Improving mushroom whiteness – Best Bets

White mushrooms are *quality* mushrooms

Presenting clean, white mushrooms to consumers at retail is a proven method of increasing sales. For mushrooms, whiteness signals quality. It may also be assumed to indicate storage life, flavour and freshness.

Conversely, browning on mushrooms is a negative. Browning may be due to disease, bruising, dehydration or simply age and senescence. Browning mushrooms are more likely to be soft, slimy and/or with poor flavour and texture, as expected near the end of storage life.

Mushrooms turn brown due to a reaction between phenolics normally kept inside the cell vacuoles and enzymes in the cell cytoplasm. When these mix, they oxidise, producing the brown pigment melanin.

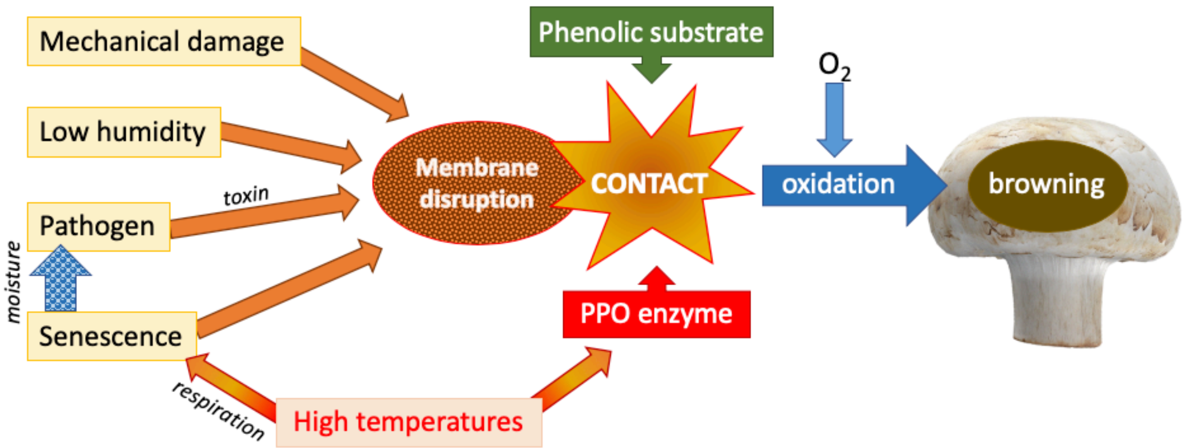

Figure 1. Mechanisms of mushroom browning.

Many of the strategies used to improve mushroom storage life and whiteness are focused on inhibiting the reactions that form melanin. Treatments may aim to enhance the strength of cell membranes, prevent oxidative reactions, or create genetic changes that reduce enzyme activity. Methods to improve whiteness can be employed at all stages of production, from casing to harvest, packing and storage.

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This document summarises the "Best Bets" for enhancing mushroom whiteness at each stage of the production process

Crop production and nutrition

Using healthy, well-balanced compost is the first step to producing high quality white mushrooms.

Nutritional supplements are commonly added to compost to increase yield. They may also be added to casing, either to increase yield or improve pinning. While most supplements are protein based, they can include mineral micronutrients, lipids, acids and activated carbon. Their effectiveness depends on:

- Delaying release of nutrients to ensure they are available through the cropping cycle
- Controlling temperature increases triggered by adding the supplement
- Matching the minerals and nutrients required with the attributes of the compost

Although most supplements have little or no effect on colour at harvest, differences may develop postharvest. Limited research has found that mushrooms produced with supplements brown more slowly during storage. This could be partly linked to dry matter, which can be increased by supplements. Mushrooms with high dry matter have larger carbohydrate reserves, which helps to sustain them during storage.

Even though mushrooms with high dry matter can sometimes be **less white** at harvest they often **stay whiter** during storage when compared to mushrooms with low dry matter.

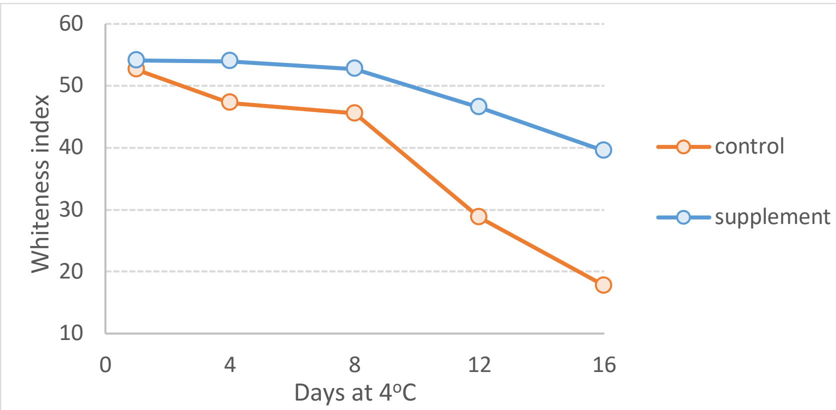

Figure 2. Effect of supplementing casing with 10g/kg corn or soybean meal (average of both treatments) on the whiteness index of stored mushrooms. Derived from Adibian and Mami, 2015.

Casing

The whitest mushrooms are generally produced using black peat. However, blends of peat with up to 25% coal tailings, or 60% spent mushroom compost, did not impact colour. Local trials have also found little difference in colour when peat based casings were blended with up to 50% recycled organics. Although some trials have found that mushrooms were less white when cased with only 0 - 20% peat, a Spanish study found that a local blend of mineral soil with coconut fibre produced high quality white mushrooms.

Pinning

Pinning is stimulated by bacterial activity in the casing (which removes volatiles produced by the mycelia), dropping temperatures and changes in CO_2 levels in the room air.

Of these, reductions in CO_2 are the key factor determining the number of mushrooms that develop.

Avoiding over-pinning on mushroom beds is essential to prevent bruising, both during development and at harvest. Over-pinned crops are likely to become over-mature and soft, further reducing whiteness.

Gradually reducing CO_2 can stagger pin set, known as 'choking the beds'. However, it is important not to delay airing too long, or yield will be reduced.

Managing the room environment

While it is important to keep relative humidity (RH) high inside the room, it is clearly essential to avoid free water sitting on the mushrooms themselves. Accurate control of temperature, manipulation of CO_2 to increase/decrease pinning and avoiding excessively high or low airflow are all essential in order to produce high yields of white, smooth, high quality mushrooms.

Irrigation is a balance between the mushrooms being too dry – which can result in the caps being scaly and dry – and too wet, which allows bacterial blotch to develop. Mushrooms are 90 to 95% water, so the quality of water used and when and how it is applied will strongly influence quality and storage life.

It is essential that mushrooms dry within four hours of irrigation:

- *Before irrigating* – Dropping the air temperature to reduce absolute humidity (RH).
- *After irrigating* – Raising the room temperature and increasing fan speed by approximately 5-10%.
- *After irrigating* – Introducing fresh, dry air to the grow room, if conditions are conducive.

The temperature difference between the bed and the room air also drives evaporation; beds are likely to be warmer after addition of supplements, during first flush and when the compost volume to surface area ratio is high.

A new, automated drip irrigation system is available from Netafim which can maintain constant moisture (and nutrient) levels in the substrate throughout the cropping cycle. By avoiding water contacting the mushrooms, the system is claimed to reduce bacterial blotch and improve quality, as well as reducing casing material requirements by 30%.

Figure 3. The Netafim "Mushroom Master" drip irrigation system (left) and the insertion unit on a Thilot head filler. From Raz et al., 2016.

Airflow needs to balance the metabolic heat produced by the crop. So, for example, higher rates of air exchange may be needed approaching flush 1 than for flush 3. Good airflow is also essential in order to manage CO_2 levels and to help mushrooms dry after irrigation.

However, if air velocity is too high the mushrooms will be scaly and discoloured. High airflow can physically damage the delicate caps, increasing browning. This can be avoided using air-trainers, such as netting diffusers and cones linked to airlines, to soften or increase speed, guiding ventilation to where it is needed.

Relative humidity affects mushroom texture and structure. Low RH results in the mushroom caps developing a scaly, off white appearance as well as increasing enzyme activity. This in turn increases susceptibility to bruising, an effect that is particularly pronounced in the early flushes. However high RH reduces drying, so can increase development of blotch. Room RH should be held as constant as possible, ideally between 82-90%.

Casing moisture levels should be maintained at approximately 60% water content by volume. Dry casing results in mushrooms that are soft, susceptible to premature opening and less white overall. However, wet casing reduces yield and evaporation, resulting in mushrooms that are low dry matter, may have water-soaked 'windows' and are prone to browning. Keeping casing well hydrated can be difficult if there is a heavy first flush, as this removes a lot of water from the substrate. It is essential casing does not dry out, as it never regains its previous moisture holding capacity.

Additives to irrigation water

There is a long history of including sanitisers in irrigation water. While chlorine (in the form hypochlorous acid) can control human pathogens in water, high concentrations are needed to reduce bacterial blotch on mushrooms.

Stabilised chlorine dioxide has a more specific mode of action than hypochlorous acid and is relatively unaffected by pH and organic matter. A concentration of 50ppm has been shown to be effective against bacterial blotch.

Stabilised chlorine is dioxide is registered for treating water (5ppm) and disinfecting equipment (100ppm) in mushroom facilities. Like all chlorine products, stabilised chlorine dioxide should be used with care, according to label directions.

Calcium chloride ($CaCl_2$) has been widely demonstrated to improve whiteness at harvest, with effects increasing during postharvest storage. Application of a 0.3% $CaCl_2$ solution from pinning increases cell wall integrity, improving firmness and reducing susceptibility to bruising and browning. Calcium chloride is used as an ingredient in a range of foods and beverages and is "generally recognised as safe" by the US FDA.

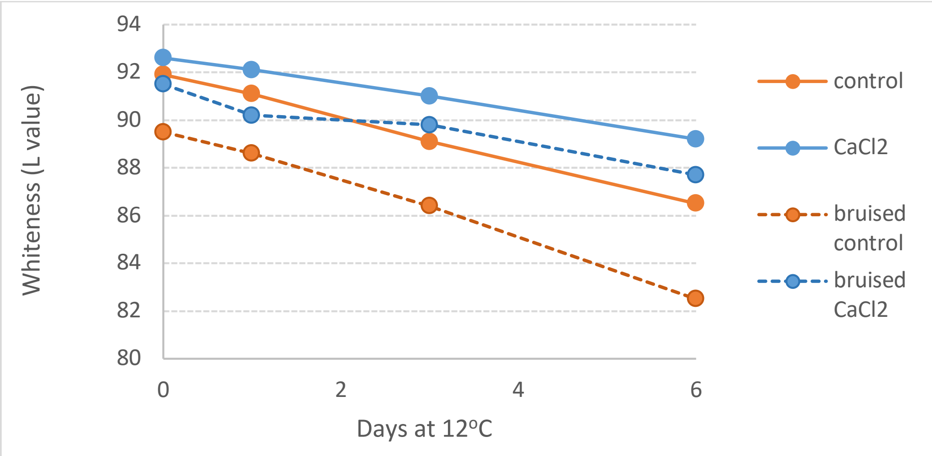

Figure 4. Effect of irrigation with 0.3% $CaCl_2$ on whiteness of intact and bruised mushrooms during storage at 12°C. Derived from Kukura et al., 1998.

Figure 5. Mushrooms irrigated with tap water (left) or 0.3% $CaCl_2$ (right) following 6 days storage at 3°C (AHR data).

The legal status of adding $CaCl_2$ to irrigation water for mushrooms is currently being investigated by the AMGA.

A large number of other additives to irrigation water have been tested, including hydrogen peroxide, citric acid, Vitamin C, plant growth regulators and selenium. While many of these had minor or mixed effects on quality, selenium improved both whiteness and nutritional value, so appears worthy of further investigation

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Harvest and storage

Temperature is the most important factor affecting mushroom storage life. The faster mushrooms are cooled, the less moisture and quality they will lose. To maximise storage life, mushrooms should be cooled below 4°C within one hour of harvest. The best way to do this is by vacuum cooling.

The benefits of vacuum cooling are not just due to the speed of cooling, but to effects on enzyme activity. Vacuum cooling has been shown to inhibit polyphenol oxidase and increase anti-oxidant activity, thereby inhibiting browning reactions.

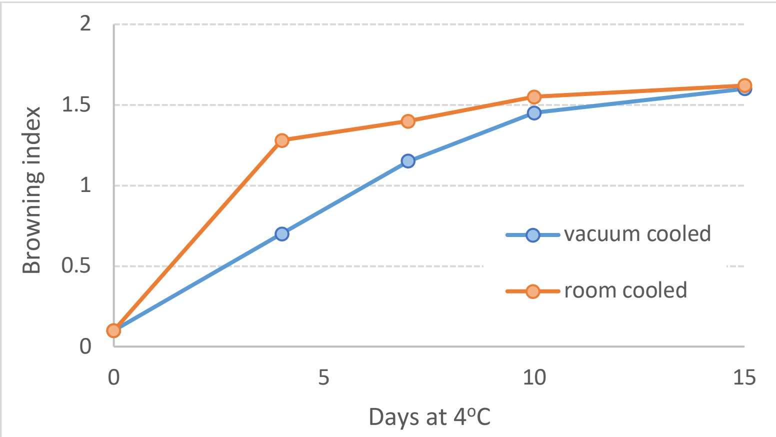

Figure 6. Increases in browning during storage at 4°C of vacuum cooled or room cooled mushroom. Derived from Tao et al., 2007.

Once mushrooms are cold, minimising fluctuations in temperature is the best way to avoid condensation and, therefore, development of bacterial blotch and moisture loss. Uniform temperatures can be achieved by;

- Reducing the gap between the coolrooms' high and low temperature setpoints (when the compressor turns on/off).
- Minimising the frequency with which doors are opened, and using an air curtain to reduce ingress of warm air.
- Ensuring cold rooms are well insulated, and that insulating materials are sealed against moisture.
- Loading directly from cold rooms into pre-cooled trucks.

A lot of new research (especially from China) has examined the application of various dips, washes, coatings, fumigants, packaging and other novel treatments to extend mushroom storage life. Examples include films made from biodegradable materials or impregnated with anti-bacterial compounds such as essential oil or chitosan. Although none of these are currently commercially available, this is certainly a fast-developing area to watch.

The future – Mushroom breeding

As mushroom browning occurs through the relatively narrow physiological pathway that ends with formation of melanin, it should be possible to breed mushroom varieties resistant to browning reactions.

New molecular techniques have successfully identified three genes which are responsible for up to 90% of variation in mushroom colour. This progress should facilitate faster development of varieties with improved quality attributes.

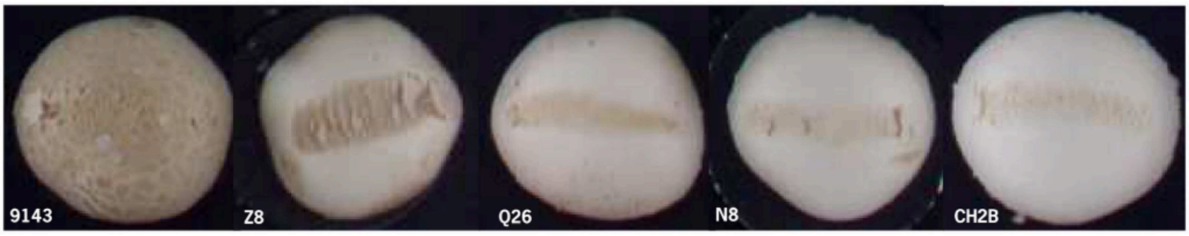

Figure 7. Differences in bruise susceptibility of a range of first flush hybrid mushrooms, photographed 60 minutes after bruising. From Gao et al., 2013.

A new, browning resistant mushroom has already been produced in the USA using CRISPR-Cas9. This technology allows deletion of specific, targeted parts of the genome – such as the genes responsible for browning. While the resulting organism is not officially considered "transgenic" (no genes were added), there is still public resistance to use of this technique. FSANZ is currently reviewing how the food standards code should apply to this type of product, for example whether it should be classified as "GM"..

The development of new, whiter mushroom strains is an area of significant international effort, with major potential future benefits.