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a technical update published by HORTGRO science

# Mitigating the Risk of Internal Browning in Fuji

**Dr Ian Crouch**

**In 2015, unacceptable levels of internal browning (IB) (up to 80%) reported for shipments of Fuji apples to the Far East lead to many claims against fruit exporters, resulting in a loss of client confidence in South African Fuji apples. These fruit were initially from short term regular atmosphere (RA) storage, but later included longer term controlled atmosphere (CA) examples. No obvious trends linked to IB incidence could be found regarding orchards, pack houses, growing regions or logistic handling systems.**

**The exact reasons behind the extremely high incidence of IB in Fuji during the 2015 season are thus still unclear. Without knowing why 2015 resulted in such a problem, it is not easy to take remedial action to ensure that it does not occur again in future seasons. This communication summarises international research on Fuji internal browning and outlines current practises to reduce the risk of expression following storage.**

## Literature Summary:

Internal browning disorders in `Fuji' apples have been studied since the early 1990's in California and Washington State and in more recent years by Korean researchers. Many factors have been investigated from pre-harvest growing and harvesting conditions to postharvest storage regimes. From the literature several common threads and areas of research could be identified. In most instances, **expression of IB is linked to either endogenous or exogenous $CO_2$** at harvest or during storage (Park and Lee, 1992; Park *et. al*, 1997; Park and Youn, 1999).

Studies indicate that several pre-harvest factors may play a role in the susceptibility of `Fuji' to IB. It has been reported that growing region (colder regions), field conditions, higher altitudes, rainfall and diurnal temperature ranges during the growing season (colder seasons) may all play a role in expression during cold storage (Argenta *et. al.,* 2001, Kweon *et. al.,* 2012, 2013). These factors may also explain the year to year variability in IB incidence and severity (Grant and Mitcham, 1995). Possibly the **greatest single pre-harvest factor affecting IB is harvest maturity** (Hwang et. al., 1998a). Fruit of advanced or post-optimum maturity are of highest risk and it has been recommended to harvest fruit no later than 180 DAFB. Later harvested fruit are also more prone to watercore as sorbitol content in the fruit increases. Watercored fruit have lower intercellular air spaces which results in reduced permeance to gas diffusion. This may cause a build-up of $CO_2$ in the fruit and an increase the risk of IB (Kweon *et. al.*, 2013). Correlated to this was an increase in ethanol and acetaldehyde levels in watercored fruit (Volz *et. al., 1998,* Argenta *et. al.,* 2002a). Apart from harvest date, different orchards and **IB severity after storage also correlated to watercore severity**. Linked to harvest maturity was the discovery of `callus hairs' in the air spaces of mature fruit. These hairs are thought to restrict gas diffusion and may also result in the build-up of $CO_2$ in the fruit prior to harvest (Parker, 2008). A postharvest application of DPA was also found to reduce IB incidence in an orchard with later harvested fruit and high watercore incidence (Argenta *et. al.,* 2002b).

Later harvested fruit have higher rates of respiration (Grant and Mitcham, 1995). Increased respiration may be triggered by elevated temperatures and anything reducing the rate of diffusion of $CO_2$ out of the fruit (such as watercore or callus hairs) could result in a build-up of $CO_2$ and increase the risk of IB expression during cold storage. In a study by Volz and Mitcham (1997), fruit from different orchards harvested at the same harvest date showed IB expression that could not be explained by fruit maturity at harvest. It was observed that all populations had low $CO_2$ in the tissues and so it was suggested that IB incidence was not related to the amount of $CO_2$ in the fruit, or to skin resistance to $CO_2$ diffusion, but rather was a factor of tissue *sensitivity* to $CO_2$. By keeping samples of fruit in high levels of $CO_2$ (20 to 50%) directly after harvest, IB was expressed after 3 days at 20°C. Results indicated IB incidence comparable to fruit stored for several months under CA storage, suggesting that this method could be used as a predictive model for assessing IB potential prior to storage.

**Postharvest handling of fruit prior to and during CA or RA storage** may also affect the expression of IB during storage Hwang, 1998b). Research clearly indicated that **fruit stored under CA is more susceptible to IB** mainly due to the elevated $CO_2$ levels during storage (Kweon *et. al.*, 1998). It is recommended not to store `Fuji' above 0.5% $CO_2$ as this increases the risk of IB. Fruit stored at 3% $CO_2$ may develop IB after only 15 days storage (Argenta *et. al.,* 2000). However, many researchers have shown that `Fuji' is most susceptible to IB during the first weeks after harvest and that a delay in CA conditions may negate or reduce IB expression. A delay of between 2 to 12 weeks is recommended depending on the maturity of the fruit (Volz and Mitcham, 1997; Kweon *et. al.*, 1998; Argenta *et. al.,* 2000, 2001). The more mature the fruit the longer the required delay. However, delaying CA may have a negative effect on fruit quality after long term storage. The use of 1-MCP was also examined and found to reduce the incidence of core flush under CA conditions compared to similar fruit stored under long term RA storage (Argenta *et. al.,* 2001, Argenta and Matteis, 2010). 1-MCP had the added benefit of maintaining fruit quality which would prove advantageous during delayed CA storage. Park *et al.* (2011), however suggest that 1-MCP alone may not be sufficient to maintain fruit quality throughout the cold chain for long term (8 months) storage unless used in combination with CA. However, Argenta *et. al.* (2001), indicated that the use of 1-MCP increases the delay requirement prior to CA as it extends the susceptibility of the fruit to IB incidence after harvest. Methyl Jasmonate was also found to be effective in reducing the severity of $CO_2$ damage at high $CO_2$ storage.

A stepwise increase in $CO_2$ levels during CA storage has also proven effective in preventing IB in `Fuji' apples. Fruit kept for 4 months at 1.5% $O_2$ + 0.5% $CO_2$, prior to an increase of $CO_2$ to 3% did not result in any IB, compared to fruit stored only at 1.5 $O_2$ + 3% $CO_2$ for the full storage period (Argenta *et. al.,* 2000, Kweon *et. al.*, 2013). Similar results were noted in another study when IB occurred in fruit stored under 1.0% $O_2$ + 3.0% $CO_2$ for 10 months, but was supressed completely by stepwise CA storage when fruit were held at 1.0%

$CO_2$ for 2 months then increased to 3.0% for the remaining 8 months (Chung *et. al.*, 2005).

Other studies looking at conditioning the fruit during CA storage have included elevated temperatures (Brackmann and Bortoluzzi, 1996) and CA/RA combinations. It was found by Brackmann and Bortoluzzi (1996) that exposure to elevated temperatures (2.5°C) in combination with low RH, totally eliminated IB, when compared to fruit stored under at -0.5°C. Kweon *et. al.* (2014) studied the effect of different combinations of CA and RA durations on IB expression. They found up to 30% incidence of IB when fruit were stored for 7 months CA. However, no IB was recorded when fruit were stored for 4 months CA + 3 months RA and 5 months CA + 2 months RA. As internal ethylene levels increased with increasing RA storage, the recommended regime was the 5 months CA + 2 months RA storage. Elevated levels of $O_2$ (5 to 6%) have also been shown to reduce IB incidence after storage (Kweon *et. al.*, 1998). Park *et. al* (2011) analysed postharvest 1-MCP treatment and CA storage effects on quality of `Fuji' apples during export simulation.

## Strategies to minimise the risk of internal browning in Fuji

From the literature it appears that the main causative factors that result in IB expression in `Fuji' apples is elevated levels of $CO_2$. For this reason, most of the strategies to minimise risk are linked to preserving fruit quality through minimising $CO_2$ levels in the fruit, either at harvest, in storage or during transport and resale.

1. Practise **good crop load management** to minimise harvesting fruit that are too mature
    a. Minimal use of nitrogen fertiliser can result in earlier harvest with good red colour
    b. Earlier harvest reduces watercore incidence
    c. Harvest fruit before 180 DAFB

2. **Identify high risk areas**, seasons and monitor risk
    a. Light crop load year
    b. Colder areas
    c. Colder seasons
    d. Fruit grown in higher altitudes

3. **Delay CA** if fruit are high risk due to post optimum harvest maturity
    a. Fruit most susceptible to IB initiation in first few weeks after harvest
    b. Only CA store early harvested fruit
    c. 1 to 3 months depending on season and fruit maturity
    d. Optimum maturity, delay of 10 to 14 days, no $CO_2$ accumulation for 1 month
    e. Late harvested fruit, 4 week delay, $CO_2$ accumulation less than 0.5% for 2 months
    f. Quick cooling

4. **Test new storage regimes and procedures**
    a. Use 1-MCP to store fruit at higher temperatures (2.5°C), at low RH
    b. Store fruit at elevated $O_2$ levels (5 to 6%)
    c. Store fruit below 1% $CO_2$ (preferably 0.5% $CO_2$)
    d. Look out for non-destructive technologies that can monitor and detect the progression of IB (MRI)

5. **Assure good air circulation in storage rooms**
    a. Assure good air circulation in storage rooms to prevent pockets with higher $CO_2$ concentrations.
    b. $CO_2$ can develop to damaging levels in air storage or marine containers if fruit temperature is 3°C or warmer and ventilation is not good.
    c. Proper temperature management and good ventilation will prevent build-up of $CO_2$
6. **Pay attention to packaging to prevent build-up of $CO_2$**
    a. Avoid excessive packaging or thick bags
    b. Rapidly cool fruit after packaging
7. **Container vents**

    The international practice for container vent settings is 100% open.

## Research Programme 2016

A project has been initiated to determine the causative factors that give rise to IB expression in Fuji and will encompass the following objectives:

1. The development of a simple predictive test to assess the risk and potential for IB expression in a particular season
2. The assessment of delaying CA storage as a means of eliminating IB incidence in Fuji
3. The development of an industry protocol that will reduce the risk of IB expression in Fuji apples and restore client confidence in South African Fuji apples

## Disclaimer

The above recommendations to mitigate risk of IB in Fuji are taken at the discretion of the user and have not been assessed at a scientific level under South Africa growing and storage conditions. ExperiCo cannot be held responsible for any claims or negative market sentiments:

**PLEASE find the full literature survey here: http://www.hortgro-science.co.za/wp-content/uploads/2016/03/16-Summary-of-Fuji-Browning-Study-and-Literature-Review-ic.pdf**

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