning (PB), superficial and senescent scald was evaluated according to Li *et al.* (2016).

Sensorial attributes

The sensory analyses were conducted by a panel of 10 trained panelists for determining the eating quality of the fruits. Visual quality was evaluated by using a scale of 1-9: 1-4: unmarketable, 5: marketable, 6-8: good, 9: excellent. Fruit juiciness, taste and aroma were evaluated using a scale of 1-5: 1: very poor, 2: poor, 3: mild, 4: good, 5: excellent (Dilmaçunal, 2009). For evaluation of the overall liking, panelists were asked to taste three coded samples of peeled pear slices for each sample to indicate the degree of liking on a nine-point hedonic scale 1: dislike extremely, 2: dislike very much, 3: dislike moderately, 4: dislike slightly, 5: neither like nor dislike, 6: like slightly, 7: like moderately 8: like very much, 9: like extremely. Ripeness was evaluated using a scale of 1-3: 1: unripe, 2: ripe, 3: overripe (Predieri and Gatti, 2009). Sourness was evaluated using a scale of 1-6: 1: very sour, 2: sour, 3: medium, 4: sour-sweet, 5: sweet-sour 6: sweet. Firmness was evaluated using a scale of 1-5: 1: very firm, 2: firm, 3: medium, 4: soft, 5: very soft. Grittiness was evaluated using a scale of 1-6: 1: very gritty, 2: gritty, 3: medium, 4: few, 5: very few 6: not gritty.

Experimental design and statistical analyses

The experiment followed a completely randomized design with 3 replication and 10 fruits was regarded as a replication for each of the storage period and condition. The data were subjected to the analyses of variance (ANOVA) using Minitab® 17 statistical software (MINITAB Inc. USA). The means were separated with Tukey's test at the 5% level of significance.

Results and Discussion

Flesh firmness

Firmness is better retained during storage under low O₂ level than in air (Saquet and Almeida, 2017). Decreased O₂ and/or elevated CO₂ levels over long-term storage can reduce respiration, delay ripening and senescence, as well as slow down firmness loss and colour changes, thereby maintaining postharvest quality and extending SL of pear (Liu *et al.*, 2013). Successful long-term storage of pear must assure firmness maintenance during storage, but allow softening during subsequent ripening in shelf life (Saquet *et al.*, 2017). In the same manner the positive effects of CA on the physicochemical and sensory quality attributes of ‘Atago’ were seen in this research (Tables 1 and 3).

Abnormal patterns of softening, called loss of ripening capacity, reported for pears due to prolonged storage (Predieri and Gatti, 2009) were not seen in this study (Tables 1 and 3). The loss of firmness stored in NA (29.20 N) was higher than CA (32.53 N) less juicy fruits were evaluated in NA.

Fruits had lower firmness values during SL than CS for both of NA and CA (Table 1). Likewise, Goliáš *et al.* (2016) reported that the effects of low oxygen combined with considerably higher than normal CO₂ levels, accompanied by subsequent exposure to temperatures of 18 °C, do not lead to a significant softening of the flesh.

Table 1. Mean values of physicochemical properties of pear cultivar ‘Atago’ tested as a function of cold storage period (CS) and post storage shelf life (SL)

Storage conditions	Physico-chemical properties	Storage period									
		Harvest	Harvest + 5 d SL	8 weeks CS	8 weeks CS + 5 d SL	16 weeks CS	16 weeks CS + 5 d SL	24 weeks CS	24 weeks CS + 5 d SL	32 weeks CS	32 weeks CS + 5 d SL
NA	SSC	11.32	14.48 aA	15.18 aA	15.52 aA	15.15 aA	15.17 aA	15.32 aA	14.82 aA	14.95 aA	15.02 aA
	TA	1.85	2.44 aA	1.21 bA	1.39 bA	1.91 aA	1.39 bB	1.12 bA	1.22 bcA	1.03 bA	1.08 cA
	pH	4.98	4.68 bA	5.61 aA	5.26 aA	4.42 dA	5.28 aA	5.11 bA	4.81 bA	5.73 aA	5.33 aA
	Weight loss	-	1.43 cA	5.66 dA	2.36 abB	7.94 cA	2.03 bB	9.90 bA	2.44 aA	10.92 aA	0.78 dB
	RR	38.00	77.76 bA	120.49	107.68	244.52	280.24	243.88	382.74	76.62	92.85 bA
	EP	0.01	0.01 bA	0.17 bcA	0.51b A	6.72 aA	9.25 aA	7.06 abA	10.99 aA	1.05	9.50 aA
	Fleshfirmness	36.56	38.04 aA	35.44 aA	31.70 bA	36.60 aA	26.76 cB	29.27 bA	21.18 dB	29.25 bA	29.20
	Peel color L*	66.52	68.46 aA	67.60 aA	68.66 aA	69.00 aA	68.92 aA	68.87 aA	70.56 aA	68.46 aA	69.30 aA
	Peel color a*	-8.53	-6.19 bA	-4.49 bA	-2.62 aA	-2.43 aA	-1.81 aA	-1.61 aA	-1.08 aA	-0.97 aA	-1.92 aA
	Peel color b*	46.53	42.22 aB	43.17 cA	41.06 aA	41.07 dA	40.87 aA	43.71	42.31 aA	44.83 bA	41.04 aA
	Peel color C*	47.31	42.68 aB	43.41 cA	41.15	41.15 dA	40.91 cA	43.74	42.33	44.84 bA	41.10
	Peel color h°	100.3	98.35 aB	95.93 bB	93.65 bA	93.39 cB	92.53 bB	92.12	91.47 bA	91.24 dB	92.69 bA
	Flesh color L*	66.44	63.48 dB	65.40	66.02 cA	65.21 bA	67.99 bA	67.24 aA	71.56 aA	66.38	67.49
	Flesh color a*	-1.57	-1.37 cB	-1.62 bB	-1.32	-0.64 aA	-1.24	-0.98 aA	-1.06	-0.69 aA	-0.88 aA
	Flesh color b*	11.95	11.12	11.46 bA	10.65 bA	14.13 aA	12.05 aA	10.68 bA	11.20	10.91 bA	11.60
	Flesh color C*	12.05	11.21	11.58 bA	10.73 bA	14.14 aA	12.11 aB	10.73 bA	11.26	10.94 bA	11.64
	Flesh color h°	97.49	97.05 aA	98.02 aA	97.06 aA	92.61 cB	95.86	95.23 bA	95.41	93.64	94.36 cA
	CA	SSC	11.32	14.48 aA	15.13 aA	14.33 aB	14.18 aB	14.73 aB	13.92 aB	13.98 aA	14.60 aA
TA		1.85	2.44 aA	1.27 bA	1.39 cA	1.72 aA	2.19 bA	1.12 bcA	1.34 cA	0.86 cA	0.99 dA
pH		4.98	4.68 cA	4.93 bcA	5.25 aA	4.49 cA	5.04 bB	5.21 abA	4.83 cA	5.77 aA	5.32 aA
Weight loss		-	1.43 cA	0.68 cB	3.29 aA	0.95 bcB	2.38 bA	1.29 abB	2.95 abA	1.52 aB	1.01 cA
RR		37.62	77.70	66.08 bB	69.68	184.81	205.57	214.16	223.94	63.12 bA	51.12 cB
EP		0.01	0.01 aA	0.16 bA	0.19 aA	4.25 abA	7.66 aA	6.89 aA	10.74 aA	0.98 abA	0.74 aB
Fleshfirmness		36.56	38.04 aA	34.60	31.57 cA	40.46 aA	37.34	33.41 bA	24.64 dA	34.75	32.53
Peel color L*		66.07	64.98 aB	66.12 aA	65.86 aA	66.20 aB	64.83 aB	63.90	68.11 aA	62.07 bB	65.04 aB
Peel color a*		-9.23	-10.88	-6.18 aB	-6.40 aB	-4.97 aB	-4.19 aB	-4.80 aB	-3.01 aA	-4.33 aB	-4.69 aA
Peel color b*		45.47	44.47 aA	42.80	39.44 bA	39.16 cB	38.45 bB	40.73	41.66	40.42	38.60 bB
Peel color C*		46.41	45.79 aA	43.24 bA	40.00 bA	39.48 cB	38.68 bB	41.02	41.82 bA	40.65	38.90 bB
Peel color h°		101.4	103.75	98.21 bA	99.33	97.23 bA	96.23 bA	96.70 bA	94.24 bA	96.09 bA	96.94
Flesh color L*		66.44	67.49 aA	65.33	63.52 bB	65.49	63.87 bB	63.78 bB	66.75 aB	64.23 bB	63.68 bB
Flesh color a*		-1.57	-0.89	-1.42 bA	-1.39 cA	-0.99 aA	-0.51 aA	-1.04 aA	-1.05	-0.92 aA	-0.95 bA
Flesh color b*		11.95	11.60 bA	10.95 aA	11.15 bA	11.34 aB	13.64 aA	10.31 aA	10.68 bA	11.16 aA	10.97 bA
Flesh color C*		12.05	11.64 bA	11.04 aA	11.24 bA	11.38 aB	13.65 aA	10.37 aA	10.73 bA	11.20 aA	11.02 bA
Flesh color h°		97.49	94.36 bB	97.39 aB	97.12 aA	94.99 bA	92.15 cB	95.78	95.59	94.86 bA	94.96 bA

Note: Means (n=3) followed by the same small letter (within the rows) and capital letter (within the columns) do not differ significantly at p = 0.05 (LSD test) during cold storage or shelf life. (NA: normal atmosphere, CA: controlled atmosphere, SSC: Soluble solid content %, TA: Titratable acidity g malic acid L⁻¹, Weight loss %, RR: Respiration rate nmol kg⁻¹s⁻¹, EP: Ethylene production nmol kg⁻¹s⁻¹, Flesh firmness N, L*: lightness, C*: chroma, h°:hue angle)

Ethylene production and respiration rate

Japanese pears include climacteric and non-climacteric cultivars (Saito, 2016). Fruit storage potential is closely related to the maximum level of EP in Japanese pear (Itai and Tanahashi, 2008). Asian pear cultivars were classified according to EP levels during fruit ripening and the values between 4.95 to 99.02 nmol kg⁻¹s⁻¹ is accepted as showing moderate, and over 99.02 nmol kg⁻¹s⁻¹ is accepted as showing high ethylene production (Itai and Fujita, 2008).

As reported by Lee *et al.* (2017) the maximum EP of a Japanese pear cultivar 'Wonhwang' was 14.85 nmol kg⁻¹s⁻¹, which is equivalent to the "moderate" range of the ethylene-generating group of Japanese pears and accepted as a climacteric fruit. There is not any literature about the EP of 'Atago'. The EP of 'Atago' was at low values at the beginning to 16 weeks of CS and CA had lower values than NA. The EP level of 'Atago' was changed between 0.01 and 10.99 nmol kg⁻¹s⁻¹ (Table 1). According to these findings 'Atago' can be evaluated in the moderate range of the ethylene-generating group of Japanese pears and accepted as a climacteric fruit.

The RR of 'Bartlett' pear was changed between 385 and 518 nmol kg⁻¹s⁻¹ during 24 weeks of storage at -1 °C in air plus 5 d at 20 °C (Whitaker *et al.*, 2009). The RR of 'Atago' was changed between 37.62 and 382.74 nmol kg⁻¹s⁻¹ throughout the storage. Similar with Mattheis *et al.* (2013) the RR was reduced better by CA (51.12 nmol kg⁻¹s⁻¹) than NA (92.85 nmol kg⁻¹s⁻¹) during 32 weeks CS + 5 d SL (Table 1).

Lee *et al.* (2017) stated that the RR of Asian pear fruit is significantly affected by temperature. Similarly, the pear cultivar 'Atago' generally had the higher values of RR in SL conditions for both of NA and CA (Table 1).

Weight loss

Similar to Gago *et al.* (2013), Kaur and Dhillon (2015), Zucoloto *et al.* (2016a), Pasini *et al.* (2017) and Lee *et al.* (2017) the weight loss (WL) increased significantly throughout CS and after the SL periods, with significant differences among and within the conditions analysed. But pears stored in CA had significantly lower WL (1.52%) than that of NA (10.92%) at 32 weeks CS (Table 1). This situation can be explained by low air movement and relatively high RH level of the small CA chamber because of its high impermeability. Likewise, Holcroft (2015) stated that water loss is minimized by reducing the transpiration coefficient or the vapor pressure deficit (VPD). According to the researcher, the VPD is decreased by reducing temperatures including reducing the time between harvest and cooling, increasing RH and reducing air movement.

Soluble solid content, titratable acidity and pH

Similar to results obtained by Pasquariello *et al.* (2013), a slight fluctuation was observed in SSC of the fruits in both NA and CA. SSC was at high values throughout the storage in NA compared to CA (Table 1). Park *et al.* (2016) stated that accompanied by changes in SSC and acidity, fruit softening is one of the major factors that indicate ripening and is used as an index for measuring postharvest storability to evaluate the quality of fruit.

The pH values of the fruits increased compared to harvest date in all storage conditions. Similar to results obtained by Rizzolo *et al.* (2015) TA decreased from harvest to the end of the storage in all conditions (Table 1).

Peel and flesh colour

Lee *et al.* (2017) reported that a^{*} generally increased during fruit maturation and h^{*} tended to decrease gradually as the SL of the Asian pear progresses and can therefore be used as an index of ripening in pear fruit. Xiao-hui *et al.* (2018) stated that the decrease in h^{*} during storage indicated that the peel colour of pear changed from green to yellow. Similar to previous researches a^{*} increased and h^{*} decreased in both NA and CA throughout the storage. But, the increase in a^{*} in CA was slower than NA. Chlorophyll degradation is a key

trait for the change of pigment compositions in fruit peel during the ripening or yellowing of the fresh fruit (Zhao *et al.*, 2018). Similar to Saquet and Almeida (2017) fruits stored in NA yellowed faster than CA. This shows that CA slowed down the maturity of fruits. The h^* generally exhibited lower values at SL than at CS for both NA and CA and also CA inhibited the decrease of h^* better than NA (Table 1).

Greasiness of the skin is the result of the change in fruit wax components and is a visual phenotype of fruit senescence. L^* indicates the degree of greasiness of the skin, and the higher the L^* value; the greasier the skin is (Xiao-hui *et al.*, 2018). CA retained initial L^* values. Higher L^* values were recorded in NA compared to CA. L^* was generally higher in SL than CS. These results show that the fruits in SL are more mature than in CS, and those in NA are more mature than CA (Table 1).

Peel, internal and core browning, superficial and senescent scald and rotting

Crisosto *et al.* (1994) reported that, Asian pears should be picked when most of the pears on the tree are still green and only a few exposed top fruit are beginning to show yellow spots to avoid IB. CA can improve fruit quality and extend storage life; however, pear fruits are sensitive to CO₂ during storage. High CO₂ concentrations usually lead to CB in pears; thus, it is essential to determine how to regulate the CO₂ concentration inside the storage environment effectively (Cheng *et al.*, 2015). The CB was not recorded in the fruits stored in both NA and CA until 24th weeks of CS. CB was at higher levels in NA than CA at the 32nd week of CS + 5 d SL (Table 2). Yan *et al.* (2013) reported that the core of early harvested 'Yali' pears began browning at 60th d of storage and the CB index was higher in late harvested fruits than in early and mid-harvested fruits. Cheng *et al.* (2015) reported CB in pear cultivar 'Yali' at the 60th d of storage. Dong *et al.* (2018) recorded IB in pear cultivar 'Gem' at 5th months of storage in untreated fruits. CB was at very low level in pear cultivar 'Atago' at the end of the storage (Table 2).

Fan *et al.* (2016) reported IB in 'Laiyang' pear at 75th d of storage in atmospheric pressure storage and at 90th d of micro-vacuum storage. Saba and Moradi (2016) observed IB after 30 d of storage. Sheng *et al.* (2016) recorded pericarp browning in 'Nanguo' pears at 20 °C in shelf life condition after storing for 120 and 180 d and declared that the severity of the pericarp browning in shelf life was increased with the length of time in refrigeration.

The end of storage life of the Asian pear is usually due to physiological disorders, especially superficial scald (Yazdani *et al.*, 2011). Superficial scald is one of the main physiological disorders affecting postharvest quality of pears leading to great economic losses worldwide, which manifests as brown or dark patches on the fruit skin, affects the fruit appearance and makes the fruit unsuitable for sale as a fresh commodity (Calvo *et al.*, 2015). Superficial scald generally occurs after several months of storage at low temperature and rapidly intensifies when the fruits are transferred from cold storage to room temperature (Hui *et al.*, 2016). To date, superficial scald has been associated to many different preharvest and postharvest factors which are ultimately affected by the genetic characteristics of each cultivar (Larrigaudière *et al.*, 2016). It is reported that although refrigeration is a common technique for impeding the postharvest ripening of the 'Nanguo' pear, the peel of pears gradually become brown when the fruits are returned to room temperature after cold storage (Wang *et al.*, 2017; Wang *et al.*, 2018). Cascia *et al.* (2013) reported that storage in CA at 2% O₂ and 5% CO₂ caused significant amounts of storage disorders in pear cultivar 'Williams Bon Chretien'. Asian pears are susceptible to such physiological disorders as core browning, flesh browning and cavities induced by high CO₂ concentrations (Li *et al.*, 2013). The findings obtained from various researches conducted with different cultivars showed that many factors affected the beginning and intensity of the disorders. None of the fruits of 'Atago' showed IB, PB, superficial and senescent scald at the end of the storage (Figure 1). It is thought that besides the cultivar's genetic characteristic the appropriate harvest date and storage conditions prevented disorders mentioned above and early occurrence and intensity of CB. The fruits stored in NA had higher CB values than CA (Table 2).

CA slowed down the senescence of the pear fruits throughout the storage period and resulted in less rotting (18.52 fruits/100 fruits) as compared to NA (32.41 fruits/100 fruits) after 32 weeks CS + 5 d SL (data were not given).

Table 2. Mean values of core browning of 'Atago' pear cultivar tested as a function of cold storage period (CS) and post storage shelf life (SL)

Storage conditions	Core Browning (CB)	Storage period									
		Harvest	Harvest +5 d SL	8 weeks CS	8 weeks CS +5 d SL	16 weeks CS	16 weeks CS +5 d SL	24 weeks CS	24 weeks CS +5 d SL	32 weeks CS	32 weeks CS +5 d SL
NA	CB incidence (%)	0 c	0 c	0 c	0 c	0 c	0 c	33.33 bA	41.67 bA	100 aA	100 aA
	CB index	0 c	0 c	0 c	0 c	0 c	0 c	0.111 bA	0.138 bA	0.750 aA	0.778 aA
CA	CB incidence (%)	0 c	0 c	0 c	0 c	0 c	0 c	8.333 bB	16.67 bB	100 aA	100 aA
	CB index	0 b	0 c	0 b	0 c	0 b	0 c	0.028 bB	0.056 bB	0.528 aB	0.556 aB

Note: Means (n=3) followed by the same small letter (within the rows) and capital letter (within the columns) do not differ significantly at $p = 0.05$ (LSD test) during cold storage or shelf life. (NA: normal atmosphere, CA: controlled atmosphere)

Sensorial attributes

Pear fruit sensory quality can be determined from its colour, texture, aroma, and taste, the most important sensory properties that consumers recognize (Makkumrai *et al.*, 2014). Initial purchase by consumers is based on visual product attributes, while repeated sales are based on product eating quality (Blanckenberg *et al.*, 2016). The limit percentage of WL may vary according to the cultivar, since some cultivars support greater values showing no of loss of quality, while others with smaller values present damage to the appearance (Zucoloto *et al.*, 2016b). Likewise, the WL of the fruits in NA was within the limit of 5.00% after 8 weeks of CS (Table 1) but visual quality (8.50 points) and overall liking (7.00 points) scores of the pears were at good quality and shrivelling was not observed (Table 3). However, after the 24 weeks of CS shrivelling was observed in some of the fruits stored in NA.

Background colour variation can be of help as a visual indication of ripening, and is useful for assisting consumers in comparing fruit at different ripening stage (Predieri and Gatti, 2009). All of the fruits' peel colour turned to yellow in NA while there was some differences between the ripeness stages of the fruits stored in CA at 32 weeks CS + 5 d SL (Figure 1). The 26.67% were green, 20% of them were greenish yellow and 53.33% of them were yellow in CA at 32 weeks CS + 5 d SL (data were not given). This result elicited that some of the fruits stored in CA may need to be kept at SL conditions for additional few days to reach to the consumable stage and in this way the marketing period of the fruits could be extended (Figure 1).

As done in this study Cowgill and Magron (2014) recommended tasting the flesh of an Asian pear only and not the skin to make sure that the panelists evaluate the maturity of the flesh for taste and texture. Pear eating quality is affected by the harvest time, cold storage period, post-storage ripening as well as climatic conditions (Eccher-Zerbini *et al.*, 2005). The proportion of consumers that would prefer crisp, sweet (Blanckenberg *et al.*, 2016) and juicy texture (Eccher-Zerbini *et al.*, 2005) compared to pears with the characteristic soft and buttery texture (Blanckenberg *et al.*, 2016) Unlike European pears' soft and buttery texture the flesh of 'Atago' was evaluated as juicy and crisp as reported by Itai and Fujita (2008) as the characteristic texture attributes of Asian pears (Table 3).

Table 3. Mean values of sensorial attributes of 'Atago' pear cultivar tested as a function of cold storage period (CS) and post storage shelf life (SL)

Storage conditions	Sensorial attributes	Storage period									
		Harvest	Harvest + 5 d SL	8 weeks CS	8 weeks CS + 5 d SL	16 weeks CS	16 weeks CS + 5 d SL	24 weeks CS	24 weeks CS + 5 d SL	32 weeks CS	32 weeks CS + 5 d SL
NA	Visual	9.00	9.00 aA	8.50	8.75 aA	8.00 cA	8.50 aA	8.75 abA	8.50 aA	8.25 bcA	8.38 aA
	Firmness	2.00	2.00 cA	3.00 abA	3.00 bB	3.75 aA	3.00 bA	3.25 abA	4.00 aA	2.50 bcB	3.00 bA
	Ripeness	2.00	2.00 aA	2.00 aA	2.00 bA	2.00 aA	2.00 bA	2.00 aA	2.38 aA	2.00 aA	2.50 aA
	Taste	4.00	4.25 aA	3.88 aA	4.25 aA	3.00 bB	4.25 aA	4.50 aA	4.63 aA	4.38 aB	4.88 aA
	Aroma	4.00	4.50 aA	3.13 bA	3.50 abA	3.25 abB	3.38 bB	4.25 abA	4.50 aA	4.38 aB	4.00 abA
	Sourness	4.00	4.00 bA	4.00 bA	4.00 bA	4.50 bA	4.50 bA	6.00 aA	6.00 aA	6.00 aA	6.00 aA
	Juiciness	5.00	5.00 aA	5.00 aA	4.00 bB	4.88 aA	3.38 bcB	4.75 aA	3.25 cB	4.75 aA	3.13 cB
	Grittiness	4.88	4.75 aA	3.88 aA	4.00 aA	5.00 aA	5.25 aA	5.25 aA	4.50 aA	5.00 aA	5.25 aA
Overall	8.00	8.00 aA	7.00 cA	8.00 aA	7.00 cA	7.13 bA	8.00 aA	7.13 bA	7.50 bB	8.00 aA	
CA	Visual	9.00	9.00 aA	7.50 cdB	7.63 bcB	7.25 dB	7.38 cB	8.38 abA	8.00 bA	8.13 bcA	8.00 bB
	Firmness	2.00	2.00 dA	3.00 bA	3.75 abA	3.38 abA	3.25 bcA	3.25 bA	4.00 aA	4.00 aA	3.00 cA
	Ripeness	2.00	2.00 aA	2.00 aA	2.00 aA	2.00 aA	2.00 aA	2.00 aA	2.00 aB	2.00 aA	2.00 aB
	Taste	4.00	4.25 abA	4.00 bA	4.00 bA	4.75 aA	4.75 aA	4.00 bA	4.25 abA	5.00 aA	4.00 bB
	Aroma	4.25	4.38 abA	3.63 bcA	3.00 cA	5.00 aA	5.00 aA	3.00 cB	4.00 bA	5.00 aA	4.50 abA
	Sourness	4.00	4.00 cA	4.00 cA	4.00 cA	5.00 bA	5.00 bA	5.00 bB	5.25 bB	6.00 aA	6.00 aA
	Juiciness	5.00	5.00 aA	5.00 aA	5.00 aA	5.00 aA	5.00 aA	5.00 aA	5.00 aA	5.00 aA	4.25 bA
	Grittiness	4.75	4.75 aA	4.00 cA	4.25 aA	5.75 aA	5.25 aA	5.50 abA	5.50 aA	6.00 aA	5.00 aA
Overall	8.00	8.25 aA	7.25 bcA	7.25 bB	7.25 bcA	7.00 bA	7.00 cB	7.25 bA	8.75 aA	7.00 bB	

Note: Means (n=3) followed by the same small letter (within the rows) and capital letter (within the columns) do not differ significantly at $p = 0.05$ (LSD test) during cold storage or shelf life. (NA: normal atmosphere, CA: controlled atmosphere)

Better sensory characteristics could be obtained by storing fruit at temperatures higher than 0 °C and by placing fruit in shelf-life for a time sufficient to develop flavour quality and allow fruit softening (Rizzolo *et al.*, 2014). Mainly in pear, cooling induces, after rewarming, a uniform ripening process with the development of satisfactory aroma and fruit texture via ethylene biosynthesis (Saquet and Streif, 2017). The postharvest SL of pears is limited because of their rapid senescence once ripening is triggered, which is a serious problem for the marketing of this fruit (Fan *et al.*, 2016). Rapid senescence was not observed during SL period of the fruits stored in both NA and CA. The visual quality and overall liking points of fruits stored in NA were a little higher than CA at 32 weeks CS + 5 d SL. It is thought that CA retarded the ripening of the fruits and affected the visual quality and overall liking points. However, keeping these fruits for a few more days in SL conditions will improve sensorial quality and prolong the marketing period (Table 3 and Figure 1). Besides, the low consumer acceptance reported in previous studies should not be attributed to an incorrect SL (Predieri and Gatti, 2009). Although storage at low temperature is a common practice for retarding the softening of fruit, long periods of cold storage are known to alter the taste rating of pear (Itai *et al.*, 2015). The most common reasons for liking pears were sweetness and juiciness, while firm gritty textures and lack of flavor were disliked (Escribano *et al.*, 2016). The taste of the pears stored in NA scored higher than CA at the end of the storage. It is thought that the reason to perceive the fruits sweeter than CA was the ripeness stage of the fruits stored in NA. Likewise the SSC value of the fruits was higher in NA than CA. Juiciness of the fruits stored in NA was lower than CA at the end of the storage. This may be due to the higher weight loss values in NA than CA (Tables 1 and 3). The texture of the pears was not gritty and taste and aroma values were at high values at the end of the storage.

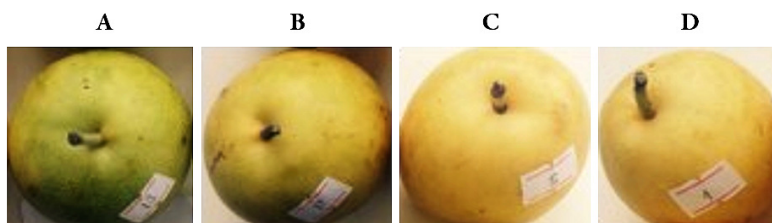


Figure 1. The ripeness stages of the fruits of pear cultivar ‘Atago’ stored in controlled atmosphere are shown in photographs labeled as A: green, B: greenish yellow, and C: yellow and in normal atmosphere labeled as D: yellow at 32 weeks cold storage + 5 d shelf life

Conclusions

It was shown with this research that pear cultivar ‘Atago’ maintained its quality characteristics at 32 weeks CS + 5 d SL in CA. ‘Atago’ can be evaluated in the moderate range of the ethylene-generating group of Japanese pears and accepted as a climacteric fruit. CA slowed down the senescence of the pear fruits better than NA throughout the storage period and resulted in less rotting as compared to NA. None of the fruits stored in NA and CA showed IB, PB, superficial and senescent scald. CB was at higher levels in NA than CA at the end of the storage. Unlike European pears’ soft and buttery texture, the flesh of ‘Atago’ was evaluated as juicy and crisp. The eating quality of the pear fruits was better with keeping them in SL conditions after each analysis period for both NA and CA storage. It appeared that some of the fruits stored in CA may need to be kept in SL conditions for additional few days to improve the visual and eating quality. Therefore, it can be said that CA could extend the marketing period of the pear fruits longer than NA. According to the results obtained from this research a new fire-blight (*Erwinia amylovora*) resistant late-maturing Japanese pear (*Pyrus pyrifolia* Nakai) cultivar ‘Atago’ is suggested to be stored under CA conditions at 2.5% O₂ + 1.5% CO₂ in order to prevent CB and rotting, to maintain the high quality and extend the marketing period.

Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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