**Problems and methods to improve the market-life of berry fruit**

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*Chapter X*

# Problems and Methods to Improve the Market-Life of Berry Fruit

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## Abstract

Berry fruit is highly perishable and it should be marketed soon after picking. When modern storage techniques are applied, fruit harvested in a particular season can be consumed some weeks later, decay is prevented and quality is ensured. In order to maximize storage life, fruit must have a high initial quality. The main factors, that limit the postharvest life of blueberries are excessive softening, water loss which results in fruit shrivelling, and the incidence of postharvest diseases (mainly caused by *Botrytis cinerea* and *Colletotrichum gloeosporioides*). Temperature management is the most critical postharvest factor, and for this reason, after harvesting, blueberries must be rapidly cooled and kept at temperatures close to 0°C for a maximum postharvest life. Cold storage, controlled atmosphere, modified atmosphere packaging, ozonation and innovative atmospheres have been used to extend the marketing season, reduce losses and increase profitability. However, the benefits of most of these treatments have been limited and often inconsistent. According to our experimental results, controlled atmosphere storage can maintain the quality and extend the storage life of blueberries. When added to refrigeration at close to 0°C, the controlled atmosphere maintained fruit firmness, the total soluble solids content and titratable acidity. Storage in plastic films reduced weight loss and slowed down the deterioration of the visual quality. In particular, berries packaged in micro-perforated (1mm ∅) and non-perforated films maintained their high quality attributes (high TSS content and titratble acidity)

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throughout the cold storage period. Non-perforated films maintained also berry crispness and a good intensity of flavour. Moreover, this treatment was the only one that reduced pathogen-induced decay during cold storage. The air treatment with ozone during the storage period was effective in reducing fungal decay, but little or no quality advantages were noted with the use of ozone on fruit firmness, soluble solids content or acidity.

## Introduction

The postharvest storage of fruit crops is interesting because the metabolism continues, although the fruit is detached from the plant. The goal of postharvest storage technology is to manipulate the metabolism of fruit and vegetables during storage, in order to maximize quality and extend the market life.

Berries are fruit that must be harvested ready for consumption in order to achieve the maximum quality, in relation to flavour, colour, firmness and also the nutraceutical properties. As a consequence, berries are quite perishable and vulnerable to physiological deterioration. Fruit must be of high initial quality to maximize the storage life, and many factors are involved in fruit quality (cultivar, cultural practices, growing environment and harvest practices) [1].

The main characteristics related to the quality of ripe berry fruit are texture, flavour and colour.

Fruit firmness is an important component of the final quality of small fruit. Fruit softening is the result of over-ripening during postharvest conservation, which is shown by an increase in the cellular wall thickness between firm and ripe fruit; textural changes in fruit are thought to be, at least in part, a consequence of changes in the composition and architecture of the cell wall [2] and the result is a rapid decay and deterioration throughout the distribution process [3,4,5].

However, texture is not easy to define, in particular in small fruit like blueberries, because there is no common standardized method. This mechanical property affects not only the oral perception of the texture, and hence its eating quality, but also postharvest properties. Firmness depends on the microstructure of the fruit, and berry firmness may decrease, increase or remain unchanged during storage. This variation may be attributed to cultivar differences and/or their interaction with postharvest storage conditions. Moreover, berries are very susceptible to water loss, which results in a loss in gloss, fruit shrivelling and often an increase in firmness. The maximum permissible amount of water that can be lost (weight loss) from raspberries, blueberries and blackberries before they become unmarketable is 6% [6].

Changes in flavour and texture during berry storage can have a profound effect on consumer acceptability and can also influence the future fruit consumption.

For these reasons, techniques that manipulate the external environment are in use to improve the storability of berry fruit, these involve slowing the respiratory metabolism and other metabolic reactions, associated with quality retention [7].

In general, the storage life of fruit varies inversely with the rate of respiration. This is because respiration supplies the compounds that determine the rate of metabolic processes, which are directly related to quality parameters (firmness, sugar content, aroma, flavour). Commodities and cultivars with higher rates of respiration tend to have shorter storage-life than those with low rates of respiration [8]. Berry fruit has a high respiration rate and, as a consequence, a high deterioration rate. Cold storage, controlled atmosphere, modified atmosphere packaging, ozonation and innovative atmospheres have been used to extend the marketing season, reduce losses and increase profitability [9,10]. Storage temperature is the most important factor that can affect postharvest life. After the harvest, berry fruit must be cooled and kept close to 0°C for a maximum market life. However, each berry fruit has an optimum storage temperature, because of their different sensitivity to chilling injury. The removal of ethylene from the storage air may also reduce disease development in all berries. Moreover, the postharvest shelf-life of soft fruit is further shortened by infection with grey mould *Botrytis cinerea* [11]. Minimizing such deteriorative losses is of primary importance.

Recently, the packaging of highly perishable fruits in polymeric films with specific gas permeabilities, in combination with low temperature storage, has gained importance [12,13] because of the benefits of film packaging (maintenance of high relative humidity, reduction in water loss, improved sanitation due to a reduction in contamination of the product). The negative effect is an increased potential for water condensation within the package.

Another technique used to reduce the decay of fresh fruit and sanitize the produce is ozonation, but the results have been variable [14,15].

# 1. Cold Storage

Temperature management is the most effective tool to extend the postharvest life of berries. Low temperatures slow the metabolism and have a particular effect on the respiratory metabolism. Respiration is based on the reserves that are accumulated in the fruit during the growing season and respiration therefore reduces the eating quality (Table 1).

**Table 1. Quality characteristics of raspberries at harvest and during storage (3 days) [16]**

| Raspberries | Harvest | | Cold storage 3 days 1°C | | Room storage 3 day 20°C | |
|---|---|---|---|---|---|---|
| | T.S.S. °*Brix* | Titratable acidity *meq/L* | T.S.S. °*Brix* | Titratable acidity *meq/L* | T.S.S. °Brix | Titratable acidity *meq/L* |
| Fairview | 10.5 | 265 | 8.8 | 220 | 7.1 | 190 |
| Skeena* | 8.7 | 315 | 8.4 | 311 | 8.4 | 288 |
| Gradina | 9.6 | 216 | 8.2 | 237 | 6.5 | 194 |
| Glen Prosen* | 10.4 | 336 | 10.4 | 176 | 10.4 | 154 |
| Meeker | 9.9 | 272 | 9.5 | 240 | 8.1 | 215 |

* stored for 2 days..

Each 10°C decrease in temperature will reduce respiratory activity by a factor of 2 to 4 (Table 2) [17] with an evident benefit on the quality. Another problem is water loss. Fruit losses water when it is on the tree, but once harvested this water cannot be replaced by the tree and a weight loss therefore occurs. Low temperatures, in association with high relative humidity, reduce the water loss rate because of the reduction in the vapour pressure difference between the fruit and the surrounding air.

**Table 2. Respiration Production rates (modified from [18])**

| Temperature | *mL $CO_2$/kg·hr* | | | |
|---|---|---|---|---|
| *°C* | blackberry | blueberry | cranberry | raspberry |
| 0 | 11 | 3 | 2 | 12 |
| 10 | 31 | 9 | 4 | 49 |
| 20 | 78 | 34 | 9 | 100 |

An additional effect of cold storage is its influence on the rate of the growth and spread of pathogens: the lower the temperature, the slower the metabolism. Certain fungi that cause severe losses do not grow at low temperature [19]. Berry fruit is a rich source of phenolic compounds. The most important group of phenolics in berry fruit is flavonoids. The high antioxidant activities in berry fruit are generally attributed to phenolic compounds, such as anthocyanins. Phytonutrient levels usually decline when fruit starts to spoil and tissues begin to break down. Therefore, any postharvest treatment that is beneficial in maintaining the quality of fresh produce can also help maintain the antioxidant and nutritional values. Storage temperature, in addition to light and oxygen exposure, is one of the key factors that influence the stability of phenolic antioxidants in fruit during postharvest storage. Higher antioxidant capacity values have, in most cases, been maintained in fruit stored at 4 °C, instead of 25 °C. Therefore, keeping fruit under refrigerated storage seems to be the recommended choice [20]. Most berry crops, including blackberries, blueberries, and raspberries, are chilling tolerant and can be stored at -0.5 to 0°C, or slightly above their freezing points, to maintain their quality. Instead, cranberries are known to be chilling sensitive and can develop low-temperature breakdown after prolonged exposure to chilling temperatures [21].

Rapid cooling is essential in small fruit to maintain quality. Cooling fruit immediately after harvesting reduces water losses and the respiration heat. Berry fruit must be marketed quickly, with particular attention to maintaining cold chain during marketing.

**Table 3. Optimum storage times and temperatures (modified from [18]).**

| Berry | temperature | time |
|---|---|---|
| blackberry | 0±0.5°C | 2-5 days |
| blueberry | 0±0.5°C | 1-2 weeks |
| cranberry | 3±1°C | 2-4 months |
| raspberry | 0±0.5°C | 2-5 days |

# 2. Modified Atmosphere Packaging

Soft fruit, such as strawberries, raspberries, and blueberries, have a short postharvest shelf-life, which is exacerbated by infection with grey mould, *Botrytis cinerea* [11]. There is a fundamental need to minimize such deterioration losses at both the retail and home levels. Modified atmosphere packaging (MAP) has been shown to delay compositional changes associated with colour, firmness, flavour and nutritional quality, and reduce the water loss of fruit [22]. When packaged, berries continue to respire the trapped air until the $CO_2$ concentration rapidly approaches the critical 10-15% level necessary to inhibit *Botrytis* growth.

Recently, the packaging of highly perishable fruit in polymeric films with specific gas permeabilities, in combination with low temperature storage, has gained importance [13]. [24] defined modified atmosphere packaging (MAP) as “the initial alteration of the gaseous environment in the immediate vicinity of the product that permits the packaged product interactions to naturally vary their immediate gaseous environment”.

The benefits of film packaging include the maintenance of high relative humidity and a reduction in water loss; improved sanitation due to a reduction in contamination of the product during handling; facilitation of brand identification and the provision of relevant information to the consumer. Instead, the negative effects include slowing down the cooling of the packaged products and an increased potential for water condensation within the package. Ideally, films should protect the fruit from mechanical damage, excessive drying and contamination. Packages should also provide safe stacking, efficient palletization, and easy storage in the warehouse or home, and assist in the display and sale of the fruit [25].

Only top quality fruit should be packed, since the fruit-to-package cost ratio is important in deciding the profit. One of the initial physiological effects of a modified atmosphere on the fruit metabolism is a decrease in respiratory intensity during the storage period, which involves a decrease in substrate consumption, $CO_2$ production, $O_2$ consumption and heat release.

MAP includes vacuum packaging, controlled atmosphere packaging and passive modified atmosphere packaging (Table 4) [23]. A modified atmosphere can be created inside a package either passively, through product respiration, or actively by replacing the atmosphere in the package with a desired gas mixture (the approach generally involves gas mixes confined to 5-15% $CO_2$, 2-5% $O_2$, with $N_2$ as the remainder). In the first method, as the fruit respires, the $O_2$ level decreases and the $CO_2$ level increases during storage [12].

**Table 4. Different terminologies used in Modified Atmosphere Packaging techniques (modified from [23])**

| Terminologies | |
|---|---|
| Modified Atmosphere Packaging (MAP) | Replacement of air with a single gas or a mixture of gases. No further control over the initial composition |
| Controlled Atmosphere Packaging (CAP) | Proportion and type of gas mixture is controlled over the whole period of storage |
| Equilibrium Modified Atmosphere packaging (EMA) | Pack is flushed with gas or sealed without modification. The permeability of packaging and respiration of the product results in an equilibrium modified atmosphere |
| Vacuum Packaging (VP) | Product sealed in low gas permeability pack after part evacuation of pack results in changes in atmosphere during storage due to the altered metabolism of the product and microbial flora and gas permeation |

In both cases, the package permeability must be compatible with the fruit respiration rate, and maintain an appropriate atmosphere for better conservation. High $CO_2$ and/or low $O_2$ levels in the micro-atmosphere around the commodities may extend shelf-life [26, 27], reduce fruit decay, delay senescence and delay softening [28]. However, excessively high levels of $CO_2$ and/or very low levels of $O_2$ can induce a transition from aerobic to anaerobic respiration, together with ethanol production, and a significant decline in the sensory quality and the development of off flavours.

Many types of plastic films are available for packaging, but relatively few have been used to wrap fresh fruit such us blueberries. Low-density polyethylene, polyvinyl chloride, and polypropylene are the main films that are used to package fruit and vegetables [13,22]. The selection of the proper MAP film with the appropriate water vapour, film permeability and gas transmission rates is essential for an optimum storage life. In general, a reduction in packaging film permeability is accompanied by an increase in the acceptability of the corresponding fruit [11]. The best quality of highbush blueberries, during long-term storage in different packaging materials, has been obtained in polyamide/polyethylene laminates [29].

Four commercially available films were evaluated for MAP in [30]: two micro-perforated films (0.3 mm and 1 mm in diameter), a non-perforated and a macro-perforated film (6 mm in diameter) during a highbush blueberry (cv Lateblue) postharvest storage period (4°C for 15 days). The benefits of small packages (consumer packs) were evaluated through chemical (total soluble solids content, titratable acidity and pH), visual (colour intensity, surface shine, firmness, intensity of odour, and overall appearance) and sensory (crispness, sweet taste, acidic taste, total flavour, and overall appreciation) evaluations. The results showed that the different packaging films significantly affected the chemical characteristics of the fruit during the postharvest storage period (Table 5).

Table 5 showed that the blueberries demonstrated the highest quality when packed in micro-perforated film (higher soluble solids content and titratable acidity). The berries stored in non-perforated film also gave better results than the control ones, and were significantly better than those in the macro-perforated film. The different packaging films also had a significant effect on the pH values: the blueberries packaged in macro-perforated film had the highest pH values (Table 5).

Moreover, the berries packaged with micro-perforated films 1 and 2 and the non-perforated film effectively controlled the loss in quality during shelf-life and had a higher colour intensity than the other samples. The non-perforated film also maintained berry crispness and a good intensity of flavour.

**Table 5. Quality characteristics of blueberries stored under modified atmosphere packaging for 15 days [30]**

| *Film type* | *T.S.S. (° Brix)* | *Titratable acidity (meq/L)* | *pH* |
|---|---|---|---|
| *Microperforated (0.3mm ∅) film* | 10.53 b | 49.43 bc | 3.44 b |
| *Microperforated (1mm ∅) film* | 11.7 a | 147.89 a | 3.01 d |
| *Non-perforated film* | 11.47 a | 59.58 b | 3.32 c |
| *Macroperforated (6mm ∅) film* | 10.13 b | 38.89 c | 3.54 a |
| *Control* | 11.16 b | 60.25 b | 3.39 bc |

Means separated by Tukey’s test. Means in columns with different letters are significantly different at p ≤ 0.05.

**Table 6. Weight loss of blueberries stored under modified atmosphere packaging for 15 days**

| *Film type* | *1° day* | *2° days* | *3° days* | *4° days* | *5° days* | *6° days* | *7° days* | *8° days* | *9° days* | *10° days* | *11° days* | *12° days* | *13° days* | *14° days* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Microperforated (0.3mm ∅) film* | 0.03 n.s. | 0.06 b | 0.14 b | 0.17 c | 0.25 c | 0.25 c | 0.25 c | 0.29 c | 0.29 c | 0.30 c | 0.33 c | 0.42 c | 0.42 c | 0.44 c |
| *Microperforated (1mm ∅) film* | 0.45 | 0.80 ab | 1.09 a | 1.378 b | 1.85 b | 2.09 b | 2.18 | 2.28 b | 2.39 b | 2.49 b | 2.57 b | 2.77 b | 2.89 b | 2.98 b |
| *Non-perforated film* | 0.00 | 0.01 b | 0.04 b | 0.07 d | 0.08 d | 0.10 d | 0.10 d | 0.10 d | 0.10 d | 0.10 d | 0.10 d | 0.13 d | 0.13 d | 0.13 d |
| *Macroperforated (6mm ∅) film* | 0.37 | 0.63 ab | 0.88 b | 1.13 b | 1.53 b | 1.74 b | 1.88 b | 1.99 b | 2.11 b | 2.23 b | 2.31 b | 2.55 b | 2.63 b | 2.76 b |
| *Control* | 0.78 | 1.41 a | 1.85 a | 2.47 a | 3.55 a | 4.14 a | 4.52 a | 4.77 a | 5.05 a | 5.43 a | 5.78 a | 6.38 a | 6.69 a | 6.9 7 a |

Means separated by Tukey’s test. Means in columns with different letters are significantly different at p ≤ 0.05.

All the package films effectively reduced the loss in weight compared to the unwrapped control (Table 6). The control berries showed the highest loss in weight (7%) during the same storage period (15 days), due to transpiration and respiration. The macro-perforated film exhibited a higher fruit weight loss (3%) than the micro-perforated films and the non-perforated film 3 packaging systems. This loss became more evident and significant as storage continued.

Overall, the film packaging also reduced the incidence of *Botrytis cinerea* infection, compared to the control berries. Packaging the berries in microperforated and macro-perforated films reduced the total amount of fungal incidence to only 7.37% (film 1), 2.96% (film 2), and 19.4% (film 4), respectively, compared with 20.3% for the unwrapped control sample. Instead, the *Botrytis cinerea* infection was not observed in the case of the non-perforated film, which could be attributable to the presence of high $CO_2$ and low $O_2$. No major differences were observed between the effectiveness of the various micro-perforated and macro-perforated films that were used, but there was a significant difference in effectiveness for the non-perforated one.

In conclusion, the present study has demonstrated that if non-perforated and micro-perforated packaging films are used for blueberry packaging, it is possible to retain both the sensory and visual quality and also to reduce the development of post-harvest diseases.

# 3. Ozonation

Ozone, the tri-atomic form of oxygen, is a strong antimicrobial agent and may be an alternative antifungal agent in the storage of fruit. Ozone is a potent disinfecting agent, and the combination of cold storage and this gas may create new opportunities for the blueberry industry and in postharvest handling. Ozonation is a technology that can be used to reduce the decay of fresh fruit and vegetables and sanitize the produce [14]. Investigations into the effect of ozone on reducing decay have found that ozone can be used as an alternative postharvest fungicide, in addition to cold storage, to reduce the decay of blueberry fruit [31]. In lowbush blueberry, [32] found significant microbial reductions in all the samples treated with 1 ppm of ozone compared to the control berries. [33] concluded that ozone increases the storage life of rabbiteye blueberries and reduces weight loss and fruit decay.

In our study [34], we evaluated the evolution of berry (cv Bluecrop, Coville and Brigitta) quality, firmness and decay during a postharvest storage period (4 weeks). Two different storage conditions were compared: Traditional Storage (Normal Atmosphere, 3°C and 85% R.H) as a control and Innovative Storage (Normal Atmosphere, air enriched with ozone). The ozonation was created using AgroCare™, an environmental ozone generator. In order to evaluate the effect of the ozone treatments, the firmness of blueberry fruit was also determined, using a penetrometer test, which was performed in a Texture Analyzer TaxT2i® (Stable Micro System, UK).

The results have shown that ozone is an efficient inhibitor of postharvest modifications. The statistical testing of the data confirmed the significant difference between storage methods. In particular for Bluecrop (Figure 1); the berries stored for four weeks with a concentration of ozone in the atmosphere were not as sweet as the other samples. Moreover, the berries stored in ozone were less acid and were less firm than the samples stored in the Normal Atmosphere (3°C and 85% R.H) (Figure 1).

The atmospheric composition had no detectable effect on the total soluble solids content in Coville: there were no statistical differences ($p \leq 0.05$) between fruit stored in a normal atmosphere and that stored in the innovative way. As far as titratable acidity is concerned, the values for the innovative storage condition were higher (130.58 meq/L) than those found in the control (87.73 meq/L) at the end of the storage period. Moreover, the ozone treatment showed a significant effect on berry firmness: berries stored for four weeks in the atmosphere with ozone were firmer than the samples stored in a Normal Atmosphere (Table 6). No significant differences were found in cv Brigitta between the treatments, for any of the evaluated quality factors. Like Coville, Brigitta showed a high degree of firmness in the samples stored in the innovative conditions (Table 6).

As far as the effect of ozone storage on berry weight loss is concerned, the results showed that the different storage conditions did not differ significantly for each cultivar or for each picking date. The weight loss was not affected by the ozone air treatment.

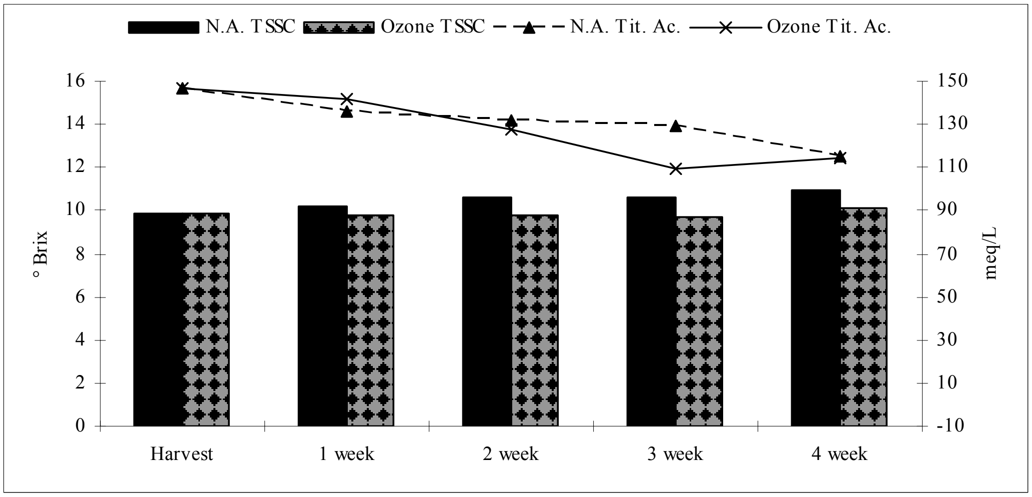



Figure 1. Total Soluble Solids content and titratable acidity during the postharvest storage period. Cv Bluecrop.

**Table 6. Berry firmness (N) under two different storage conditions. Bluecrop, Coville and Brigitta cultivars**

| | | BLUECROP | | COVILLE | | BRIGITTA | |
|---|---|---|---|---|---|---|---|
| | | Normal Atmosphere | Ozone | Normal Atmosphere | Ozone | Normal Atmosphere | Ozone |
| Postharvest weeks | Harvest | 1.48 | 1.48 | 1.54 | 1.54 | 1.53 | 1.53 |
| | 1 week | 1.41 | 1.34 | 1.69 | 1.34 | 1.67 | 1.62 |
| | 2 week | 1.32 | 1.30 | 1.67 | 1.95 | 1.63 | 1.69 |
| | 3 week | 1.23 | 1.31 | 1.61 | 1.74 | 1.67 | 1.79 |
| | 4 week | 1.24 | 1.17 | 1.67 | 1.83 | 1.55 | 1.60 |

Moreover, in order to evaluate the effect of ozone on controlling decay, the % of berries with *Botrytis cinerea* infection was calculated. *Botrytis cinerea* decay in the control was only apparent after 2 weeks of storage in Bluecrop and after 4 weeks of storage in Coville (Table 7). The results showed that ozone was effective at inhibiting the proliferation of Botrytis *cinerea*, and reducing the incidence of decay. For example, in Bluecrop, the incidence of *Botrytis cinerea* was lower after 28 storage days at 4 ºC on blueberries exposed to 0.3 ppm ozone than on fruit exposed to ambient air.

**Table 7. Incidence of *Botrytis cinerea* (% on weight) under two different storage conditions**

| | | BLUECROP | | COVILLE | |
|---|---|---|---|---|---|
| | | Normal Atmosphere | Ozone | Normal Atmosphere | Ozone |
| Postharvest weeks | Harvest | 0 | 0 | 0 | 0 |
| | 1 week | 0 | 0 | 0 | 0 |
| | 2 week | 2.33 | 0 | 0 | 0 |
| | 3 week | 3.74 | 0 | 0 | 0 |
| | 4 week | 7.48 | 1.50 | 6.21 | 0 |

# 4. Controlled Atmosphere

Controlled atmosphere storage (C.A.) is widely used to extend the storage and shelf-life of many kinds of fruit. In general, the reduction in the partial pressure of $O_2$ and the increase in that of $CO_2$ reduce the respiratory metabolism rate and minimize the changes in the physical and chemical attributes. Moreover, an elevated range of $CO_2$ is effective in suppressing many fungal decay organisms [4] and low $O_2$ has little impact on the growth of fungi [35].

Rabbiteye, highbush, and lowbush blueberries benefit from 10 to 15% $CO_2$ + 1 to 10% $O_2$ when kept at 5 ºC or below [36,37,38]. Firmness and titratable acidity are maintained and decay decreases, with a shelf-life of up to 6 weeks. [39] found that the weight loss of the blueberry cultivar 'Duke' was minimized by a high rate of $CO_2$ in association with a low temperature (0-1°C). Berries stored at 6-12 kPa $CO_2$ maintained their firmness at acceptable values. They recommend storing highbush blueberries under high $CO_2$ levels of up to 12 kPa without $O_2$ reduction for a longer storage period of up to six weeks. Higher $CO_2$ levels of more than 12 kPa cannot be recommended, due to the negative impact on flavour, firmness, and acidity content. In our experience [40] the use of a C.A. (1 °C 3% $O_2$, 11% $CO_2$, for 60 days) lengthened the postharvest life of berries, which maintained their firmness, total soluble solids and titratable acidity content.

A 7 day storage of different red raspberry cultivars in controlled atmospheres (10% $O_2$+15% $CO_2$, 10% $O_2$+31% $CO_2$) suppressed rotting significantly [42] and kept the berry colour more attractive compared to storage in normal atmospheres. The total soluble solids were unchanged after storage, and the titratable acids decreased in all the analysed cultivars. The L-ascorbic acid levels were unchanged or slightly increased after a one-week storage period [42].

Raspberries benefit from 10 to 20% $CO_2$ + 5 to 10% $O_2$ [43]. C.A. storage slows respiration, ethylene production, softening, colour changes, and the growth of moulds. Levels of $CO_2$ > 20% can cause discoloration, softening, and off-flavor of raspberries [44]. Research indicates [45, 46] that red currant and gooseberry respond very well to C.A., whereas black currant only benefit slightly. The storage duration of red currant can be extended from 8 to 14 weeks, depending on the cultivar, using 1 °C, 18 to 20% $CO_2$ + 2% $O_2$. The storage duration of gooseberry can be extended from 6 to 8 weeks, using 1 °C, 10 to 15% $CO_2$ + 1.5% $O_2$. Increasing the $CO_2$ to 20% reduces the incidence of storage rot [45, 46] and lowering the $O_2$ reduces the respiration rate [47]. Compared to red currant and gooseberry, black currant does not respond as well to low $O_2$ and its storage can only be extended to 3 weeks, using 0 to 2 °C and 15 to 20% $CO_2$ [21].

**Table 8. Quality parameters at the harvest and after C.A. (1 °C, 3% $O_2$, 11% $CO_2$) storage of Bluecrop, Coville and Lateblue cultivars [41]**

| | | Bluecrop | Coville | Lateblue |
|---|---|---|---|---|
| *T.S.S. (°Brix)* | harvest | 10.3 | 13.7 | 11.9 |
| | 60 days | 9.4 | 12.7 | 9.4 |
| *Titrat. acidity (meq/L)* | harvest | 141 | 121 | 171 |
| | 60 days | 145.5 | 173 | 248 |
| *pH* | harvest | 2.57 | 2.79 | 2.53 |
| | 60 days | 2.54 | 2.68 | 2.55 |

## 5. 1-mcp Treatment

1-methylcyclopropene is an inhibitor of ethylene receptors that can affect ripening and senescence processes in fruit, vegetables and ornamental products [48,49]. 1-mcp is classified as a plant growth regulator and it induces beneficial effects, such as a delay in the physico-chemical changes related to the ripening process, as well as a reduction in decay and softening in many fruit and vegetables such as apples, kiwifruit, peaches, nectarines, plums and pears [50, 51, 52, 53]. Ethylene has little effect on the postharvest ripening of blueberries, [54] found little or no effect on blueberry quality when the fruit were treated with 1-mcp.

In order to evaluate 1-mcp effectiveness on blueberry fruit, we determined the change in fruit firmness, weight loss, soluble solids concentration and titratable acidity, as well as antioxidant activities, total phenolic and anthocyanin content, during long term storage in air and controlled atmosphere conditions [55]. The possibility of 1-mcp inhibiting the development of *Botrytis cinerea* during the postharvest storage period was also tested. After harvesting, blueberry fruit (cv Lateblue) was exposed to 1-mcp (0.3 and 0.6 μl $L^{-1}$). After the treatment, samples were stored in air at 0°C for 35 days and in a Controlled Atmosphere (3 kPa $O_2$ + 11 kPa $CO_2$) for 60 days.

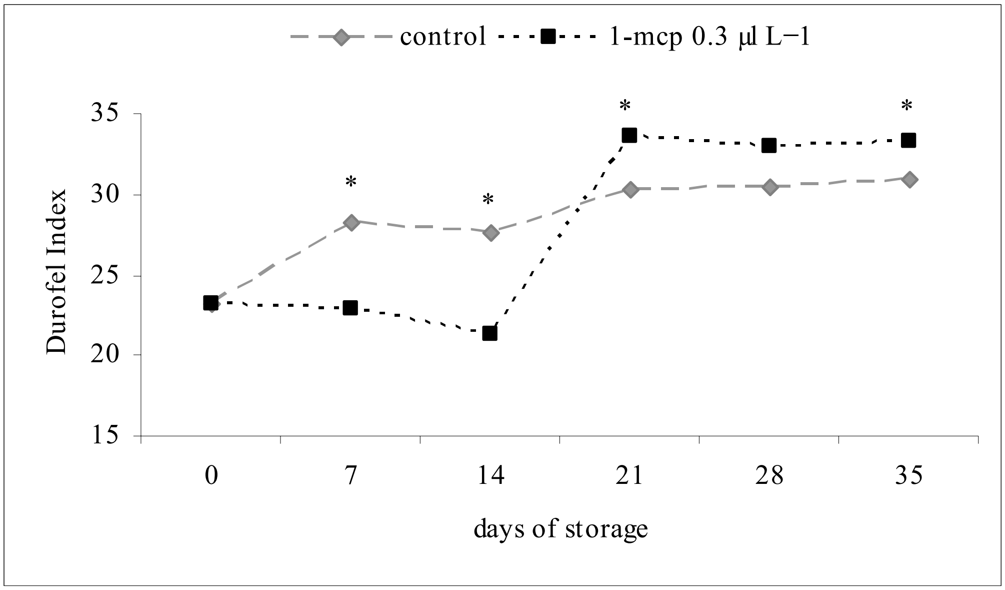
**Table 9. Effect of 1-mcp treatments on weight loss, total soluble solids content (TSS) and titratable acidity**

| | | storage times (days at 0°C) | | | | | |
|---|---|---|---|---|---|---|---|
| | treatment | 0 | 7 | 14 | 21 | 28 | 35 |
| TSS (°Brix) | control | 12.37 a | 10.63 b | 11.27 a | 11.63 a | 10.77 a | 10.97 a |
| | 1-mcp 0.3 µl $L^{-1}$ | 12.37 a | 11.97 a | 10.9 a | 11.53 a | 10.2 a | 9.6 b |
| | 1-mcp 0.6 µl $L^{-1}$ | 12.37 a | 11 ab | 10.6 a | 10.47 b | 10.9 a | 9.97 ab |
| Titratable acidity (meq/L) | control | 87.27 a | 107.92 a | 91.27 a | 111.06 b | 99.96 a | 117.49 a |
| | 1-mcp 0.3 µl $L^{-1}$ | 87.27 a | 82 b | 119.65 a | 129.4 a | 103.25 a | 130.08 a |
| | 1-mcp 0.6 µl $L^{-1}$ | 87.27 a | 100.93 ab | 111.77 a | 115.6 b | 98.63 a | 126.08 a |
| Weigth loss (%) | control | | 2.05 a | 2.83 a | 3.12 a | 3.78 a | 4.4 a |
| | 1-mcp 0.3 µl $L^{-1}$ | | 1.87 ab | 2.64 a | 3.04 ab | 3.62 b | 4.22 a |
| | 1-mcp 0.6 µl $L^{-1}$ | | 1.72 b | 2.41a | 2.94 b | 3.58 b | 4.29 a |

Means separated by Tukey's test. Means in columns with different letters are significantly different at $p \leq 0.05$.

The results have shown that blueberries treated with 1-mcp have a reduced weight loss during storage and a lower soluble solids content compared to untreated fruit (**Table 9**). A delay in the increase in the soluble solids content has been reported for pears [52] and plums [56] while the soluble solids content in apricots and plums was unaffected by 1-mcp treatments [57].

Titratable acidity increased during storage to a similar extent in all the treatments, but little or no significant effect of 1-mcp was observed on this parameter. Changes in berry weight (up to 4%) which occurred during the postharvest period may have influenced the titratable acidity values; it is possible that a portion of the increase in this variable during storage was due to water loss. These differences in effectiveness of 1-mcp on the quality parameters may be due to the different behaviour of the fruit, maturity stage or other experimental conditions, as suggested by [58]. Fruit firmness increased during storage and this increase was delayed by the application of 1-mcp, over the first few weeks of storage and was then quite stable until the end of the storage period (Figure 2).




Means separated by Tukey's test. * = significantly different at $p \leq 0.05$.

Figure 2. Blueberry firmness stored under the normal atmosphere.

The antioxidant activity was relatively stable during air and C.A. storage and the effects of 1-mcp on the individual phytochemical groups were similar: no significant effect of 1-mcp treatment was observed on the anthocyanin content or on the total phenolic content.

The postharvest shelf life of blueberries is also limited by fungal decay. In the study by [55], the infection rate caused by *Botrytis cinerea* was very high and the 1-mcp treatments only reduced decay incidence in the first three weeks of storage. The presence of pathogens was expressed as a percentage of decayed fruit and is show in Table 10. Moreover, the incidence of *Botrytis cinerea* in fruit treated with 0.3 and 0.6 µl $L^{-1}$ 1-mcp increased considerably with the storage time.

In conclusion, 1-mcp treatments have shown to partially control weight loss and decay development without any undesirable changes in the quality attributes, total sugars or acids after short and medium term cold storage, but these results are too inconsistent to recommend the use of 1-mcp in commercial applications.

**Table 10. Incidence of *Botrytis cinerea* (%) during the storage period in the normal atmosphere (RA)**

| | | storage times (days at 0°C) | | | | |
|---|---|---|---|---|---|---|
| | treatment | 7 | 14 | 21 | 28 | 35 |
| incidence (%) of *Botrytis cinerea* | control | 3.12 | 27.72 | 5.04 | 16.84 | 40.72 |
| | 1-mcp 0.3 µl $L^{-1}$ | 2.68 | 14.88 | 4.8 | 31.12 | 50.24 |
| | 1-mcp 0.6 µl $L^{-1}$ | 4.64 | 10.6 | 7.8 | 23.56 | 34.8 |

# Conclusion

Cold storage, in association with high humidity, has a positive effect on berry fruit quality and extends postharvest life. Among the various types of berry fruit, highbush blueberry can be considered important because of the increase in consumers' demand and there is therefore a considerable need to maintain the quality and extend shelf-life. Blueberry can be stored for long periods, which vary according to the variety. Normal atmosphere storage (-0.5 to 1 ºC; 85-90% RU) helps maintain acceptable quality levels for two to five weeks (depending on the cultivar).

C.A. can extend storage to over six weeks without any loss of fruit quality, but the extension of berry life is sometimes not the main effect and C.A. storage results in a better quality of the fruit. The use of modified atmosphere packaging is effective in retaining both the sensory and the sensorial quality and in reducing the development of post-harvest diseases, thanks to the use of non-perforated and micro-perforated packaging films. Moreover, storage in plastic films reduces weight loss and slows down visual quality deterioration.

Ozone treatments seem to be effective at inhibiting the proliferation of *Botrytis cinerea*, and reducing the incidence of decay, but few results have been found concerning the preservation of blueberry quality and the extension of postharvest life. 1-mcp treatments have shown to partially control weight loss and decay development, and no undesirable changes have been observed in quality attributes, total sugars or acids after short and medium term cold storage. However, these results are too inconsistent to recommend the use of 1-mcp for commercial application.

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