Project Background:

The National Mango Board (NMB) organized a Fresh-Cut Mango Taskforce in 2021. The main purpose of the taskforce is to identify and prioritize the main issues holding back faster growth of the fresh-cut mango category and begin developing solutions to these issues. The NMB Fresh-Cut Mango Taskforce is composed of 14 industry leaders, and the recommendations made by the taskforce will be reviewed and considered by the NMB members for future projects starting as early as 2022.

Based on the recommendations of the task force the NMB is evaluating a project to determine, design and test optimal package designs for fresh-cut mango; with the goal of extending and optimizing fresh cut mango shelf life.

Qfresh Labs background:

As an independent consulting and quality testing laboratory, we bring over fifty years of collective experience in packaging technologies, shelf-life analysis, process design, packaging line equipment, material design as well as project management. Our resources and contacts are global in reach; so that we can not only provide access to the full gamut of available technologies; but as an independent resource we can recommend and specify what is truly optimal for the NMB. With our independent structure, as well extensive knowledge in all of these areas, we are uniquely suited to bring this project to a successful conclusion.

Executive Summary:

- **Proper peeling** and subdermal removal are VITAL to the shelf-life extension of fresh cut mango. Removing the stem side of the ends of fresh cut mango is also vital. Anywhere fibers/channels are present must be removed to completely stop browning.
    - Fresh cut mango does not require additional anti-browning solutions if the peel and subdermal layer are removed.
        1. Clean cuts with a sharp knife is the best method
        2. Peelers increased localized browning
        3. The stem side, in particular, requires more trimming
- **Modified atmosphere packaging improves shelf-life outcomes but is not a complete solve for fresh cut mango:**
    - Moderate atmospheres (<10% CO_2 is most important) to improve texture, flavor and aroma but only through about 8-10 days post cutting
    - Low residual O_2 (<5%) had mixed results in our testing. Fresh cut mango does not seem to have a high tolerance to low O_2 and can develop ethanol off flavors and aromas.
    - Sustained high CO_2 environments (>10% CO_2 for 3+ days) causes tissue softening and water soaking
    - Fresh cut mango is a good candidate for breathable films with or without micro-perforations
        1. Larger pack sizes (>5oz) tend to outpace the breathability of the film, requiring micro-perforations to ensure package does not reach <3% O_2

2. Smaller pack sizes are better candidates for breathable films, as these types of films let out excess CO_2, and the respiration rate of the product does not outpace the breathability of the film.
3. We have put a table together under the packaging section which includes packaging specifications for various pack sizes, which includes the total breathability required and how to accomplish it with both breathable, micro-perforated, and combination packages utilizing both technologies.

- **Dips, coatings, treatments:**
  - High CO_2 gas flushing (30%) in the package led to tissue softening earlier in shelf-life than controls. Not a good solution for fresh cut mango. It is possible that a lower gas flush may be beneficial (10 to 15% initial but was not tested by Qfresh).
  - Using food grade CO_2 gas from a food grade cylinder directly onto the fresh cut mango surface, followed by packing showed very promising results. It had the best texture, aroma and flavor retention of any minimal solution. It did not brown or develop microbial issues. It worked well in packaging targeting 5 to 15% residual O_2 and 5-10% CO_2 environments. The mode of action seems to be 2-fold:
    1. Using CO_2 gas directly onto the fresh cut mango with some pressure pushed the fresh cut juice around the surface. This coats the cut mango in its' own wounding response/juices evenly on the cut surfaces helping to lock in flavors/aromas/textures and prevent bacteria growth. The next step might be to then add a coating over the top which matches the chemistry and viscosity of the natural mango juice
    2. High CO_2 for short periods of time has a bacteriostatic effect. This is localized to where the CO_2 gas is used, and best of all the texture was improved. Previous studies showed PROLONGED CO_2 exposure caused negative texture effects. But short burst CO_2 gas caused extremely positive effects that lasted.
  - A High CO_2 gas application could be accomplished with air knives and a dewatering belt in a commercial setting. While mangos do not tolerate prolonged CO_2 in a package, they tolerated a quick flush very well. A key component of this may be the gas velocity though, as in our testing it was high enough to disperse the surface juice. It was also viscous enough that juice stayed on the fresh cut mango. N_2 gas and air drying had negative effects for both texture loss and microbial growth when tested side by side, so it is the CO_2 gas also promoting positive outcomes (testing ongoing as of 3/15/2023, will update).
  - Alginate coatings at 1% were very promising, but have some commercial challenges in terms of viscosity, reusability and cleanliness in a tank application, but a spray application may work. The alginate coats the surface of the mango, locking in flavor/texture/aroma through 14 days of shelf-life and beyond. More research is required to find the right % of alginate, the right viscosity, and exactly what to combine it with. CaCL2 seemed to help, but also imparted bitter off

flavors which most consumers would detect. Literature showed no need for modified atmosphere in conjunction, but we saw no problem using it and saw a slightly improved outcome.

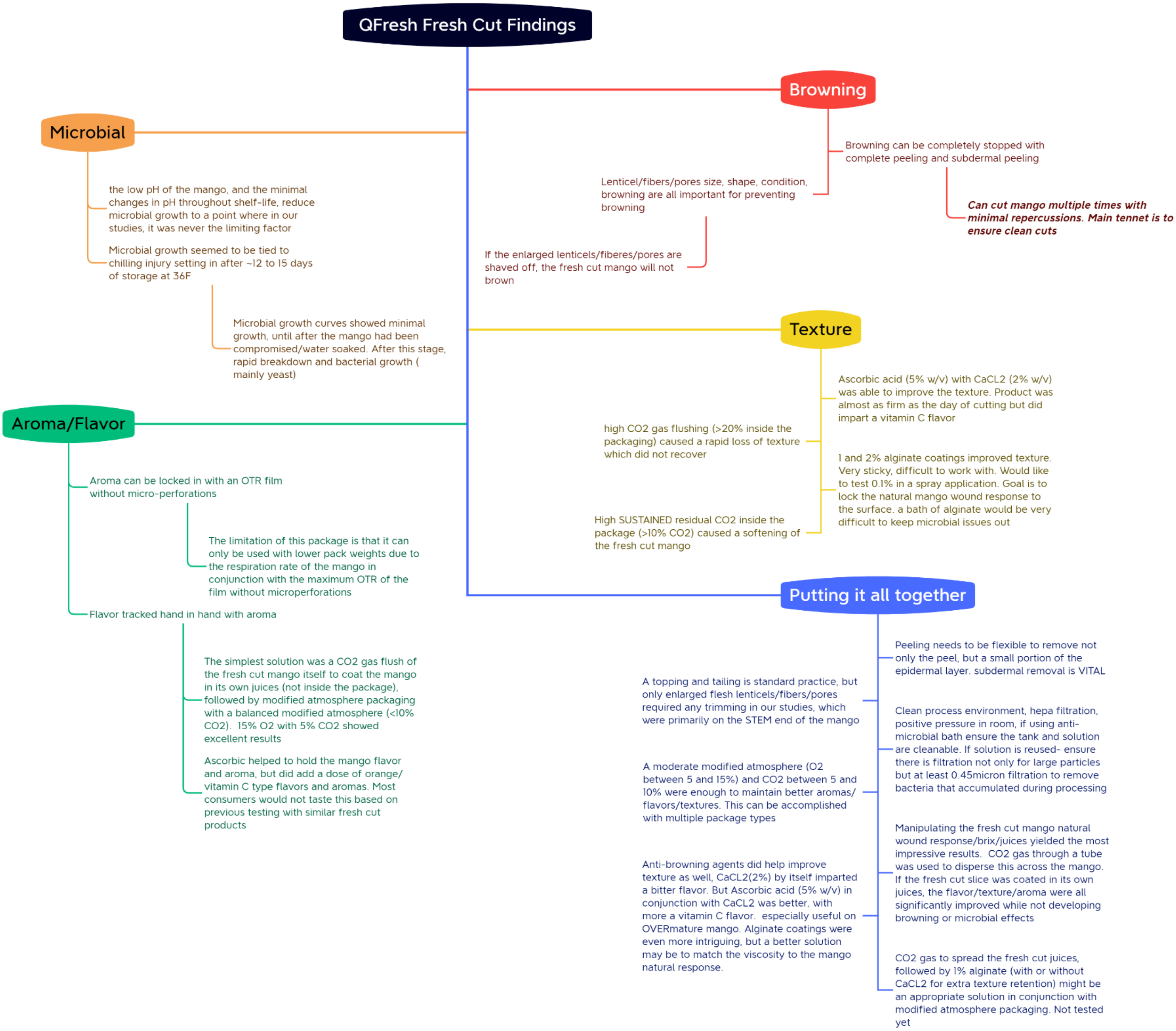
- Ascorbic acids with or without CaCL2 provided mixed results. In one test, there was MORE bacterial growth than in control samples. They do a good job of preserving color (although they do darken the samples, it happens uniformly across the mango), preserving texture, preventing browning. They do impart a flavor and aroma, which are not off putting but do change the natural mango flavors and aromas. It is posited that the Ascorbic acid viscosity was not high enough, penetrating the fresh cut mango and causing water soak and premature breakdown, leading to bacterial growth. They seem like a marginally effective solution that could add more problems.
- Washing the fresh cut mango may or may not improve outcomes. The mango has a natural wounding response once cut. If this is washed away, other treatments must be used to seal the outer coat of the mango and prevent dehydration and texture loss.

Literature Review: This table summarizes some of the main findings from available literature. This was an early roadmap for potential tests. We have this research summarized in much more detail and can share.

Literature Review

Browning	Peeling — Subdermal Peel — Most studies chose an absolute subdermal peel depth to use
	Anti-browning dips and sprays — Ascorbic Acid (2 to 5% w/v) — Naturally present in Mango; Antioxidant, synergistic to polyphenols; Heat sensitive Anti-browning dips and sprays — Chlorine wash — Sugar Lixiviation a potential mode of action Anti-browning dips and sprays — Alginate dip — Surface drying and modification of atmosphere
	20% or more browning considered unacceptable
Microbial	Light — 405 ± 5 nm LED in storage — Reduces Salmonella, Listeria, E. Coli Light — Pulsed light, 20 full spectrum pulse 80 J/cm — Reduce Psychrotroph, Y&M
	Sanitizers — PAA, 50 to 100ppm Sanitizers — Free chlorine- 200 to 300ppm on whole mango prior to cut — fresh cut mixed results for washing
	2-5%O2 and 10%CO2 show micro inhibition at temp abuse storage condition
Texture	Softening caused by enzymatic activity and decompartmentalization between enzyme and substrate
	>10% CO2 found to cause softening repeatedly. Time/Dose dependent
	Hydrolysis of pectic acids in cell walls
	Melatonin in one study was found to improve softening, slow RR, slow ripening and color loss on WHOLE mango
	CaCL2 (2% w/v). by itself improves texture but imparts off odor
Aroma/Flavor	Low temperature= lower aroma
	pH stays steady throughout studies under multiple pack conditions
	low pH of product along with washing outside of mango prior to cutting caused low micro in most studies
	Brix increases slightly throughout studies
Modified atmospheres	2% O2 along with 10% CO2 seems to be what the researchers have settled on
	Superficially high O2 environments (>21% to 100%) extremely negative results on multiple attributes
	Anaerobic compensation point is around 2% O2. Some studies showed positive results down to 0.5% O2 though under certain conditions

Qfresh Results Summary:



Initial testing:

Early testing focused on mango respiration rates, bacterial growth curves, anti-browning index and chill sensitivity at cold temperatures. Understanding the basic physiology of the fruit, along with the tolerance it has to different commercial processing and packaging conditions often pays dividends later during more involved shelf-life trials. In our early tests, we spent an inordinate amount of time trying to solve for browning (data not added here). It was not until later when we were trimming the mango better and focusing on topping and tailing did, we realize browning could be solved a different way, opening testing up to evaluate how to improve texture/flavor/aroma.

Respiration Rate Testing:

Mango is an interesting fruit for respiration, in that it has similar, or in some cases an even lower respiration rate, than when it is freshly cut. This was particularly interesting and peculiar early in this study. At that point we did not have enough time with the product and enough understanding to know how to manipulate this part of the mango physiology.

A low respiration rate often means several things in fresh cut fruit:

- A high tolerance to low O_2 environments (turned out to be a false avenue for fresh cut mango)
- Low heat generation, low transpiration effects (true)
- It has a large wounding response when injured (true)
  - This has been shown in chopped iceberg and romaine lettuces with the amount of latex expressed in fresh cut applications. This latex is washed away commercially due to the negative look of the latex, and the cut end discoloration is solved instead using gas flushing in conjunction with a very low residual O_2 in the package (<1% O^2). In testing performed by Qfresh labs, if the latex is left, the residual O_2 value can be higher without as much pinking. But the lettuce is washed to remove insects and dirt and the latex gets removed in this process.
  - The wounding response was able to be manipulated in fresh cut mangos to coat the mango and promote a sealing in effect to improve all mango attributes. Aroma and texture were the two primary quality increases. Alginate coatings helped to lock in texture/aroma flavor. Food grade CO_2 gas sprayed on the fresh cut surface helped to disperse the mango natural healing substances, reduced microbial growth and improved aroma/texture/flavor very significantly.
- Low respiration rate products often benefit from breathable films without micro-perforations.
  - If the respiration rate is low enough (typically <8 ml O_2/kg·hr), it might not need micro-perforations

- This is important, as breathable films help to *maintain aroma* in the package and improve flavor
- Breathable films provide moderate CO_2 environments, which fresh cut mango are sensitive to high CO_2 environments
    - Breathable films had 3x the CO_2 flux to O_2. Meaning 3x more CO_2 can exit the package than O_2 can enter. Helping to achieve lower CO_2 environments.
- Typically, breathable films work better in smaller package sizes (<6oz of product). This is due to the size of the package and the amount of product respiring in the package.
- The respiration rate of the product being high, or too much product in a smaller package will outpace the breathability of the film and cause very low O_2 environments

Respiration rates:

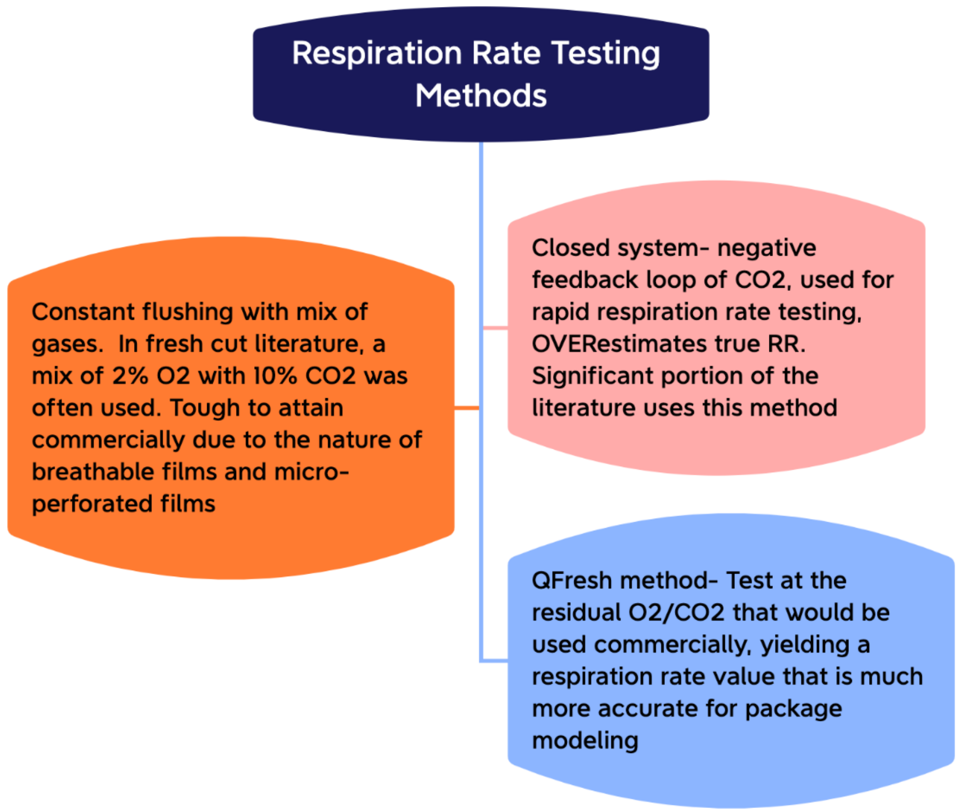
Most literature studies test respiration rate under steady state conditions using varying gas combinations of O_2 and CO_2. The O_2/CO_2 chosen are constantly flushed into the system. Or they test in a short -term manner in a closed chamber, measuring rapid changes in O_2. This method can only be used for short periods of time, as the rising CO_2 causes a feedback loop to slow respiration. Both methods will give accurate respiration rate values, but only under those EXACT circumstances.

QFresh Lab tests respiration rate differently, we use breathable films or perforated films with known oxygen transmission rates (OTR) values and volume, and samples are packed with varying weights of produce. We target O_2/CO_2 values in the package that would be used in a correctly designed modified atmosphere package. Therefore, this method gives very accurate values that can be used for package design. We have done this for >20 years with incredible results. While the values attained from a closed system, or under constant flush of O_2/CO_2 are accurate, they often OVERestimate the true respiration rate of the product for package design. For this reason, our values are often lower than literature states. But these values can be directly used to design a package.

Below are some results we measured on Kent, Tommy Atkins and Ataulfo mangoes. We do not put a lot of weight into variances in respiration rate throughout different seasons, areas, harvests, maturity levels, etc. There are far too many factors at play to ever test and understand it all. What we focus on is understanding how the respiration rate changes with varying temperatures to be able to bracket the true respiration rate. Then a respiration rate is chosen for package design. This value considers the typical cold chain and is designed to ensure the package does not reach anaerobic conditions under mild abuse conditions, while still providing a modified atmosphere to extend shelf-life.

With this in mind, mangoes have been proven to consistently perform better in moderate CO_2 environments (5 to 10% CO_2) and varying levels of O_2 (literature has shown positive results from 0.5 to 10% O_2, depending on the mango type and maturity levels. We tested respiration rates at a target of 10% O_2, with CO_2 levels reaching 5 to 10% depending on the mango and temperature. We feel these values will consistently provide the best commercial shelf-life. Too low of O_2 (<3%) was shown in our testing to cause texture loss and anaerobic off odors depending on length of time at these values. Therefore, targeting 10 to 15% O_2 for a package design gives leeway with temperature abuse to ensure product does not reach anaerobic levels. It also means that if all the airflow from a package comes from micro-perforations, the CO_2 will not increase significantly above the 10% CO_2 threshold where excessive texture loss occurs. An even better approach may be to target 15% residual O_2, ensuring the CO_2 threshold is not reached.

Another interesting part of respiration rate testing and package design that is not discussed in fruit/vegetable physiology are the effects of moderate modified atmosphere, and the positive benefits. We define a moderate atmosphere as between 15 to 21% O_2. In a micro-perforated package this would result in CO_2 values ranging from 0 to ~6% CO_2. Micro-perforations allow a 1:1 exchange of gas molecules, meaning if the O_2 drops by 1% the CO_2 would rise by 1%. Moderate environments, in most cases, show the LARGEST quality and shelf-life change. As O_2 continues to drop below 15% O_2 and CO_2 values continue to rise >6%, additional benefits are seen, but these increments are often less than the initial moderate environment. This has positive implications for the commercial package design of fresh cut mangoes. They do not require very low O_2 environments to extend shelf-life. Moderate atmospheres can be accomplished with clamshell packaging but is often inconsistent. The package relies on the tightness of fit and venting to move air, which is inherently unstable but is often used commercially without knowing the atmosphere is being modified. It can also be accomplished easily in bag applications through combinations of breathable films with micro-perforations. Tray applications with lidded film would need to target high residual O_2, or be combined with a breathable liner, to ensure high CO_2 environments do not develop, causing texture loss and off flavors and aromas.



Respiration rate results, Qfresh. RR tested monthly while mango was in season. We focused on easily findable varieties and those that were most discussed in literature (Ataulfo/Kent/Tommy Atkins). Respiration was tested in *slices* only, as this was the primary commercial product on the market.

	Aggregate Respiration Rates (mL O2/kg/kr)	
Mango and Month	**36F**	**42F**
Ataulfo		
March	6.6	11.4
April	7.0	12.1
May	8.5	13.5
June	8.1	13.4
Kent		
Jan	5.1	8.2
Feb	5.3	8.9
March	4.6	8.3
Tommy Atkins		
March	6.3	10.1
April	6.2	12.6
May	7.6	12.2
June	8.1	13.5

These values can be used for package design work, depending on the expected cold chain and target residual O_2 in the package. Qfresh advises using a RR of 5 to 7 for Kent, 8 to 12 for Ataulfo and 6.5 to 11 for Tommy Atkins for commercial packaging. Tracking of residual O_2/CO_2 inside commercialized packaging throughout shelf-life can further improve these recommendations for commercial processors. The package can be changed simply based on results.

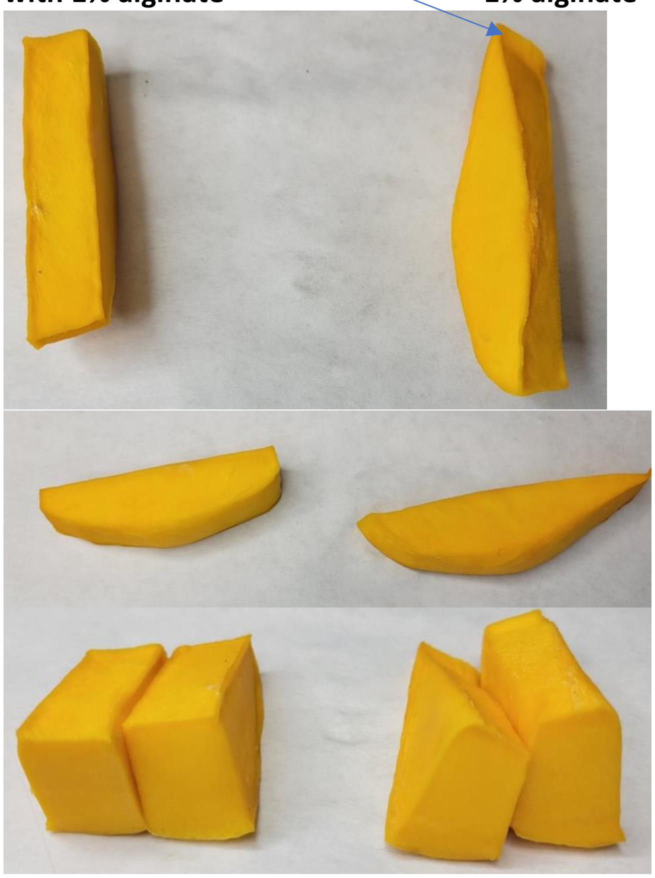
Interesting result to guide future work:

Sliced Kent mango leftover from a test was left at ambient temperature (68F) and ~70% RH for 2 days (accidentally). The treatments left out included:

- 5% w/v ascorbic acid and 2% w/v Cacl2 coated with 1% w/v alginate
- Fresh cut mango coated with 1% w/v alginate.

The results were fascinating, as the mango had not lost texture/aroma/flavor and was not dried out. The alginate coating locked the mango cut juices to the surface of the mango, giving it a sheen and almost candied like appearance. Ascorbic acid with CaCL2 had *lost* texture compared with the alginate coating by itself. It did seem to decrease a slight orange/browning effect. But both were entirely edible, juicy, with typical mango flavor and aroma 2 days later. The coating seemed to be simply locking the natural mango response to the cut surfaces. Edge shaving of the mango decreases browning, this has been shown in multiple studies.

5% w/v Ascorbic with 2% CaCl2(w/v) with 1% alginate **1% alginate**



Microbial effects:

- Depth and extent of surface scars and pitting influences microbial growth.
    - Not only does the mango need to work harder when there is mechanical damage, this also breaks the surface and releases everything bacteria needs to grow
        - Increased respiration rate
        - Increased senescence rate
        - Sugars, enzymes, substrate all mix for microbial growth
    - Increased micro growth in damage sites has been seen on many similar fresh cut items, such as sliced apples, fresh cut jicama, fresh cut carrots amongst others.
    - Low pH and high sugar are both known to select for yeast growth in food products.
        - Mango has both a low pH and high sugar, making yeasts the most likely endpoint indicator for microbial growth. This growth is delayed in mango, typically only showing after 16 days post cutting.
        - When feeding on sugars, the byproducts from yeast growth are ethanol and carbon dioxide. High CO_2 found in the packages may be due to both mango respiration and yeast growth.
        - While there are yeasts that can ferment sugars in the absence of oxygen, in most cases they require oxygen for growth.
        - Therefore, one of the most effective ways to control yeast growth in mango is by starving them of oxygen. This can be accomplished several ways, some of which are more powerful than others:

- Ways to control yeast growth:
    - **Gas flush**: A gas flush is often used in fresh cut items which have a primary defect of discoloration/browning/pinking reactions *early* in shelf-life. It is especially powerful in items such as fresh cut apples and chopped head lettuces due to starving the enzymes (PPO/PAL) of the oxygen required for the reaction to proceed.
        - Every fresh cut item has a different anaerobic compensation point and a different tolerance to both low O_2 and high O_2 environments.
            - There is often a delicate balance of the correct residual O_2 environment to stop browning reactions, keep the product out of anaerobic fermentation, and prolong shelf-life. This band of residual O_2 can be exacerbated due to temperature abuse.
    - Low residual O_2 target (~3% O_2):
        - This is accomplished by matching the respiration rate of the product to the total package OTR.
        - In testing performed by Qfresh Lab browning reactions were more related to incomplete peeling and subdermal layer removal
            - Very low O_2 values is NOT recommended for fresh cut mangoes. The negative effects of high CO_2, anaerobic fermentation, and

difficulty of achieving through commercial packaging make this a higher risk than reward. This is especially true due to the mode of action of browning in fresh cut mango being tied more to peel and subdermal layer removal than low O_2 environments.

- Yeast growth and the O_2 level mango can tolerate are at odds with each other. We would recommend a cleaner process with microbial reducers in the process and choose a moderate CO_2 level of 5-10% to extend shelf-life.

Bacterial growth mode of action:

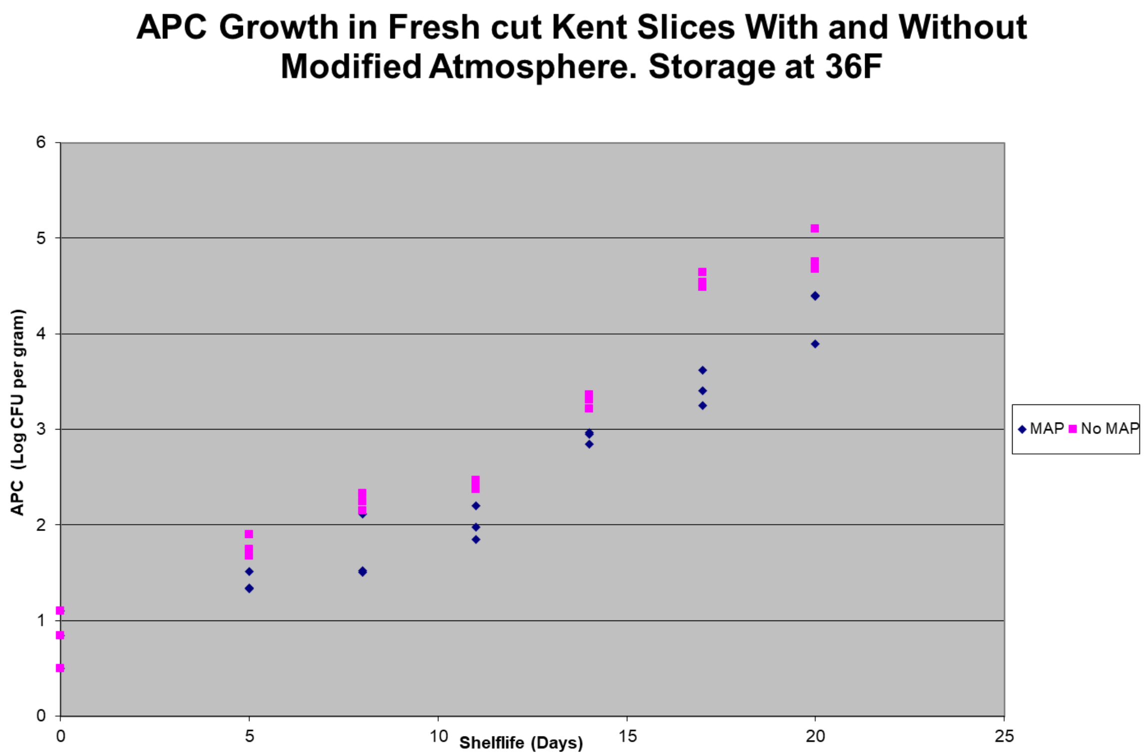
Repeatedly, in mangoes kept after 14 or so days, the mangoes which were not completely peeled with subdermal removal would develop a water soak like appearance, which progressed very rapidly causing surface level browning when the package is opened. This is *believed* to be chill injury setting in and is a dose dependent response. The temperature, along with the time at that temperature, dictated the level of chill injury. These chill injured mangoes would spill their internal contents, causing very rapid bacterial growth. It is shocking how fast the bacteria grows once chill injury/water soaking infects fresh cut mango. When the internal structures rupture, the brix was about 0.8 units higher, and the entire mango had a water-soaked appearance. This would often rapidly turn to microbial breakdown, mainly in the form of small white spots.

Bacterial growth curves are something a commercial processor should understand and test in their process. Every process is different, with different storage and packaging used after the day of processing. The most important value to track is the final APC or Y/M of the fresh cut mango, *inside* the final package. This is the final stage of the process, and should have the most bacteria post cutting, unless a processing aid is used on the fresh cut mango to reduce spoilage organisms in the final process. It is important from the time of packing to reduce the micro below a certain threshold (which will vary by processor, mango type, time of year, maturity, prep practices, temperatures, etc.). There are far too many factors to consider.

With this understanding, there will be a commercially successful initial value for a specification to prevent microbial growth within the shelf-life chosen. For example, if APC or Y/M consistently increase to the point of visible colonies at a certain date, this date can be extended if either the initial microbial load is LOWERED in the process, or there is something (such as anti-microbial treatment or modified atmosphere packaging) reducing the microbial load during shelf-life. Some produce items require very low initial APC (sliced apples <100cfu/g, fresh cut jicama <500 cfu/g, lettuces <4 log). There is a wide range of acceptability by product type, but this is a test a commercial processor should conduct regularly and understand the downstream ramifications, and to guide improvements to the process.

The outside of the whole mango should be washed prior to processing to reduce the spoilage bacteria on the outside surface which can cross-contaminate during the pitting and peeling processes. This has been seen in sliced apple processing, where they have implemented robust washing of the whole apples, with agitation, to reduce dirt and microbes prior to slicing. Fresh mango, due to its low pH, does not necessarily require a washing step post fresh-cut. This has been shown in literature to be either positive or negative for the shelf-life outcome. From our testing, it would wash off the natural mango healing and juices which have been shown repeatedly to extend shelf-life. So, if a post-cut wash is used, it would most likely need to go hand in hand with another treatment to extend shelf-life (anti-microbial/anti-browning).

Fresh-cut Kent mango bacterial growth curve, with and without modified atmosphere. No atmosphere was 20.9% O_2 and 0.1% CO_2. The other was in a modified atmosphere packaging reaching ~12% O_2 with 8-10% CO_2.



QFresh Test: Gas flushing (N_2) with low and high residual O_2 in package targets
Mango: Kent and Ataulfo
Storage: mangoes picked up storage at 52F, stored cold (39F) until pack next day.
Product of: Peru

Mangoes:
Kent- Product of Peru, Packed Jan 12, 8 count. Exporter: Camposol S.A.
Ataulfo- Product of Mexico. Packed Jan 14th, Organic, Agrofrutas del istmo

Experimental design:

10 bags of each treatment below were packed. Targeting 320 grams. Product was stored at 36F for the duration of study.

Mango prep: mangoes were removed from refrigeration in batches, pitted using handheld pitter, followed by peel removal with peelers. cheeks were sliced, (4 cuts for Kent, 3 for Ataulfo). Product stored in stainless bowls with lids on ice post cutting until packing.

Sanitation: a water bath with 80ppm PAA was prepped, and all slicing and peeling equipment was sanitized every 5 mangoes. Gloves were sanitized every 5 mangoes as well.

Executive summary:
- Peel browning was not able to be stopped with gas flushing with N_2 gas or very low O_2 environments
- Water soaking mode of action seems tied to incomplete peeling
    - Low oxygen environments resulted in MORE water soaking, seems to be tied to transpiration being obstructed when fresh cut.

Kent mangoes (31 mangoes)
Ataulfo (50 mangoes)

Packaging:
Bag used: 8x10" LLDPE 3 mil, OTR 186cc/pckg/day

Perforations:
- 0.20um needle for micro-perforations (average perforation size of 91.6, measured).
- 20ga (5um) needle for *macro*-perforations

Testing Protocol (performed on both Kent and Ataulfo mangoes):

Test 1: Control, macro-perforated package targeting no change in residual O_2 or CO_2. 10 macro perforations using a 20ga needle were added to each package. Test labels: KM for Kent and AM for Ataulfo)
Test 2: K- Gas flushed with a target O_2 of 6-9%, with a final residual O_2 target of 3% bag label: (KGF3,AGF3)
Test 3: K-gas flush target of 6-9% O_2 with a residual O_2 target of 12% O_2 bag label: (KGF12, AGF12)
Test 4: K No gas flush, with a residual O_2 target of 3%. bag label: (KnoGF3, AnoGF3)
Test5: K- no gas flush with a residual O_2 target of 12%. bag label: (KnoGF12, AnoGF12)

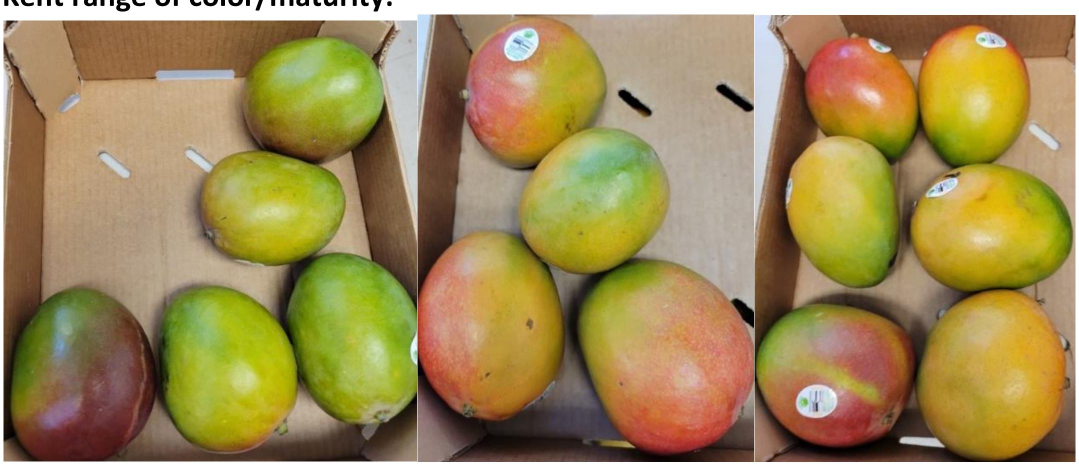
Mango prep-

- To target 12% residual O_2 at equilibrium in both mangoes, used 7 perforations targeting 100 microns.
- To target 3% residual O_2, used 2 perforations targeting 100 microns

Kent and Ataulfo whole mango results:

whole mango Pack date	mango count	Mango	Mango color	Brix	pH	pressure side 1 (PSI)	pressure side 2 (PSI)	L*	a*	b*	Notes
12-Jan	6	Kent	range 2 to 4, most 3	15.0	3.7	7.6	7.4	60.5	14.6	62.2	Light lenticel discoloration on <10%
14-Jan	12	Ataulfo	range 1 to 4, most 2	14.8	3.2	7.1	7.5	65.7	12.1	58.6	medium lenticel discoloration on up to 40% of fruit

Kent range of color/maturity:



Kent range of maturity on day of cut/pack:

Ataulfo range of maturity: 5 mangoes with internal pithiness, heavy lenticel discoloration on these 5. More prevalent on under mature mango.

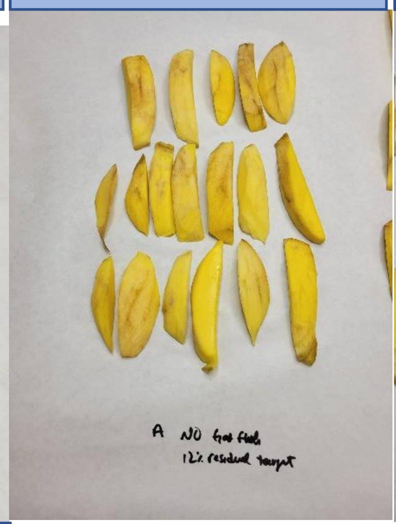
Kent Results (day 6):

Low gas flush with N2, and low residual O_2 in the package were unable to stop peel side browning. Regardless of treatment, browning was present in all samples. Gas flushing, and a low residual O_2 (3%) helped but could not completely prevent browning.

Ataulfo Results (day 6):

No treatment, no change in O2- heavy peel side browning when subdermal layer not removed

No gas flush, 12% O2. A little better, but still heavy browning



N2 gas flush, 12% O2. Product had much less peel side browning, but still browned

No gas flush, 3% O2 target. Sample browning was much improved. But the peel still needs complete removal to prevent browning reactions

Gas flush with low O2 target- A little MORE browning than the non-gas flush sample.

The no gas flush samples having less browning was intriguing, and led to several more tests to elucidate the mode of action. Every product we've worked with prior has LESS discoloration when using a gas flush. The hypothesis is the incomplete peel process caused an INCREASED wound response and reduce the transpiration, leading to ill effects

Day 6 flesh side pics:

Control

No gas flush, 12% O2.

gas flush, 12% O2

No gas flush, 3% O2 target

Gas Flush 3% O2 target

On the flesh side, an increase in water soaking was noticed in the gas flushed samples, which was another intriguing result. The literature never attributed water soak to a mode of action. These results point towards reduced transpiration on the peel side due to the poor peel causing increased water soak due to compromised RR and transpiration

Kent- Control Peel and flesh side


Kent no gas flush 12% O2


Kent Gas flush 12% O_2.


Kent no gas flush 3% O_2

Kent Gas flush, 3% O_2 target

These results sent Qfresh Labs on a fervent literature search, combined with testing to elucidate the methods of water soaking, browning, peel/subdermal removal. Gas flushing works on a host of products, from cut cabbages, romaines and icebergs, sliced apples, cut jicama, cut carrots, etc. Water soaking never occurs in these products as a result. It seemed like the excessive peel left over reduced transpiration on the peel side, resulting in increased water soaking, browning, and eventually product breakdown

Shelf-life Data tables:

Mango type, bag treatment	Average of CO2	Average of Brix	Average of pH	Average of Average L*	Average of Average a*	Average of Average b*	Average of Product score (1-10)
ataulfo							
Gas flush low and high residual							
Control- macro perforated							
6		15.6	3.1	78.3	5.4	52.8	2.5
14	1.1	14.0	3.2	77.8	4.5	49.4	3.5
gas flush high residual							
6		13.1	3.0	81.5	5.1	46.1	4.5
14	5.4	14.1	3.0	77.3	1.0	36.5	4.0
gas flush low residual							
6		14.7	3.2	76.8	4.6	50.3	3.0
14	10.9	15.1	3.2	72.6	4.8	54.2	3.5
no gas flush high residual							
6		14.0	3.2	78.7	6.7	60.5	6.0
14	5.2	13.4	3.1	74.4	6.1	55.8	4.0
no gas flush low residual							
6		13.6	3.1	77.7	5.0	53.7	4.0
14	10.2	14.1	3.4	74.7	7.1	56.6	3.5
Plastic clamshell (microgreen)							
14	2.5	13.3	3.3	80.9	1.5	42.7	3.0
kent							
Gas flush low and high residual							
Control- macro perforated							
6		14.3	4.4	74.1	6.1	48.2	3.0
12	1.0	14.9	3.9	70.4	9.3	56.0	1.0
gas flush high residual							
6		13.6	4.9	73.3	8.0	47.0	4.0
12	3.9	13.5	3.9	69.1	7.4	52.6	2.5
gas flush low residual							
6		14.4	4.7	73.6	8.8	52.9	3.5
12	4.4	13.2	4.1	74.4	4.0	48.2	4.0
no gas flush high residual							
6		16.2	3.9	76.3	7.7	55.2	8.0
12	3.4	15.2	3.9	69.4	9.2	56.9	1.0
no gas flush low residual							
6		16.3	4.3	73.3	9.0	56.2	5.5
12	4.2	11.5	3.9	73.5	3.7	47.2	7.0

QFresh Test: Chill injury/lenticel/fiber pore development changes test on Tommy and Kent

Introduction: Based on various shelf-life results, and an extended literature review, we had an idea to elucidate the mode of action for chilling injury, lenticel development, fibers and pore browning and internal fresh cut mango condition.

Hypothesis: mango chilling injury is a result of a dose dependent time/temperature combination of temperatures too low for proper respiration and transpiration. When respiration/transpiration are compromised, the mango must either switch to anaerobic respiration, or open its' lenticels, degrade fibers and open pores in the flesh to increase respiration and transpiration. This opening causes browning and texture loss.

Executive Summary:

- Transpiration and respiration occur on the peel side of the mango. During processing, if this is compromised such as with peel or subdermal layers remaining, this increases the level of water soaking, fleshy material browning and lenticel browning
- The same effect was found on both Tommy and Kent mangoes, highlighting the importance of the following:
  - Clean knife cuts
  - Subdermal removal
  - Stem side fibers and pore removal
  - Flesh removal of oversized pores and fibers

Discussion: Based on the evaluation of the lenticel color changes on the outside peel of the mango, in combination with the internal flesh fiber/pore development; we tested both Tommy and Kent mangoes to better understand how internal color changes occur and begin to break down. Not removing the peel and subdermal layers entirely were repeatedly shown to cause a whole host of negative effects in shelf-life, such as:

- Texture loss
- Browning
- Water soaking

During fresh cut processing, the following consistently provided mangoes without ANY browning:

- A moderate residual modified atmosphere O_2 between 5 and 15%.
- A moderate residual CO_2 between 2 and 10%
- Complete removal of the outer peel
  - A clean cut with a sharp knife was the best way to remove the peel
  - A handheld peeler removed most of the peel and prevented browning, but this method does NOT remove the subdermal layer.
    - The subdermal layer causes excessive water soaking
    - The subdermal layer has enlarged lenticels still present, primarily on the stem end, increasing the likelihood of browning

- Removal of the subdermal layer is also vital to prevent browning

The following treatments were prepared (all were bagged in 8x10" LLDPE 3 mil bags, with micro-perforations added to target minimal residual gas changes in the bags, but maintain RH:
2 whole mangos, as is
2 whole mangos, peeled with a clean knife cut and subdermal removal and packed
2 whole mangos, peeler peeled, peel was complete. Less subdermal removal than knife
2 halved mango, 1 half was left peel on, and the other half used a clean knife cut with subdermal removal
2 halved mango, 1 half was left peel on, and the other half used a peeler to remove all the peel but without subdermal peel removal

Product was stored at 36F for 9 days, and all was evaluated. The purpose of the study was to understand how the product breaks down based on complete removal of peel and see if the mode of action for chill injury and later fresh cut shelf-life breakdown could be discovered

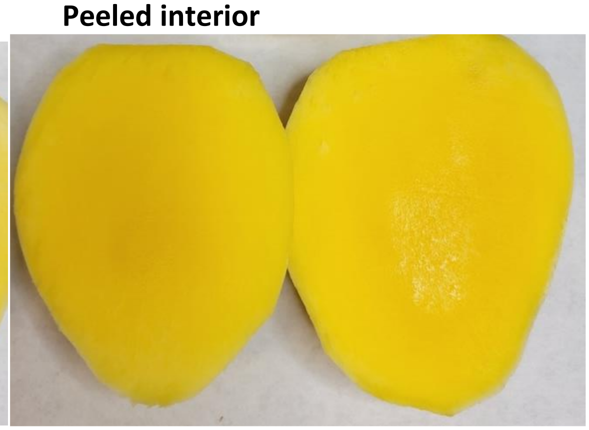
Tommy Atkins Results:

Whole mango results- the outer peel lenticels had browned significantly. After halving the under-mature mango, the lenticels were porous and opened (see through), had not browned but created channels through the flesh to the fibers. After halving the OVER-mature mango, the outer edges developed heavy water soaking, the lenticels opened significantly larger and browned.

Comparing clean knife cut vs peeler peeled WHOLE mangoes, the fibers on the peeled mangoes were browner. Fibers on the clean cut were not browning. The clean cut had NO large pores/fibers visible and no browning when cut. The peeled whole mango, once cut, had some pores on the flesh and they were opening but not browning. The peeling helped to stop any browning, but they are opening. Peeling a whole mango was enough to stop excessive browning, water soaking, and texture loss.

Clean knife cut whole mango **Peeled whole mango**

Knife cut interior **Peeled interior**



On halved mango clean knife cut, the halved mango without peel had less pit side drying than the peeler peeled halved with peel. The mangoes that were halved, with peel on, developed heavy browning of the pores (also enlarged) and fibers also opening of the lenticels. The mangoes that were knife cut and halved had no large pores or fibers present, no water soak.

Picture: Clean knife cut, with and without peel on. Notice the level of water soaking on the peel sample (right), along with the size and coloring differences of the pores on the outer edges.

Side view of knife cut, halved mango, with and without peel and the effects. Notice the heavy levels of browning (bottom, with peel on). Pores enlarged, browned and breakdown effects occurred on the mango.

We didn't know what to call these. We couldn't find any pictures or descriptions in our searches. When we reference fiber/pore/lenticel browning on the ***flesh***, this is what we are referring to. Also when we reference sizing of them, we are referring specifically to the ones on the flesh, which open large channels. These seem to be the cause of water soaking effects in most cases

The samples that had the peel removed with a peeler had browning present on the stem side ends only, and some were channels were opening and porous. The unpeeled halved mangoes, regardless of cut, showed browning, large pores, and some water soaking

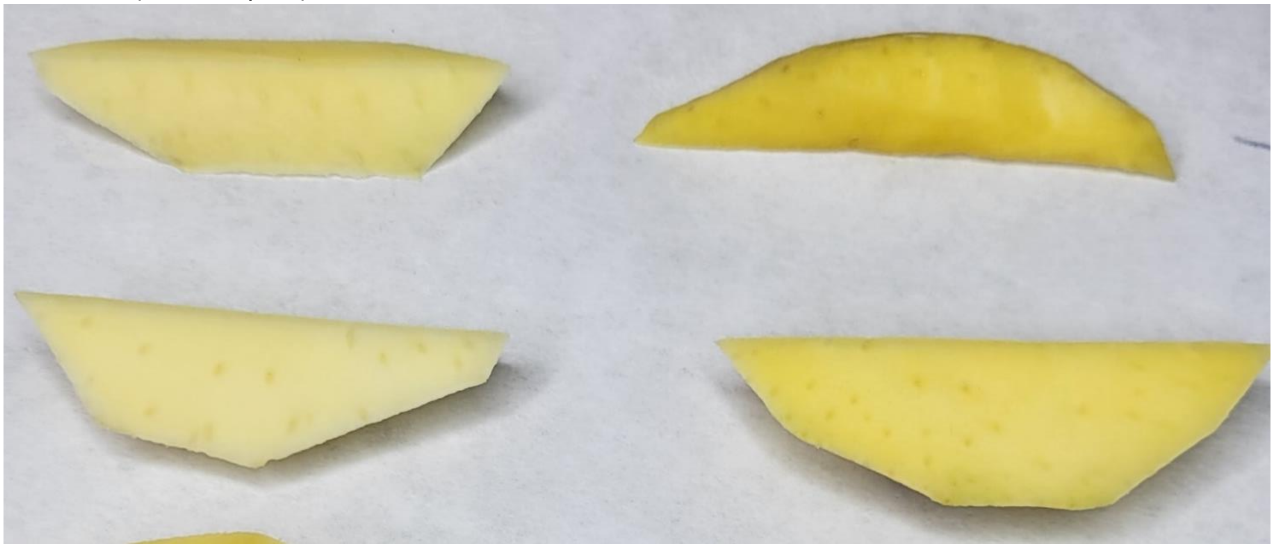
Picture:

Halved, with and without peel, peeler to remove. Note the difference in water soak, brown and sizing of the flesh side fibers/pores

Cross slices of the Tommy treatments and flesh fiber/pore changes:

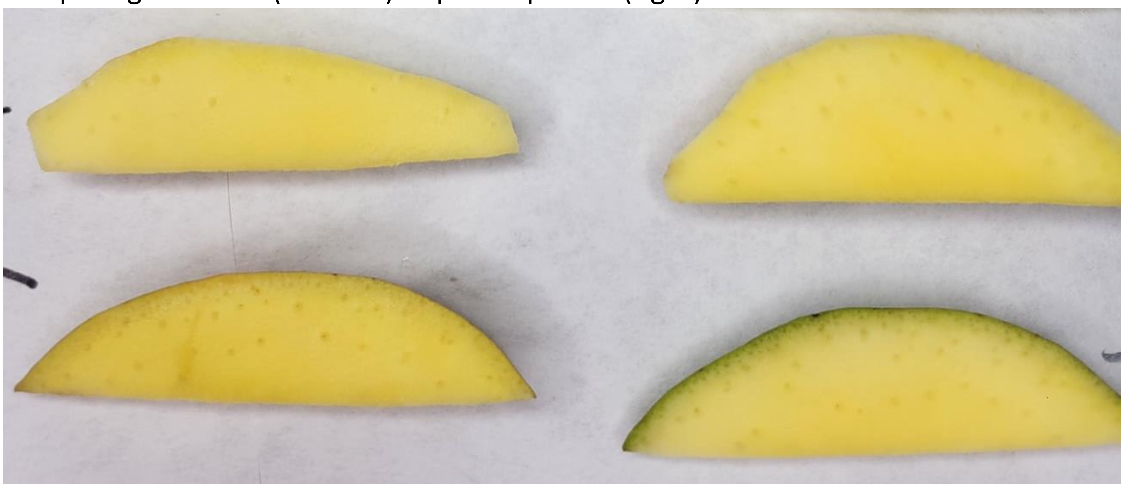
Whole mango, knife peeled (left) **Whole mango, peeler peeled (right)**

Notice the size difference of the fibers/lenticels. The clean knife peel helped to reduce the size and color (left samples)



Halved samples: Knife cut (left) **Halved samples: Peeler peeled (right)**

Notice the fiber/pore sizing and coloring on the knife cut samples were much better (left pics). Any sample with peel on developed very large holes and browning. Showing the effect of low temperatures, and how the peel effects this result. Subdermal layer removal also helps when comparing the knife (left side) vs peeler peeled (right)



Key Takeaways:

The mango appears to opening flesh fibers/lenticels/channels based on how much of the peel side respiration/transpiration is compromised. The more peel is removed, the smaller these pores are, the less browning is present, the less water soak as well. The more subdermal layer is removed, the smaller the flesh pores less browning and less water soak as well.

Kent Results:

Kent:

Whole mango results:

Notice the enlarged flesh side fiber and pores color changes and water soaking levels.

Knife peeled whole mango

Knife peeled whole mango internal: Note the lack of water soaking, no prominent fibers/pores. Excellent internal condition. A complete and clean peeling with subdermal layer removal prevents water soak, browning and enlarged flesh fibers and pores

Peeler peeled whole mango: Note the browning levels even with a complete peel

Peeler peeled Kent Internal condition: water soaked, large flesh fiber and enlarged pores

Knife cut and halved mango (1 side peel on, other peel off):
Notice the difference in water soaking, size and number of fibers/pores on flesh. Complete peel and subdermal layer removal stops water soaking and reduces flesh browning, but still requires a topping due to the concentration of fibers/pores on the stem side of the mango. Once these areas are removed, Kent mangos are extremely resistant to browning.

Peeler peeled and halved mango (1 side with peel on, other peel off):
Kent mangoes are especially prone to water soaking and browning. Simply using a peeler to remove the peel is not enough to stop flesh browning and water soaking completely. Leaving the whole peel on is detrimental, but also not removing the subdermal layer causes a pretty similar looking effect on Kent mangoes.

Cross section slices taken from each treatment:

Whole mango Kent cross section. Note the enlarged flesh pores. With the peel on, and cold temperatures, the mango cannot respire and transpire properly.

Clean Knife cuts, whole mango (left)
Anywhere the peel and subdermal were Not completely removed there is localized water soak

Peeler peeled, whole mango (right)
Notice the enlarged flesh side fiber/lenticel More water soaking than clean knife cut

Knife cut, halved mango, w/wo peel.
Note the water soak and flesh enlarged pores with browning

Peeler peeled, halved mango, w/wo peel. Note the enlarged pores with the peel on. The flesh pores were also enlarged compared to the knife cut

QFresh Test: Browning can be prevented through proper peeling, subdermal removal and clean cuts.

Mango: Kent

Introduction: Clean knife cuts with subdermal removal vs. peeler peeling without complete subdermal removal can stop browning reactions. We then took these 2 treatments and packed them in either no atmosphere, modified atmosphere packaging at moderate CO_2 levels (5-10%) or in a vacuum application.

Executive summary:

- Clean knife cuts reduced water soaking
- Modified atmosphere with gas flush reduced water soaking and texture loses
- A complete removal of the peel and subdermal layers are required to maintain better texture, less water soaking, and less browning

Experimental design:

5 bags of each treatment below were packed. Targeting 280-300 grams. Product stored at 36F for duration of study.

Mango prep: mangoes were pre-washed in 80ppm PAA. Mangos removed from refrigeration in batches in 2 different treatments:

1. Pitted using handheld pitter, followed by top and tail, with peel removal with peelers. cheeks were sliced, (4 cuts for Kent). Product stored in stainless bowls with lids on ice post cutting until packing.
2. Clean cut with knife only, ends top and tailed, product peeled with sharp knife and cut (4 cuts). Product stored in stainless bowls with lids on ice post cutting until packing

Sanitation: a water bath with 80ppm PAA was prepped, and all slicing and peeling equipment was sanitized every 5 mangoes. Whole mangoes contact time 90s in 80ppm PAA, air dried for at least 2 minutes. Gloves were sanitized every 5 mangoes as well.

Kent mangoes (30 mangoes)

Packaging:
Bag used: 8x10" LLDPE 3 mil, OTR 186cc/pckg/day
Perforations:

- 0.20um needle for micro-perforations (average perforation size of 91.6, measured).
- 20ga (5um) needle for *macro*-perforations

Testing Protocol (performed on Kent):

Cut method	Bag packaging	Treatment	Our label	Additional notes
Pitted and peeler peeled	8x10” 3 mil bags	Vacuum pack	DV	No perfs, 3 mil LLDPE breathable film, vacuumed down to no air
Pitted and peeler peeled	8x10” 3 mil bags	Macro-perf (control)	DM	10 macro-perfs added @20ga
Pitted and peeler peeled	8x10” 3 mil bag	Gas flush with low O2 target	DGF	7 perfs @ 0.2um, gas flush 10% O_2, 10% residual O_2 target
Knife cut clean	8x10” 3 mil bag	Vacuum pack	CV	No perfs, 3 mil LLDPE, vacuumed down to no air
Knife cut clean	8x10” 3 mil bag	Macro-perf (control)	CM	10 perfs added @20ga
Knife cut clean	8x10” 3 mil bag	Gas flush with low O_2 target	CGF	7 perfs @ 0.2um, gas flush 10%, 10% residual O2 target

Package prep-

- To target 10 to 12% residual O_2, used 7 perforations targeting 100 microns.

Whole Kent range of color/maturity:

Raw mango data:

Raw mango pack date	Importer	whole mango Pack date	mango count	Mango	Mango color	Brix	pH	pressure side 1 (PSI)	pressure side 2 (PSI)	L*	a*	b*	Notes
6-Jan	globalex inc- agrocosta peru	14-Feb	7	Kent	range 3 to 4, most 3	15.75	4.39	8.5	8.1	73.4	8.83	56.1	light peel side lenticel damage

Kent slices day 9 evaluation:

A full vacuumed package test in a bag was performed to test for anaerobic tolerance and outcomes from that. The reason we chose a vacuum was we wanted to ensure the result was strictly due to a low O_2/high CO_2 environment and no effects of the samples reaching the anaerobic compensation at different dates (based on respiration/package mismatches/etc). Also, we have tested produce items in a complete vacuum with breathable films and shockingly some produce can withstand this low environment with minimal off odors/flavors and no product breakdown for up to 14 days. Produce items with great ability to resist anaerobic off odors/flavors/metabolism in breathable vacuumed films include peeled yams, shredded Brussels, shaved carrots, diced fennel, sliced apples, shredded cabbage, cleaned and husked corn, diced onion. Other items have been shown to have VERY poor outcomes in a vacuum seal with breathable film, such as broccoli florets, cauliflower rice, snow peas, shredded beets.

In this test with both knife cut and peeled mango, the vacuumed down samples were starting to ferment and smelled of alcohol by day 7. They had such a tight vacuum; the oxygen reader was only able to run for about 5 seconds before it read clogged, and the intake went to 0 ml/min. It ran out of air to pull, but the values showed 0.5 to 3% O_2 with 20 to 22% CO_2. That is the highest sustained CO2 tested thus far. The vacuumed samples had a very water-soaked effect, all the way through, making them almost translucent. The aroma was anaerobic (ethanol off odors) and did not tolerate this environment well.

The samples which were clean cut with a knife and gas flushing performed the best, but still lost texture. Anywhere excess peel was noted with fibers, the area under had a tiny water soak effect. They maintained the highest texture of the tests and were considered a borderline texture failure by day 9. A complete peeling is vital for stopping water soaking and browning effects. It seems to be due to the product not being able to transpire properly on the peel side of the mango. The 2nd best result was with peeler peeled samples also in modified atmosphere. Texture loss only occurred on the overmature mangoes at this stage, the flavor and aroma were like the knife cut gas flushed. Neither of these samples browned during the evaluations. Moderate CO_2 effects (7 to 10%) helped a lot in early evaluations.

Peculiar result:

During evaluations, simply leaving the samples exposed to air for 20 to 30 minutes during evaluations and tastings caused the samples in the MACRO-perforated packages to brown rapidly. These packages had 20.5% O_2 and 1% CO_2 in the package. These browning sites started anywhere the mango was damaged, but eventually caused a localized browning effect on samples which previously had none. Anywhere the pit side of the mango was left behind also had a small increase in localized browning effects.

Qfresh has conducted similar tests in sliced apples, but when you slice an apple, it browns in <20 minutes without anti-browning solutions (even in very low O_2 environments). The same mode of action happens across apples, but they have different tolerances to how long they are exposed to high O_2 before browning.

It seems after packaging, and exposing to air, if the mango dries out excessively it develops rapid browning later in shelf-life. These browning effects were not present in the first few days post cutting in our studies. It also happens very quickly in air (<20 minutes). Even in packages which had 20 large holes, and no residual oxygen, samples with browning would get localized browning in damage sites rapidly when exposed to air. It seems it is caused/exacerbated once the RH decreases rapidly, drying the mango out quickly and maybe breaking surfaces open. It is seen rapidly in damaged areas. See pics below:

Day 9 evaluations pictures: Top row were all done with a clean knife cut, and in a macro-perforated package, a modified atmosphere package gas flushed to 10% O_2 with a O_2 of 10%. And then vacuumed samples, which came out to very low O_2 (0.5% to 3%) and very high CO_2 (20+%) and smelled fermented. Top middle is the one we expected to look best, and its far better, but still losing texture. But that samples looks like it's going make 14 days I think in terms of flavor, odor, color, but the texture will most likely progress. Even the peeler peeled samples in the gas flush were the 2nd best and much better than rest (bottom in the middle) on picture.

Knife cut Control- No change in residual O2

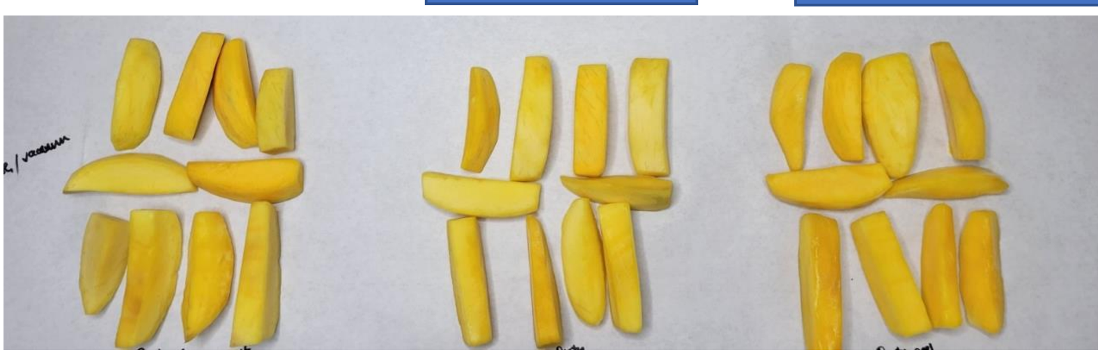
Knife cut Gas Flushed Low O2, moderate CO2

Knife cut Vacuumed. Looks fine, but heavy water soak and texture loss

Peeler peeled Control- no change in residual O2

Peeler peeled Gas flushed low O2, moderate CO2

Peeler peeled Vacuumed. Sample water soaked, loss of texture



Anywhere peel is left behind, without subdermal removal results in browning. Not modifying the atmosphere, at least moderately (15% O_2 /5% CO_2) results in excessive browning without other anti-browning solutions applied.

On day 14, the following effects were clearly seen consistently across packages:

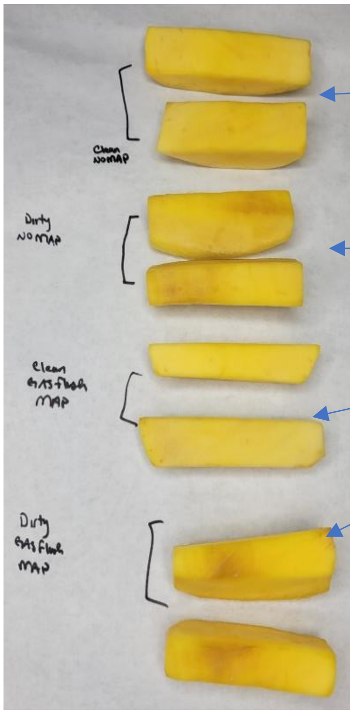
Modified atmosphere helps to lock in aromas better and if <10% CO_2, the texture is better. The slices are much whiter, with less browning. When exposed to air, they dried rapidly, showing underlying browning primarily from the fibers running through. The browning was not there on first open but within 5-10 minutes of exposure to ambient air and temperatures, the fibers showed rapid browning. This may be due to rapid drying out (packages-maintained RH between 95 and 100%)

Clean knife cuts reduced the amount of water soaking effect on the peel side as well. Modified atmosphere with gas flush reduced the water soaking, but the only way to get rid of it completely was to properly peel down below the subdermal sections, top and tail, and use modified atmosphere helped to control.

The cleanliness of the peel is VITAL for stopping browning reactions. We tested a host of anti-browning solutions and modified atmosphere with a gas flush doesn't stop the browning. Anti-browning solutions only slow, do not stop completely. The primary mechanisms for stopping discoloration in fruits/veg do not completely stop it on a sliced mango. Therefore, it is IMPERATIVE to peel completely, removing subdermal with exposed fibers/air channels.

A complete Vacuum flush wasn't even able to stop the browning reactions, as evidenced by the vacuum samples put up in this test as well. Even at very low O_2 there was still browning present.

Day 14 results:



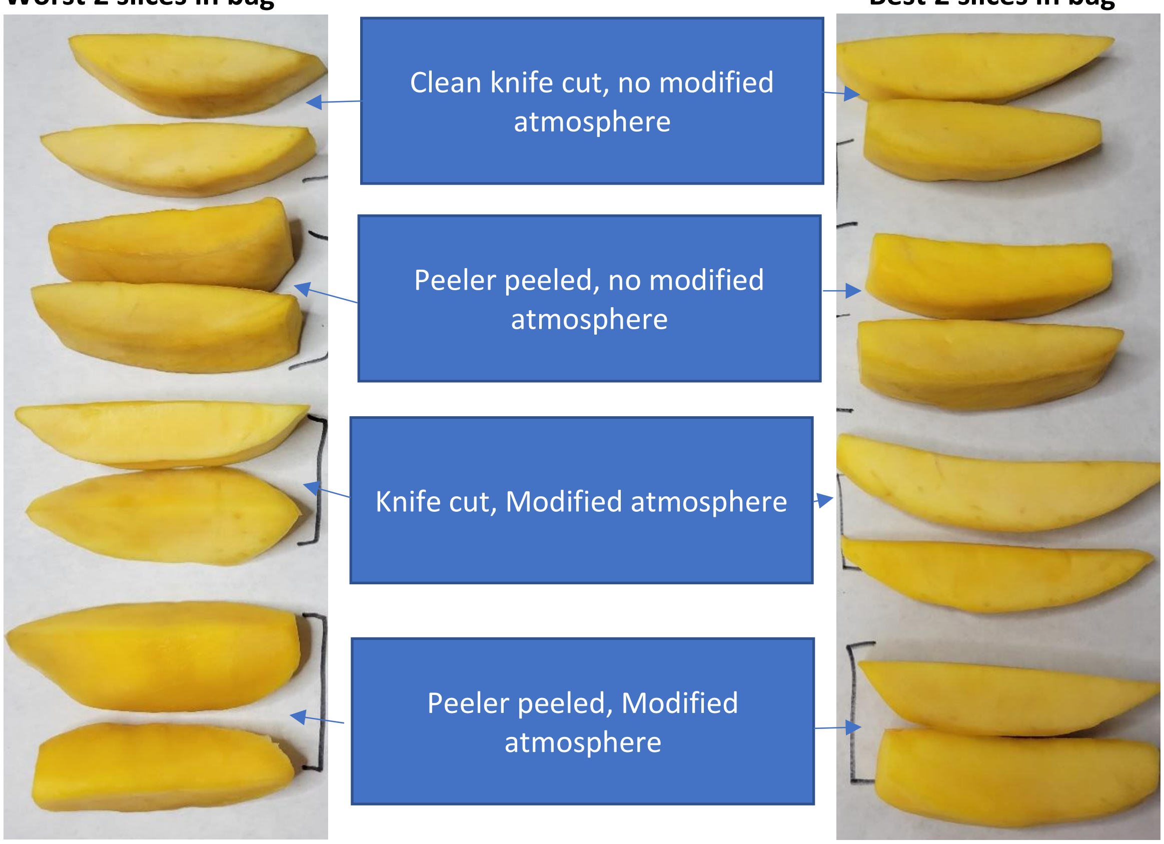
clean cuts *without* modified atmosphere. They have the 2nd least amount of browning, showing the importance and effectiveness of complete peeling on fresh cut mango shelf-life. They lost texture without modified atmosphere
Pitted and then peeled with a peeler, the subdermal layer was mainly intact, but the peeling was thorough and complete. These mangoes have heavy browning on all sides. A clean cut is required for stopping browning without anti-browning agents
Clean knife cut along *with MAP* and gas flush. These mangoes had no browning, maintained better texture, aroma and flavor than the other treatments
peeled completely***, subdermal layer intact***, with gas flush and low O_2. Low O_2 is not enough to prevent browning in mango if the peel is not completely removed along with the subdermal layer. The texture and aroma were better in these samples than the same treatment without modified atmosphere.

Day 19 results:

The mangoes which were peeler peeled well, but without subdermal removed, were significantly more yellow/brown. All treatments had lost their texture, so texture is still something to solve for. There was no microbial growth on any, but the water-soaked appearance had increased significantly in the *less* peeled mango. The mango pieces with subdermal intact had more of a waxy/sticky/translucent outer coat, with the internal water soaking increasing significantly. Dry pieces were the less mature slices, with texture loss but flavor was good, aroma still of faint fresh mango. Some of the well peeled mango still had some slight water soaking, but it looked like it was lagging by 3 or 4 days from the other treatments, meaning it looked better and had much less water soak, but would soak soon. This looks like a chilling injury related injury. Not sure how to solve for that commercially, but subdermal peeling delays this reaction by 4 to 5 days.

The flavor of the product in most treatments, even after 14 days with minimal processing was still good. Microbial growth had not risen to a point where visible mold is present. But the texture does decline, reducing the sensory of the product. Texture may be solvable, as in using an alginate coating that is specifically formulated not to thicken but to coat the mango. This would need to be formulated specifically for mango and kept consistent. If combined with an ascorbate + $CaCl_2$ blend, this will retain the color, texture and consistency.

Worst 2 slices in bag **Best 2 slices in bag**



Fresh Cut Mango Report

2022-2023

Shelf-life Table:

Mango type, bag treatment	Average O2	Average CO2	Average Brix	Average pH	Average L*	Average a*	Average b*	Average product score (1-10, 10 best)	Average water soaking %
kent									
Peeler peeled, macro-perforated									
Day 9	20.5	1.0	15.1	3.9	73.3	7.7	51.7	7.0	30%
Day 14	20.7	0.9	15.0	3.9	71.5	8.4	49.3	1.5	61%
Day 19	20.8	0.6						2.0	95%
clean knife cut, macro-perforated									
Day 9	20.5	0.9	14.9	3.9	72.7	8.0	44.8	7.5	8%
Day 14	20.8	1.0	13.6	4.0	74.4	7.4	45.6	2.5	9%
Day 19	20.7	0.7						3.0	80%
peeler peeled, gas flush, 10% O2 target									
Day 9	12.8	8.6	15.0	4.0	73.0	7.6	54.9	8.0	40%
Day 14	12.1	8.6	12.7	4.2	71.9	9.2	52.9	3.0	78%
Day 19	12.6	5.7						3.0	70%
clean knife cut, gas flush, 10% target O2 target low O2									
Day 9	12.2	7.0	14.4	4.1	75.4	8.6	52.0	9.0	0%
Day 14	12.1	6.9	14.1	4.0	75.6	5.9	43.8	5.8	0%
Day 19	13.4	4.0						4.5	5%
clean knife cut, vacuum seal									
Day 9	0.5	20.1	15.4	3.9	73.6	8.8	55.0	6.0	25%
Day 14	2.1	15.4	14.1	4.1	73.6	5.0	47.7	1.0	
peeler peeled, vacuum seal									
Day 9	3.0	22.8	14.1	4.4	69.8	9.6	59.2	3.0	70%
Day 14	9.8	9.5	14.1	3.9	69.9	6.3	51.1	1.0	

Alginate mango study:

Various treatments were put up and evaluated for modes of action of breakdown, texture improvements, browning improvements and microbial knock down effects. Some of these samples only had a handful of packages made and were tested based on some theories we had from literature.

Additional Info: Both Bags and vented clamshells were used in various studies. The vented clamshells change the modified atmosphere slightly, in relation to the bags where we aimed for a balanced O_2 (10 to 15%) in combination with a moderate CO_2 (5 to 10%) level.

Executive Summary:

- Fresh cut mango, which had food grade 99.9% purity CO_2 gas blown on the surface, and then packed into moderate modified atmospheres (10 to 15% O_2 and 5 to 10% CO_2) maintained textures/aromas/flavors without browning or developing water soaking through 14 days @36F storage. It also did not get microbial breakdown, whereas most of the other samples packed along with it did. The CO_2 gas dispersed the surface juices uniformly on the surface, none of it was blown off, and that was enough to improve the quality parameters across the board.
- Alginate coated samples (1 and 2% w/v) were able to maintain the flavor/aroma and texture of fresh cut mangoes without any microbial breakdown. The flavor and juiciness of the mango were impressive through 14 days of shelf-life. In some cases, and when combined with CaCL2 (2% w/v), it did cause some light browning. It added a gloss/sheen to the surface as well, and the alginate sloughed off. We used a thickening version on accident. A coating alginate should fare much better. It seems like the viscosity match is good to the natural juices of the mango but needs to be thinner for commercial purposes. It can't be dripping after application, and the tank must also be cleanable so the viscosity can't be too high. It would most likely need to be applied as a spray due to difficult processing to overcome.
- Ascorbic acid alone causes texture loss, in conjunction with CaCL2 there is a slight bitter flavor and had more microbial issues. It causes a uniform darker color of the mangoes and improves textures and stops browning in most cases. But it doesn't seem to be a good match with mango, other alternatives would need to be explored
- Moisture absorption pads increase water loss and hard surfaces and are not a good fit for fresh cut mango
- Ethylene absorption sachets performed like controls with no treatment, and are not effective on fresh cut mango
- A 60-degree brix solution was found to cause the aroma and flavor of the mango to disappear and caused excessive texture loss
- Modified atmosphere alone, if deployed correctly, continues to show very positive outcomes at moderate values. This makes package design easier and makes clamshells possible. They should be checked for fit, venting and have the residual O_2 /CO_2 checked inside them. A lot of time processors choose an inappropriate package because they don't realize the clamshell, they currently have *forms uncontrolled modified*

atmospheres. Relying on the vent pattern or lid to tub fit has far too much variability to consistently deliver a good result. Since fresh cut mango does not tolerate high CO_2 , the package should be evaluated for internal residual atmospheres.

Mango: Kent

Treatments:

Mango treatment	package
CO_2 gas, from a food grade gas cylinder was blown on the fresh cut mango surface, dispersing the juice of the fresh cut mango evenly	Vented clamshell and MAP bag
Alginate (1 and 2% w/v)	Vented Clamshell and MAP bag
Alginate (2% w/v) followed by CaCL2 (2%w/v)	Vented Clamshell and MAP bag
Ascorbic acid (5% w/v) with and without CaCL2 2% w/v	Vented Clamshell and MAP bag
No treatment with moisture absorption pad	Vented Clamshell and MAP bag
Control- no treatment	Vented Clamshell and Macro-perforated bag
Modified atmosphere, no treatment	MAP bag
Ethylene absorption sachets	Vented clamshell
60-degree brix solution (sucrose)	Vented clamshell with and without absorption pad

Vented clamshells- these were smaller, and we packed with 5 to 6 mango slices. The clamshells venting was small, and they achieved CO_2 atmospheres between 0.5 and 4.5% CO_2 . This is enough to improve some shelf-life outcomes.

Modified atmosphere bags: Packages were not gas flushed, and we targeted 10 to 15% O_2 along with 5-10% CO_2 . Previous studies showed large benefits with just moderate atmospheres, and we have seen repeatedly high CO_2 % cause texture loss and other issues.

Fresh Cut Mango Report 2022-2023

Raw mango data:

Importer	whole mango Pack date	mango count	Mango	Mango color	Brix	pH	pressure side 1 (PSI)	pressure side 2 (PSI)	L*	a*	b*	Notes
Asica farms S.A.C. Peru	24-Jan	7	kent	range 1 to 4, most 2 to 3	15.1	3.8	9.3	9.2	71.1	10.9	57.8	Overall pretty good quality

Day 9 results:
In bags:

Untreated, no modified atmosphere. This sample was a borderline pass on day 9, with water soaking, losing texture but not browning

In modified atmosphere without any treatments, the sample looked great, with no water soaking, no browning and just 2 slices losing slight texture. Muted aroma and

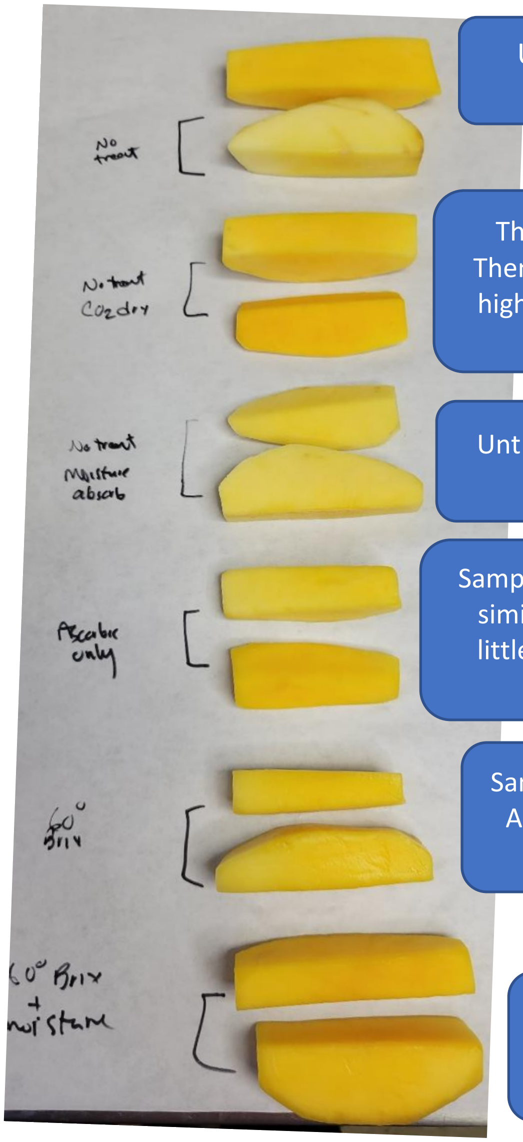
30% CO_2 flush in package caused water soaking, a muted flavor and aroma, and localized drying on the surfaces
Borderline pass on day 9

No MAP

MAP

Ascorbic plus CaCl2 in both modified and non-modified atmospheres were excellent. Both caused a more uniform coloring and a little darker in color. Texture was very good, and a little improved in the modified atmosphere. No water soak or browning in either sample

Shelf-life outcomes in trays (range of 1 to 5% CO_2)



Untreated samples were very dry, with browning not much aroma or flavor

These samples used CO_2 gas to disperse the surface juices post cutting. Then packed into trays. The samples were incredible. No browning, had the highest texture, aroma and flavor were excellent. The color uniformity was better. Just a stunning result

Untreated samples with moisture absorbing pads did not fair well. They dried out excessively, had almost no odors and flavors

Samples using 5% w/v ascorbic acid were a darker orange and losing texture, similar to the control untreated. The flavors and aromas were good with a little vitamin C/chemical flavor. However, textures were declining rapidly, requiring CaCL2 or another texture enhancer

Samples packed with a 60 degree brix solution were very soft, almost mushy. Aromas and flavors were of sugar, no mango flavor. They did not fair well, discontinued from testing

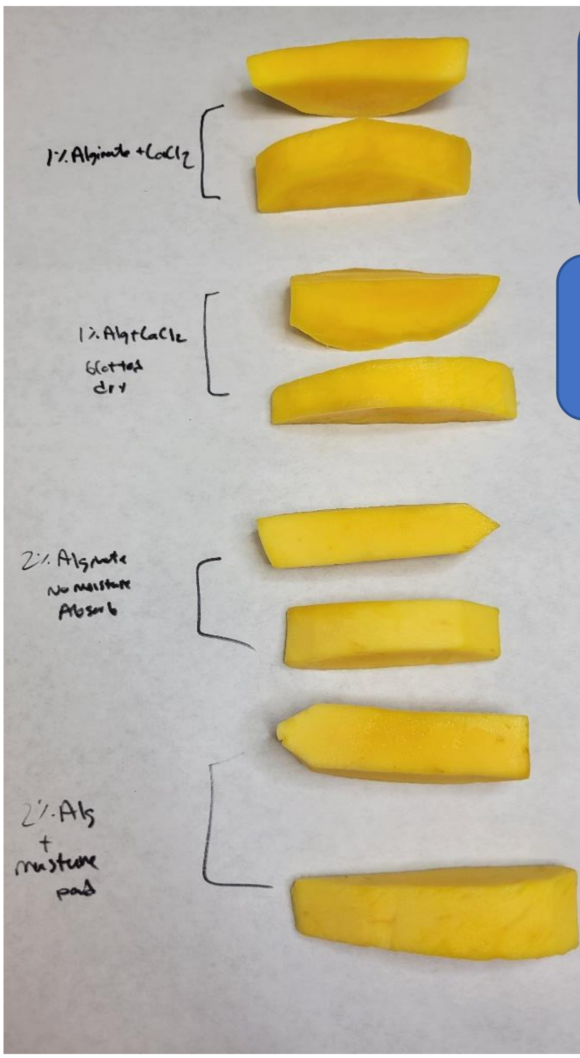
Samples packed the 60 degree brix solution and a moisture absorption pad did not fair better. There was excessive water soaking and texture loss. Discontinued from testing

In addition to these tests, we also tested ethylene absorbing pads. These had the same appearance as the control sample with no other treatment. Throughout testing, ethylene values in fresh cut have been very low. The ethylene absorption testing was discontinued.

Day 9 alginate results:

When we looked through the package at the samples, we thought they were going to be a gross failure. They looked like candied mangoes, the alginate coated the mangoes, putting off a gloss/sheen. There was also water soaking present when looked at through the package.

However, once opened, the results were stunning. The alginate coated the mango to lock in the aromas, flavors, textures with no browning or wetness. The surface of the mango is dry with a light sheen. We tested 1 and 2% alginate and used more of a thickening alginate than a coating. Even with this mistake, the mango performed excellent.



1% alginate with CaCL2 actually browned more. We applied alginate first, followed by CaCl2. There was also a slight bitter flavor imparted.

In samples prepared with 1% alginate followed by 2% CaCl2, blotting didn't help, as the texture on several slices were rock hard. Aromas were more muted

2% alginate without a moisture absorption pad performed the 2nd best in this evaluation. The texture was maintained gain with good flavor.

2% alginate with a moisture pad performed the best on this evaluation date. The texture was firm, with no browning or other ill effects. The alginate was still dripping off the mango at the time of pack, which makes sense why this worked better. We think if a better alginate coating was prepared, moisture in package should be fine without absorption

Day 14 results:

Drastic differences were seen on the day 14 evaluations. The mangoes used in this study were towards the end of the season, with some over mature.

The samples which were air*dried* using food grade CO_2 gas and immediately packed into modified atmospheres showed stunning results. The CO_2 gas dispersed the juices on the cut surfaces, dried the mango slightly, and high CO_2 had a bacteriostatic effect. The mango slices retained their texture like the day were packed, had no browning, and locked in flavors and aromas. The sliced mango was also juicy without any bacterial growth or sliminess. These samples simply used food grade CO_2 from a canister, with a small tube to disperse the fresh cut liquid over the cut mango and packed into modified atmosphere targeting 15% O_2 and 5% CO_2. The CO_2 gas alone improved every attribute of the cut mango without any microbial growth like seen in the control and ascorbic acid dips.

Controls and Ascorbic dips had yeast growth in the form of small white colonies, mainly in pitted/damaged sites and on the side surfaces (not pit or peel sides). The ascorbic acid was made with distilled water in a clean container but may have added bacteria from the dipped mangoes as processing continued. But we usually do a really good job of keeping the samples clean and having positive results. Looking closely at the cut mango, the ascorbic seems to have been absorbed, much more so than the alginate. This absorption may have increased the bacterial growth.

The samples which were GAS FLUSHED at 30% CO_2 also had very heavy yeast breakdown. The textures on the mango had turned to mush, with heavy colony growth and fermented odors. An interesting note on these samples was that the peel side looked great, dry with no growth whereas the pit sides had heavy growth. High CO_2 flushes are especially bad on overmature mango it seems.

No treatment without MAP lost their textures, dried out with some browning, and some slime on surface. The aromas and flavors were muted. Overall result wasn't terrible

Modified atmosphere samples without any other treatment performed pretty well, lost texture a little but still a pass overall with minimal browning and good flavor.

Samples which were gas flushed in package with 30% CO_2 had extreme texture loss resulting in heavy microbial decay

Ascorbic dips with or without modified atmosphere both had heavy texture loss and microbial breakdown effects. Modified atmosphere samples had a lot less microbial breakdown and held their texture, but still failed due to surface yeast colonies.

CO_2 gas cylinder air dried samples

Fresh cut mango that was dried using CO_2 air and packed in a moderate atmosphere (15% O_2 and 5% CO_2) held texture, flavor, aroma without browning or water soaking. The result is impressive, especially considering the other samples had pretty excessive microbial breakdown except for the alginate coated

1% alginate with CaCL2. There was a light sloughing off from the alginate coating. So, a proper enrobing is needed. But alginate doesn't need to be the substance to coat. It seems like it needs a similar viscosity to the natural fresh cut juice, and something that does not penetrate the fresh cut mango. Since this was a directional test, and the wrong alginate was used, it was difficult to work with. Excess had to be drip dried off and we did not think it was going to be successful so only a few packages were prepared, no more 2% samples are in shelf-life, which from the previous day 9 evaluation did a little better than this sample. But the flavor, aroma, and textures were great. The mango flavor was good and juicy. There was no water soaking but the same sheen noted earlier.

Commissary/Store Prep Findings: As a part of this project, we bought samples from commissaries multiple times to evaluate prep practices and packaging used. Our aim was to highlight 2 or 3 ways they can consistently improve mango fresh-cut shelf-life, which we feel is relatively straightforward to accomplish. Details below.

- Most commissaries are using one of two containers:
    - A circular tub with lid. These containers have shown a range of no atmosphere, to completely sealed building up atmospheres of >20% CO_2 .
    - A small rectangular clamshell with a plastic tear strip. These vary in design, with about a 50/50 split of packages with or without venting. Samples without venting performed much better in market sampling performed by Qfresh over the 2022-Spring 2023 seasons.
        - **With venting:** the average O_2 value was >18%. This does not quite reach a level where shelf-life is significantly extended. These samples would be expected to brown more, show more microbial growth late in shelf-life, respire faster and therefore senescence faster. These samples would also lose more odor and flavor as time goes on.
        - **Without venting early in shelf-life:** these packages varied depending on pack date. Product packed very fresh (within the last 3 days) had a range of residual O_2 from 4-15%. This is in the range where CO_2 rises to a level (roughly >15%) to show significant positive benefits:
            - slowing of respiration rate, reduction in fungal and bacterial growth, reduction in water loss and increased firmness.
        - **Without venting later in shelf-life**: fresh cut mango older than 4 days, in non-vented containers, showed an average O_2 of between 0 and 2%, with CO_2 values ranging from 15 to as high as 40%. These samples surprisingly held their color, aroma, flavor without developing acidic or fizzy flavors in most cases. Samples that were older (>6 days in most cases) with visible breakdown (water soaking/ excess browning) did develop off odors and flavors. These effects were due to high CO_2 or overmature mango.

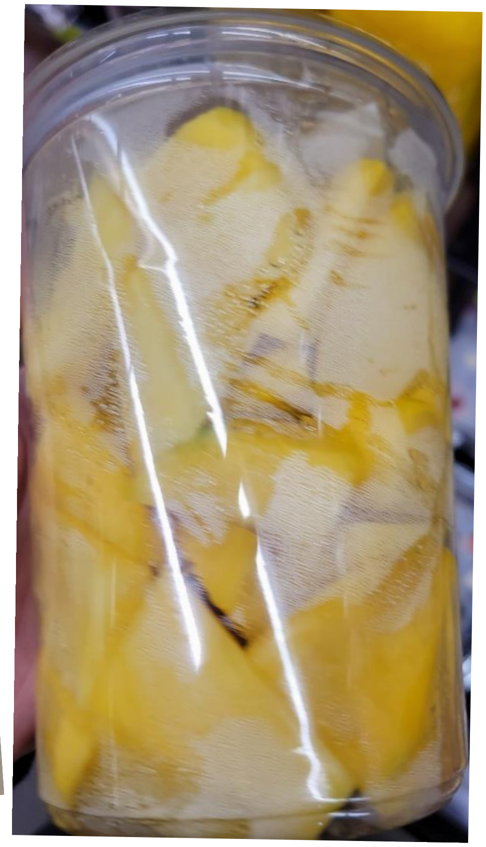
Prep practices:

- Prep of mangoes in lit was all over the board, and shelf-life outcomes were sporadic as a result. Consistently it was found that poor peeling practices showed much more browning and water soaking than samples that had clean cuts. Browning and water soak were especially apparent on the peel side consistently.
    - Proper training of mango peeling (or perhaps educational videos specifically designed for commissaries) would go a long way to increasing shelf-life in commissaries. We don't know the percentage of fresh cut mango being performed by commissaries vs. fresh-cut companies, but in our market survey, there were far more fresh cut mangoes in commissaries than brands producing large scale fresh cut mangoes on shelf
    - The range of date codes was 4 to 6 days, with most coding 5 or 6 days. A clean cut, subdermal layer removal, in combination with a tub/clam that modifies the

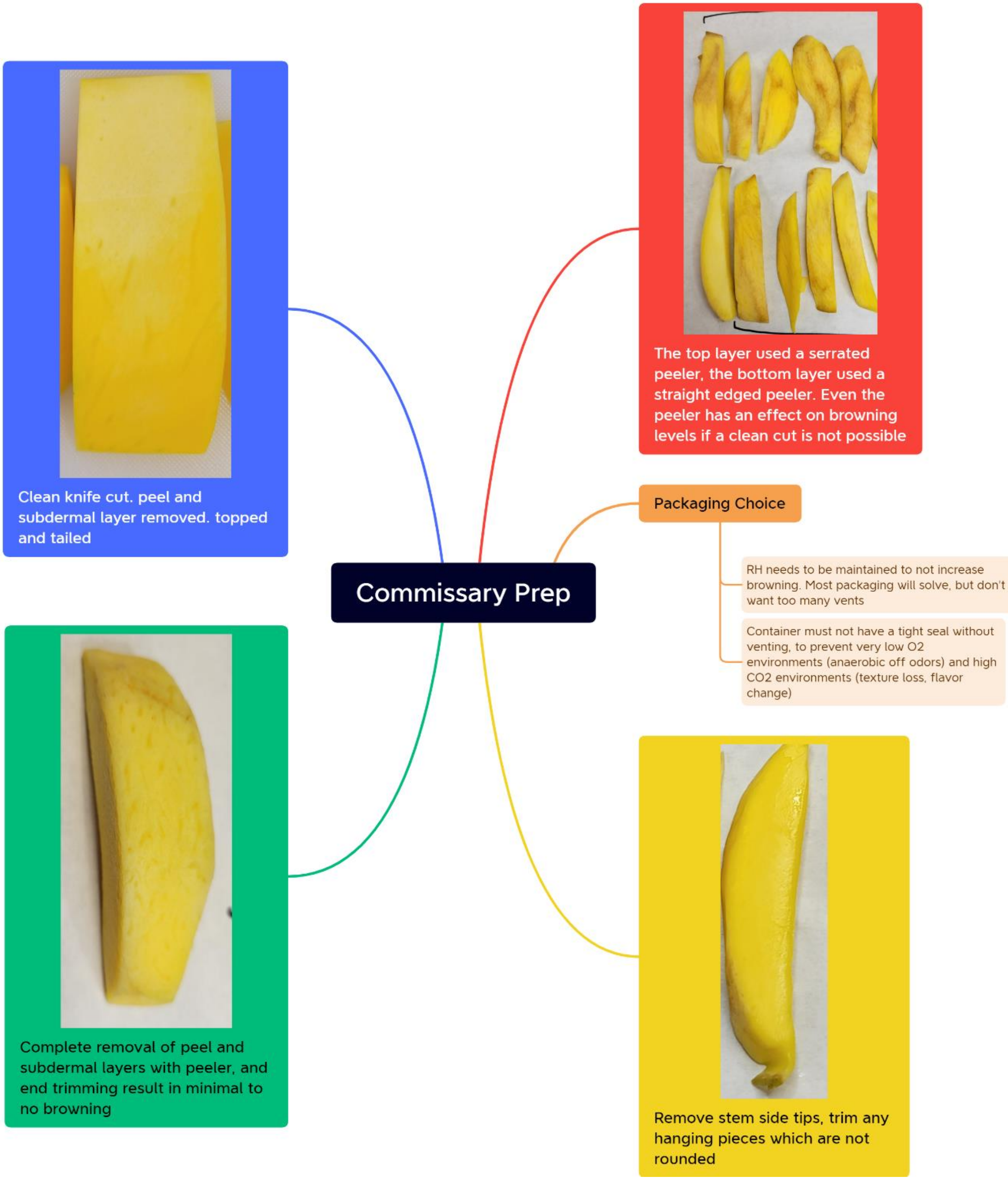
atmosphere passively, has been proven to last between 8 and 12 days consistently in testing conducted by Qfresh Lab. This holds true with no other inputs or modifications. The temperature tested was 36F, which is a common temperature found on shelf-life for these fresh cut products.

Typical commissary peel/prep: Lots of fibers left behind, not enough subdermal removal. Simply removing a little more peel and subdermal would extend this shelf-life several days

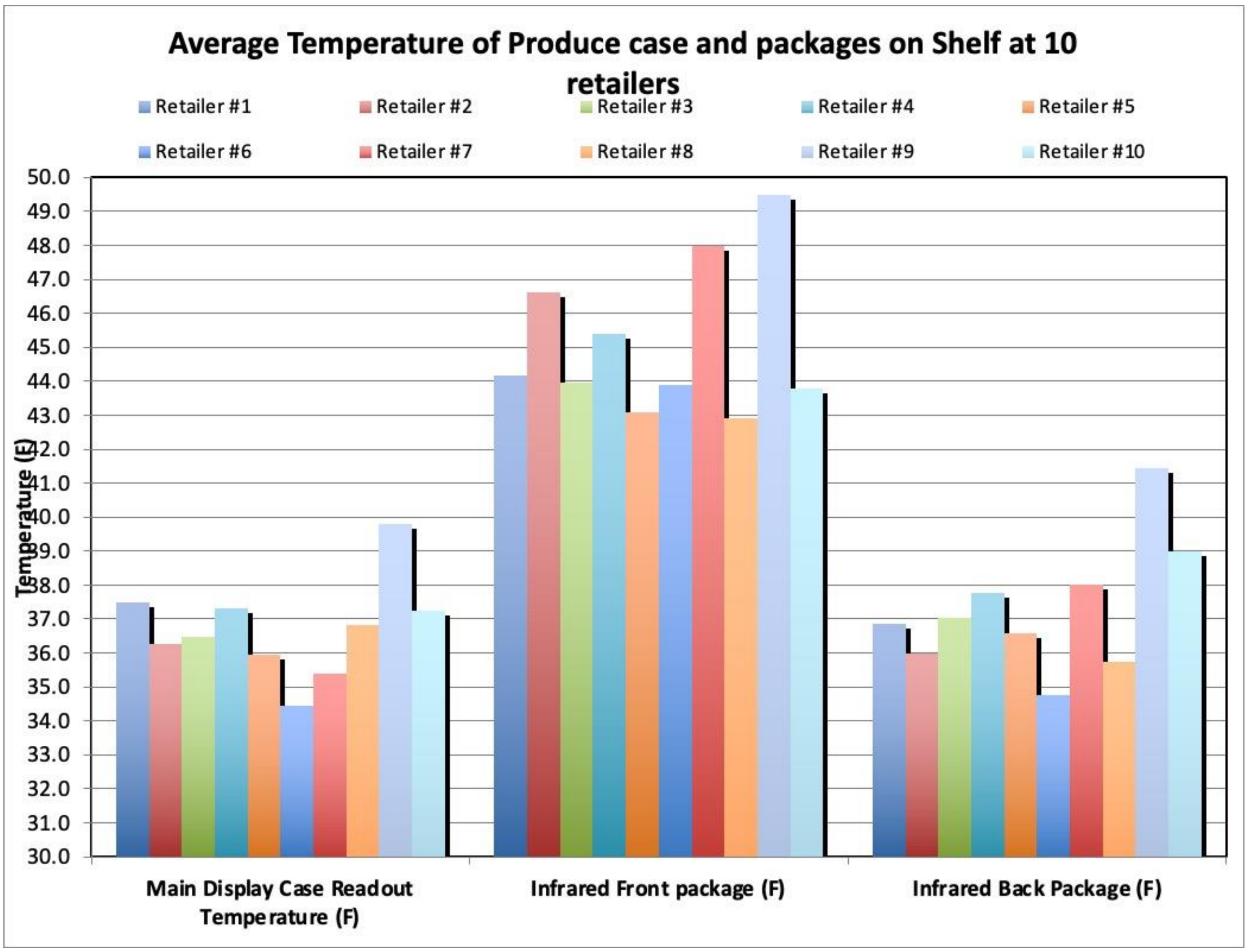
Typical commissary packaging:



Commissary Prep Suggestions for improved quality:



Average shelf temperatures in produce cases across 10 major retailers: Qfresh Lab conducts market surveillance audits consistently. These audits typically focus on quality on the shelf across various fresh cut applications for fruit/vegetable/salads. During these audits, Qfresh captures both case temps, and infrared temps of various packages on the shelf. The data below includes temperatures for the top 10 U.S. retailers. This data set includes over 35,000 packages evaluated on shelf over a 5-year period. These numbers indicate the importance of fresh cut mango location on the shelf. Glass doors at retail are preferred, as they've been shown repeatedly to reduce temperatures. The back of cases is also preferred to keep the temperature consistent with the setpoint of the produce case. The front slot of open-air produce cases are consistently 6 to 8 degrees warmer than the setpoint of the produce case.



The following pages are a more in-depth discussion of packaging, along with our findings and recommendations specifically for fresh cut mango.

<table>
<tr><th colspan="3">Packaging Executive Summary</th></tr>
<tr><td rowspan="3">Effects of moderate CO2</td><td colspan="2">Prolonged CO2 exposure >10% caused tissues softening</td></tr>
<tr><td colspan="2">Prolonged CO2 exposure >20% caused off flavors, odors and extreme softening in under 5 days</td></tr>
<tr><td colspan="2">Gas flushing high CO2 (30%) caused off flavors and tissue softening by day 7</td></tr>
<tr><td rowspan="5">Very low O2 atmospheres</td><td colspan="2">Gas flushing, with O2 values <3% did not stop browning</td></tr>
<tr><td colspan="2">Vacuum packing (0% O2) with a low breathable film, resulting in residual O2 values < 2% and in most cases 0% did not stop browning</td></tr>
<tr><td colspan="2">If the mango is not properly peeled with subdermal removal, water soak and browning actually got worse</td></tr>
<tr><td colspan="2">To use MAP with fresh cut mangoes, it is advised to COMPLETELY peel and remove the subdermal layers along with a small stem side trimming</td></tr>
<tr><td colspan="2">The primary goal of MAP for fresh cut mangoes is to attain moderate CO2 values (7 to 10%) while maintaining O2 values between 5 and 15%</td></tr>
<tr><td rowspan="8">Package Modelling</td><td rowspan="5">Based on Qfresh RR values, Qfresh modeled 48 packages. Fresh cut mango processors can pick the closest package design and request a test roll from a converter for testing</td><td>Different cuts</td></tr>
<tr><td>Multiple mango types</td></tr>
<tr><td>Varying pack weights</td></tr>
<tr><td>Varying Respiration rates</td></tr>
<tr><td>Different package types (bags), lidding trays, liner trays with lidding film</td></tr>
<tr><td rowspan="3">Modelling also took into account combinations of breathable films and micro-perforations</td><td>Fresh cut mango has been shown to benefit from combination films, due to the low tolerance to low O2 environments, and the need for moderate CO2 in the package.</td></tr>
<tr><td>Breathable films let out 3x more CO2 than influx of O2, providing lower CO2 values</td></tr>
<tr><td>A tray or lidding tray would work best when the tray itself contributes to the total package breathability. This is possible using new compostable thermofibre trays, with PE or PP liners. These can be used in conjunction with micro-perforations to better target the right atmosphere</td></tr>
<tr><td rowspan="2">Gaps in the literature</td><td>No tests conducted with anti-microbials incorporated into the package design</td><td>Qfresh worked with a company with a novel anti-microbial delivery system in package for the effects on shelf-life (testing ongoing as of 3/13/22</td></tr>
<tr><td>In lieu of live packaging studies, most literature relies on testing using a constant gas flush, which is not possible commercially and may be influencing results in very significant ways</td><td>For example, CO2 production in package has a negative feedback loop on respiration rate, causing O2 and CO2 changes throughout shelf-life, which may or may not be advantageous</td></tr>
</table>

Fruit and Vegetable Physiology and Deterioration Processes:

- The plant tissues in fresh fruits and vegetables are still living after harvest and even after fresh-cut processing. To stay alive, their metabolic processes must derive energy, primarily through the process of respiration.
  - Respiration involves the consumption, using atmospheric oxygen (O_2), of carbohydrates and organic acids and the consequent production of metabolic energy, heat, carbon dioxide (CO_2), and moisture vapor. Different fruits and vegetables, and even different varieties of a given fruit or vegetable, will vary in their rates of respiration. Those that have high respiration rates (such as asparagus, mushrooms, strawberries, and broccoli) tend to be most perishable while those with low respiration rates (such as nuts, apples, onions, and potatoes) tend to be least perishable. Respiration rate also strongly depends on temperature and may more than double for every increase of 108C.
  - The best way to reduce respiratory metabolism and thus conserve the plants stores of carbohydrate, acids and moisture, is to reduce the temperature.
  - All biological processes proceed more slowly at lower temperatures. In any case, keeping fresh produce at the lowest possible temperature without causing freezing or chilling injury is the surest way to maintain quality and shelf life. As a supplement to good temperature control, MAP can further extend quality and shelf life.

MAP

Most extended shelf-life packaging technologies involve the use of oxygen (O_2) and carbon dioxide, (CO_2), in ratios that are different from those found in air. The partial pressures, diffusion properties and permeation rates through polymer films, micro-perforations and membranes of each gas are independent of the other gases present. When designing MAP, the convergence of three unique and separate sciences must take place. These are the sciences of produce physiology, polymer engineering and converting technology.

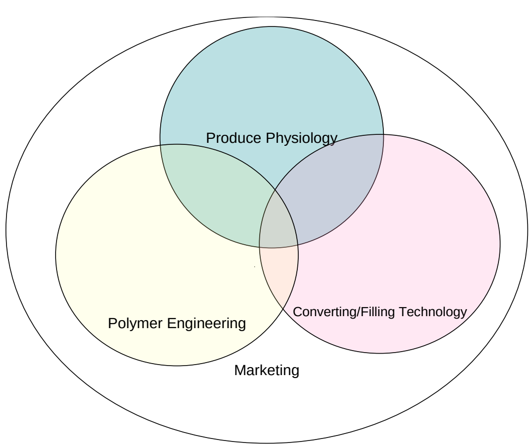


Figure 1. Sciences impacting modified atmosphere package design.

Effective MAP design can only effectively take place within the intersection of these three disciplines. In many package design scenarios, only two of the three disciplines take place; when this condition exists, it is impossible to optimize the package for quality and shelf life. Surrounding these scientific disciplines is the impact and requirements of marketing, brand management and the desires and needs of the consumer. This often includes economics which as an influence cannot be understated. What makes fresh produce packaging unique is the impact of the fresh produce. Unlike almost all other packaging applications, produce MAP involves packaging of a living product. Therefore, a critical factor in the design of an effective package is a quantitative understanding of the physiological properties and requirements.

Brandenburg, J. S. (2020). Advances in modified atmosphere and active packaging of horticultural produce. In *Advances in postharvest management of horticultural produce* (pp. 65-90). Burleigh Dodds Science Publishing.

- Many of the effects of MAP on produce are based on the often observed slowing of plant respiration in low O_2 environments. Respiration is typically measured as the amount of CO_2 produced (or O_2 consumed).
- This suppression of respiration continues until O_2 reaches about 1–3 kPa for most fruits or vegetables. If O_2 gets lower than 1–3 kPa (depending on the product and the temperature), anaerobic (fermentative) metabolism replaces normal aerobic metabolism and large amounts of CO_2, off-flavors, off-odors, and undesirable volatile compounds are produced. The relationships, for hypothetical commodities, between O_2 concentration and respiration rate and CO_2 concentration and respiration
- Similarly, as CO_2 increases above the 0.03 kPa found in air, a suppression of respiration results for some commodities (Figure 4.3). If CO_2 reaches higher levels, the production of undesirable volatiles and physiological injury occur. The amount of CO_2 that is injurious varies by commodity.
  - Reduced O_2 and elevated CO_2 together can reduce respiration more than each one of them alone (Kader et al., 1988).
  - In addition, elevated CO_2 suppresses plant tissue sensitivity to the effects of the ripening hormone ethylene.]
  - If fruits are softening during distribution or storage due to exposure to ethylene, then MAP may reduce the sensitivity of the tissues of kiwifruit, banana, apple or other fruits, and thereby retard the softening.
  - Elevated CO_2 can slow the growth of certain spoilage bacteria and molds and is widely used in strawberry shipping for this purpose.
  - However, MAP cannot enhance the safety of fresh fruits and vegetables. Most of the human pathogens of concern are either not affected by MAP, or their growth may actually be enhanced by MAP). MAP will not improve the quality of poor quality

products. At best, MAP can slow the processes of deterioration and so extend quality and shelf life, but MAP cannot reverse those processes.

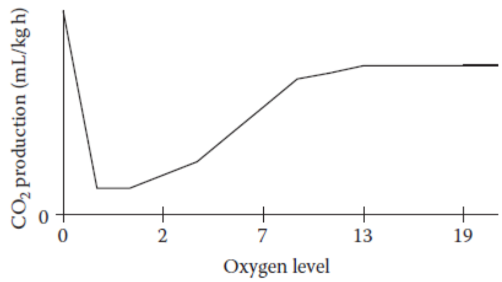


FIGURE 4.2
Effect of oxygen levels on fruit or vegetable respiration rate. (Adapted from Zagory, D., Physiology and microbiology of fresh produce in modified atmosphere packages. *Society of Manufacturing Engineers Symposium, Fundamentals of Modified Atmosphere Packaging*, December 4–5, Monterey, CA, 1996, 3.)

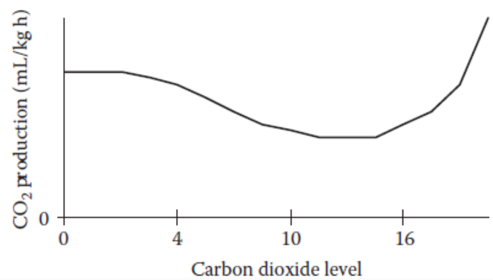


FIGURE 4.3
Effect of carbon dioxide levels on fruit or vegetable respiration rate. (Adapted from Zagory, D., Physiology and microbiology of fresh produce in modified atmosphere packages. *Society of Manufacturing Engineers Symposium, Fundamentals of Modified Atmosphere Packaging*, December 4–5, Monterey, CA, 1996, 3.)

➢ Relationship between packaging and produce physiology

TABLE 4.1
Physiological Effects of Reduced O_2 and Elevated CO_2 on Fruits and Vegetables

	General Effects of	
Cause of Deterioration	**Reduced O_2**	**Elevated CO_2**
Respiration rate	(>1%) – (<1%) +	(<15%–20%) – (>15%–20%) +
Ethylene action	–	–
Chlorophyll degradation	–	–
Anthocyanin development	–	–
Carotenoid biosynthesis	–	–
Enzymatic browning	– (Near 0%)	–
Off-flavors	+ (<1%)	+ (>15%–20%)
Vitamin C loss	–	–
Fungal growth	– (<1%)	– (>10–15%)
Bacterial growth	– or 0	– or 0

Source: Kader, A.A., D. Zagory, and E.L. Kerbel. 1988. *CRC Crit. Rev. Food Sci. Nutr.* 28(1):1–30.
Notes: –, Decrease or inhibit; 0, no effects; +, stimulate or increase.

Polymers:

There are a variety of polymers used in fresh produce MAP. A portion of these polymers is used in primarily flexible packaging structures, a portion are used in primarily rigid packaging structures and a portion are found in both applications. Each polymer has physical, chemical and transmission rate properties that are unique to that polymer. Design of a packaging structure entails matching the specific polymer properties to the requirements of the MAP application. A polymer gas transmission rate, specifically, OTR and CO_2TR are key attributes for the physiological portion of fresh-cut MA applications.

However, research, awareness and understanding of polymers abilities to transmit absorb and manage ethylene is gaining momentum. In addition most polymers used in fresh produce packaging are water vapor barriers and as such residual water, humidity and water vapor were controlled through other technologies. Recently significant work is being carried out to explore, develop and commercialize polymers which have a significantly higher water transmission rate (WVTR). Polymers such as Polystyrene and Nylon are showing promise.
QFresh Tests performed:

Biopolymers:

Many natural fiber based materials (Rice, Sugarcane and Wheat husks for example) are being evaluated for MAP. The challenge with the plant based structures includes being able to quantify the transmission properties, determine property consistency and ensure that the products can be used in a direct food application.

One of the challenges in the bio polymer/sustainability area is combining the transmission requirements for produce with the desire for sustainability and compostability. Understanding the difference and requirements between industrial composting and home composting is essential in determining the functionality and applicability of bio based polymers. Examining the entire lifecycle of the polymer and package is also critical in determining not only the best polymer for the application, but also the total cost of the technology.

Brandenburg, J. S. (2020). Advances in modified atmosphere and active packaging of horticultural produce. In *Advances in postharvest management of horticultural produce* (pp. 65-90). Burleigh Dodds Science Publishing.

Table: Lists of the common polymers used in produce modified atmosphere packaging.

Polymer	Characteristics	Typical OTR	Applications
LDPE	General purpose	450-500	Both
LLDPE	Increased stiffness	480-500	Both
MDPE	Increased stiffness,	300-350	Both
HDPE	Relatively stiff, opaque	150	Rigid
ULDPE	High OTR, decreased	900	Flexible
-	Very high OTR, soft	1100	Flexible
APET	Clear, Rigid	5	Rigid
PVC	Clear, Rigid	10	Rigid
PP	Decreased Clarity	300	Both
EVA	Sealability	600-900	Flexible
PS	Stiffness	350	Rigid

Films and structures:

MAP contains not only individual polymers but combinations of polymers, as well as other substrates such as paper, and mesh in the form of films and structures. These films and structures can consist of homopolymer monolayer films, blended mono layer films, coextruded films or combinations of both laminated, glued, together.

Determination of the structure gas transmission rate therefore requires knowledge of not only the individual polymers but also how they are combined. A blend of polymers within one layer of film, referred to as a blend, will yield a transmission that is the weighted average of the transmission of the individual polymer components. Individual distinct layers of pure polymers, or blends, created within a single total film structure, is referred to as a coextrusion.

These can be used as is, or combined with additional coextrusions or films, to create a lamination. Since gases will move through each independent layer sequentially the transmission of each independent layer of polymer must be determined and inserted into the following equation to calculate the overall structure transmission rate.

Figure 4. OTR calculations on multi-layer coextruded films and structures.

Calculating the OTR

$$\textbf{OTR} = \frac{1}{\frac{t1}{OTR_1} + \frac{t2}{OTR_2} + \frac{t3}{OTR_3}}$$

Where:

t = thickness of the individual layer

OTR = oxygen transmission rate of the individual layer at 1 mil

Based upon this equation the total structure transmission can never be greater than the lowest individual layer transmission. This limiting factor establishes a practical ceiling for polymer modified atmosphere packaging. Depending on the type of structure and the all of the converting, geometric and marketing requirements this ceiling may be as low as 175 cc/100 in^2/mil/atm/day (2713 cc/m^2/mil/atm/day) or as high as 900-1000 cc/100 in^2/mil/atm/day (13,950 -15,500 cc/m^2/mil/atm/day).

It is important to note that even though they are very thin layers; inks, adhesives and coatings, including antimist, can have a significant impact on the overall transmission rate. Therefore all layers of the laminations, not just the polymeric or paper layers must be taken into account when calculating overall transmission rate.

- The specific combination of polymers, paper, blends, coextrusions, and laminations are governed by numerous parameters in addition to the physiological requirements mandated by the product being packaged.
- These additional functional requirements often act in an opposing manor. Therefore to effectively design a MAP it is necessary to have a full understanding all of its desired features. Requirements impacting polymer and film choice can include: stiffness, sealability, aesthetics, clarity, graphics, dimensions, economics, sustainability, runnability, packaging format, Coefficient of Friction, COF, antimicrobial additives, and thickness.

Perforations:

The increase in demand for higher respiring fresh produce, outside the traditional leafy green market, has necessitated an increase in MAP gas transmission rates. A method for achieving high OTR packaging structures that is not limited by the upper end of polymer gas transmission rates, and stiffness constraints is microperforation technology.

This technology employs the science of placing micro holes in the packaging structure through the use of a laser. With microperforation technology, the gas transmission rate of the package is governed redolently by the configuration of holes and their individual geometry and size. The hole size and configuration can vary with the specific perforation method but all micro-perforations are not visible to the naked eye as they can range from 40-200µm in diameter.

The smaller the hole size, the greater number of holes can be placed in a structure while achieving the same overall transmission rate. There is a limit however as the diameter of the perforation should not be less than the thickness of the film. This is due to the laser energy dissipating though the thickness of the film; which creates a cone shape hole where the diameter of the perforation on the inside surface of the film may be less than the diameter on the outside surface of the film. If the outside diameter is too narrow and the film too think you may actually not have a hole all the way through the film.

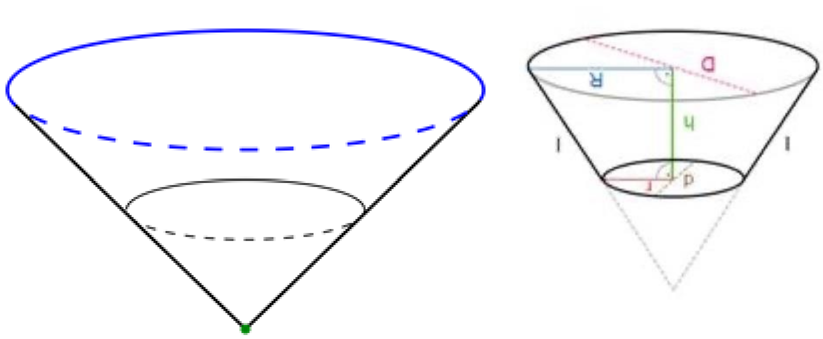


Figure 5. Micro-perforation hole geometry

It is essential to have a complete understanding of the package geometry as well as produce geometry and “bulk density” so that holes are not blocked or obstructed in any way. This is critical to the success and control of gas transmissions. Micro-perforations also have transmission rate limitations that are at the lower end of the range. Typical OTRs for this packaging are from 250 cc/100 in²/mil/atm/day and above. Gas transmission rates of microperforated structures are determined by the gas diffusion properties through the combined effect of the individual micro holes, their corresponding placement and in certain cases the OTR of the perforated structure. The number of holes decreases as the targeted OTR requirements are lower. Since microperforated structures cannot have less than one hole, the gas transmission rate through a single hole dictates the lower transmission rate level.

Modified atmosphere micro-perforation packaging with only one hole can also be problematic. With two or more holes there is less risk from hole blockage as well as there is more uniform gas flow throughout the package mitigating the possibility of package micro atmospheres. In order to avoid only one microperforated hole, alterations to the other key OTR control parameters, such as product weight, or package dimension, should be considered.

New micro perforation technologies, non-laser, are being actively researched, which if successful, could lower the effective achievable hole size. This would allow for a lower total package transmission rate as well as increasing the number of holes per package creating a more uniform gas flow throughout the package and further mitigating micro atmospheres.

The diffusion rates of various gases through micro-perforations are very similar. In effect the diffusion rates of CO_2 and O_2 are virtually the same; a Beta value of 1. Therefore for a targeted 2% O_2; the CO_2 concentration will be 19%. The beta value difference between polymeric and microperforated structures create different final MAs. It is not possible with a microperforated film to achieve a MA consisting of low O_2 concentrations and low to moderate CO_2 concentrations. Conversely if low O_2 concentrations in combination with high CO_2 concentrations are required then packaging comprising of engineered polymers is not suitable. This parameter needs to be accounted for in the packaging design process.

Macro-perforations, with holes that are visible to the naked eye, cannot consistently modify and control the gas concentrations within the package. Therefore, attempting to create a MA with low O_2 is not feasible. This does not mean however there is not a function and need for macro-perforated structures. Since the gas transmission is so high a macro-perforated structure will virtually never become anaerobic as a result of O_2 concentrations falling below 0%, even under temperature abuse situations.

If having a fresh-cut produce package not become anaerobic under any circumstances, is the highest priority and atmospheric O_2 concentrations do not significantly impact shelf life then macro-perforation technology may be applicable. Historically this has been the technology of choice for mushroom packaging. Recent advances in micro-perforation technology have provided mushroom growers and processors alternatives. If one plans to pursue micro-perforations for mushroom packaging then it would be wise to make sure that all relevant government food safety requirements are met.

6.1 Packaging format:

- Packaging formats evaluated in this study:
  - Pre formed Bag
  - Stand Up pouch
  - Clamshell
  - Rigid Tray with Rigid snap on Lid
  - Rigid Tray with lidding film
  - Rigid Tray with lidding and an antimicrobial built in
  - Fiber tray film combination with peelable lidding film

Effective MAP design hinges on the proper balance of the physiological, polymer, converting and marketing requirements. Issues such as package configuration, package stiffness, graphics, filling method, economics, environmental impact as well as ancillary requirements such as cook-in, antimist, resealability, and compostability all impact the design and make-up of the package. Many of which are similar to those found in traditional packaging applications. The significant difference with MAP is the impact that these requirements have on the gas transmission rate properties of the package. The majority of these requirements fall under the science of converting technology. The science of converting technology combines the raw material polymers, films, adhesives, inks and additives in the proper sequence to create the desired package.

Table 3. Common packaging formats advantages and disadvantages

Package format	Suitable for MAP	Natural aspiration	Leaker prone?	Applicable for fresh cut mango?	Physical Protectionm
Side weld premade bag	Somewhat	Somewhat	Yes	No	No
Pre made pouch	Yes	No	No	Yes	Yes
VFFS bag	Yes	No	Structure dependent	Yes	Somewhat
Pre made SUP	Yes	No	No	Yes	Yes
VFFS SUP	Yes	No	No	Yes	Somewhat
Thermoformed tray with attachable Lid	No	Yes	N/A	No	Yes
Clamshell tray	No	Yes	N/A	No	Yes
Thermoformaed tray with sealable lid	Yes	No	Lidding film dependent	Yes	Yes
Tray with overwrap	Package dependent	Yes	Yes	Yes	Yes
Macroperforrations	No	Yes	N/A	Somewhat	Yes

Flexible versus rigid packaging: Clamshell; Rigid tray with rigid snap on lid; Rigid tray with peelable lidding film

As the names imply the fundamental difference between flexible versus rigid packaging relates to the stiffness and often thickness of the respective packaging configuration. The relative stiffness of a given package is controlled by the choice of polymers and their respective stiffness properties as well as the thickness of the structure and geometry.

In MAP, the effective surface area available to gas diffusion between rigid and flexible packaging is another difference. The polymers required to maintain the rigid form of a package generally exhibit low gas transmission rates. These low transmission rates in combination with the thickness required to maintain the package form effectively create a gas barrier structure. This dictates that when determining the effective "breathable" surface area of the package the rigid portion of the package generally cannot be included in the calculations. This means that the flexible lidding material sealed to the top of the tray must take on the entire burden of gas transmission.

Therefore, when comparing a flexible package with a rigid tray type package the gas transmission level of the effective surface area of the flexible package can have a significantly lower overall transmission rate. This is an application where the breathable membrane when incorporated into the rigid tray portion of the package can increase the overall breathability of the structure.

When a rigid tray is used in combination with a rigid lid both components of the package are effective gas barriers. Therefore, if a hermetic seal is created between lid and tray effective gas transmission will not take place and depending upon the type and quantity of produce anaerobic conditions will rapidly develop.

Often a rigid tray and lid combination are not designed to create a complete seal. In this situation the package is not a designed MAP but rather "natural aspiration" package; meaning that depending on how effective the seal; the atmosphere inside could range from anaerobic to ambient. When designing packaging for the produce market it is important to decide which one of these packages that is being designed. Both can be effective packaging formats depending upon the initial requirements and desired outcome. Self-life optimization can only be achieved through MAP technology.

Regardless of whether flexible or rigid is chosen, an optimal MAP requires the controlled and quantifiable transmission of gases through the package in concert with the physiological characteristics of the produce being packaged is necessary.

If there is no control or quantification of gas transmission rates then optimal atmospheres cannot be guaranteed and the packaging system is thereby not controlled. There are a number of reasons for an out of control packaging system including improperly quantified produce physiological properties, an improperly specified package and out of specification raw materials. However, the most common reason is due to a leaking package.

If the package does not have a leak free seal then gases will immediately begin to pass through the leak area. Depending upon the size of the leak the impact could range from missing the optimal target atmosphere to allowing the package to remain at ambient conditions. In either case optimal shelf life and quality will not be achievable.

One of the most important packaging parameters that must be considered is the selection of the sealant layer polymer and configuration. Choice of the correct sealing polymer and format is dependent upon operating parameters including package machine type, filling speed, package configuration, seal configuration, as well as product type and weight.

Potential sealant layer polymers exhibit a wide range of seal characteristics. Common choices of sealant polyolefin sealant polymers include: Low Density Polyethylene, Ethyl Vinyl Acetate, Ultra Low Density Polyethylene, and Plastomer Metallocenes. Each polymer has its own sealing characteristics including ultimate seal strength, hot tack strength, seal initiation temperature, ability to seal through contamination, and oxygen transmission rate. Careful consideration should be given in order to optimize the specific polymer characteristics to the specific requirements of the package necessary properties.

- Pillow Pack: conventional polymers and biopolymers
- Stand Up Pouch: conventional and biopolymers
- Fiber based tray with peelable lidding film
- Identify and design the primary package as well as secondary and tertiary packaging:

- **Effects of secondary packaging**: It is a worthwhile endeavor to ensure the secondary packaging (corrugate venting and palletization pattern) are optimized for fresh cut mango
    - Corrugate should be vented in a way to ensure heat can escape the box. It should also be setup in a way so when palletized, air can flow through the boxes and across the whole pallet to ensure proper temperature control.
    - The pallet should be secured in a way to not restrict airflow to the center of the pallet (I.E. rope wrapping instead of stretch wrapping the whole pallet)
- Best Practices for Palletization
    - Cornerboards with Straps or thin band of stretch wrap is the best to secure and allow heat transfer.
    - Most likely will need cross stacking every x number of layers. Check with box manufacturer that the vent holes can be lined up with cross layering.
    - Depending on heat build-up, might want a chimney layer in middle (built around a post of sorts to reinforce strength)
    - Your box supplier should be able to provide you with the optimum box length, height and width to ensure it fits well on a standard 48"x40" pallet size.
    - Don't allow overhang, make sure the boxes are straight and aligned. Overhang significantly reduces box strength
    - Try and utilize only 1 pallet type and ensure it is in good working order prior to palletizing. Plastic is best for cleaning and offers the best rigidity but can be slippery and require slip sheets on the bottom. Wood pallets are fine for finished goods.
    - A compare and contrast matrix will be developed to quantify and analyze the various packaging designs/technologies and options with the goal of whittling down the options to one or two leading packaging types.

Qfresh Packaging Table: Package modeling for various weights of fresh cut mango (5oz,10oz,12oz,1lb,1.5lb,2lb) in lidding film, bags, fiberboard trays with 2 different cut types. 2 different respiration rates modeled (6 and 11) with targets of 13% O2 (varying CO2 values would be reached depending on package). Package sizes may be a little off, but the highlighted columns can be referenced for how to accomplish the varying weights and cuts of mango. These specifications can be provided to a film converter for test rolls of film to test in your application.

PRODUCT	Package	Cut Type	Weight (oz)	Inside Bag Dimensions (or film size)	# of micro-perfs @ 100 micron	OTR of pckg only without perforations	OTR FILM @ 5°C/100 in sq	Proposed structure OTR (cc/package/d)	Proposed structure OTR (cc/m2/d)	Proposed structure OTR (cc/100sq in)	Pack Internal Surface Area (cm2)	Product Aggregate Respiration Rate	Target Final Modified Atmosphere (O2)
Mango Sliced PET Tray	PET/PE	Slices	5	6" x 8"	3	2	5	256	8245	532	310	6	13%
Mango Cubed PET tray	PET/PE	Cubed	5	6" x 8"	5	2	5	469	15116	975	310	11	13%
Mango Sliced OPP PE Bag	OPP/PE	Slices	5	6" x 8"	2	134	140	256	4129	266	619	6	13%
Mango Cubed Sliced OPP/PE Bag	OPP/PE	Cubed	5	6" x 8"	3	134	140	469	7570	488	619	11	13%
Mango Sliced fiber Tray/PE	PE	Slices	5	5" x 7"	0	535	500	256	3704	239	690	6	13%
Mango Cubed fiber Tray/PE	PE	Cubed	5	5" x 7"	0	535	500	469	6791	438	690	11	13%
Mango Sliced fiber Tray/PP	PP	Slices	5	5" x 7"	0	321	300	256	3704	239	690	6	13%
Mango Sliced Cubed Tray/PP	PP	Cubed	5	5" x 7"	0	642	600	469	6791	438	690	11	13%
Mango Sliced PET Tray	PET/PE	Slices	10	6" x 8"	3	2	5	511	16490	1064	310	6	13%
Mango Cubed PET tray	PET/PE	Cubed	10	6" x 8"	5	2	5	937	30232	1950	310	11	13%
Mango Sliced OPP PE Bag	OPP/PE	Slices	10	6" x 8"	2	134	140	511	8258	533	619	6	13%
Mango Cubed Sliced OPP/PE Bag	OPP/PE	Cubed	10	6" x 8"	3	134	140	937	15141	977	619	11	13%
Mango Sliced fiber Tray/PE	PE	Slices	10	5" x 7"	0	535	500	511	7409	478	690	6	13%
Mango Cubed fiber Tray/PE	PE	Cubed	10	5" x 7"	4	535	500	937	13583	876	690	11	13%
Mango Sliced fiber Tray/PP	PP	Slices	10	5" x 7"	2	321	300	511	7409	478	690	6	13%
Mango Sliced Cubed Tray/PP	PP	Cubed	10	5" x 7"	3	642	600	937	13583	876	690	11	13%
Mango Sliced PET Tray	PET/PE	Slices	12	6" x 8"	6	2	5	614	19800	1277	310	6	13%
Mango Cubed PET tray	PET/PE	Cubed	12	6" x 8"	10	2	5	1125	36300	2342	310	11	13%
Mango Sliced OPP PE Bag	OPP/PE	Slices	12	6" x 8"	5	134	140	614	9916	640	619	6	13%
Mango Cubed Sliced OPP/PE Bag	OPP/PE	Cubed	12	6" x 8"	9	134	140	1125	18179	1173	619	11	13%
Mango Sliced fiber Tray/PE	PE	Slices	12	5" x 7"	1	535	500	614	8896	574	690	6	13%
Mango Cubed fiber Tray/PE	PE	Cubed	12	5" x 7"	5	535	500	1125	16309	1052	690	11	13%
Mango Sliced fiber Tray/PP	PP	Slices	12	5" x 7"	3	321	300	614	8896	574	690	6	13%
Mango Sliced Cubed Tray/PP	PP	Cubed	12	5" x 7"	4	642	600	1125	16309	1052	690	11	13%
Mango Sliced PET Tray	PET/PE	Slices	16	7" x 10"	8	3	5	817	18120	1169	451	6	13%
Mango Cubed PET tray	PET/PE	Cubed	16	7" x 10"	14	3	5	1498	33219	2143	451	11	13%
Mango Sliced OPP PE Bag	OPP/PE	Slices	16	7" x 10"	6	196	140	817	9050	584	903	6	13%
Mango Cubed Sliced OPP/PE Bag	OPP/PE	Cubed	16	7" x 10"	13	196	140	1498	16591	1070	903	11	13%
Mango Sliced fiber Tray/PE	PE	Slices	16	5" x 7"	3	535	500	817	11843	764	690	6	13%
Mango Cubed fiber Tray/PE	PE	Cubed	16	5" x 7"	9	535	500	1498	21713	1401	690	11	13%
Mango Sliced fiber Tray/PP	PP	Slices	16	5" x 7"	4	321	300	817	11843	764	690	6	13%
Mango Sliced Cubed Tray/PP	PP	Cubed	16	5" x 7"	8	642	600	1498	21713	1401	690	11	13%
Mango Sliced PET Tray	PET/PE	Slices	24	7" x 10"	12	3	5	1228	27219	1756	451	6	13%
Mango Cubed PET tray	PET/PE	Cubed	24	7" x 10"	22	3	5	2251	49902	3220	451	11	13%
Mango Sliced OPP PE Bag	OPP/PE	Slices	24	7" x 10"	11	196	140	1228	13595	877	903	6	13%
Mango Cubed Sliced OPP/PE Bag	OPP/PE	Cubed	24	7" x 10"	21	196	140	2251	24924	1608	903	11	13%
Mango Sliced fiber Tray/PE	PE	Slices	24	5" x 7"	7	535	500	1228	17791	1148	690	6	13%
Mango Cubed fiber Tray/PE	PE	Cubed	24	5" x 7"	17	535	500	2251	32617	2104	690	11	13%
Mango Sliced fiber Tray/PP	PP	Slices	24	5" x 7"	9	321	300	1228	17791	1148	690	6	13%
Mango Sliced Cubed Tray/PP	PP	Cubed	24	5" x 7"	16	642	600	2251	32617	2104	690	11	13%
Mango Sliced PET Tray	PET/PE	Slices	32	7" x 10"	16	3	5	1636	36279	2341	451	6	13%
Mango Cubed PET tray	PET/PE	Cubed	32	7" x 10"	29	3	5	3000	66512	4291	451	11	13%
Mango Sliced OPP PE Bag	OPP/PE	Slices	32	7" x 10"	15	196	140	1636	18120	1169	903	6	13%
Mango Cubed Sliced OPP/PE Bag	OPP/PE	Cubed	32	7" x 10"	28	196	140	3000	33219	2143	903	11	13%
Mango Sliced fiber Tray/PE	PE	Slices	32	5" x 7"	11	535	500	1636	23713	1530	690	6	13%
Mango Cubed fiber Tray/PE	PE	Cubed	32	5" x 7"	24	535	500	3000	43474	2805	690	11	13%
Mango Sliced fiber Tray/PP	PP	Slices	32	5" x 7"	13	321	300	1636	23713	1530	690	6	13%
Mango Sliced Cubed Tray/PP	PP	Cubed	32	5" x 7"	23	642	600	3000	43474	2805	690	11	13%

Qfresh Protocols/addendums:
These include some of the protocols we used throughout testing, for additional context and methods.

Mango Whole and fresh-cut Test Protocols for measurements:

Whole mango storage temperature (45F, until 24 hours prior to cutting where it was moved to 36F).

The following tests were performed prior to all shelf-life trials on *whole* mangoes:

- Pressures were taken on 5 mangoes using an 8mm tip.
  - Remove outer flesh using a clean cut vertically of an upright mango
  - Measure pressure on both sides using pressure gauge with 8mm tip
  - Use smooth motion to the seed for the test
- Brix and pH measurements:
  - Utilized the flesh from the whole mango, juiced with an atago Pal-1 brix meter.
  - pH measured using the same juice used for brix
- Internal flesh color:
  - Using a color chart for the appropriate mango type and grading
  - L*a*b* measurements taken along the seed at center of mango after cutting
  - L*a*b* measurements on fresh cut mangoes were taken on the pit side for flat sided mango and on one of the sides for curved slices
- General info:
  - Shoulder characterization categorized as full, partial, underdeveloped
    - Full mango shoulders are a good indicator of their maturity at harvest and will ripen normally
  - Red skin is not considered a good indicator so outside colors were not relied on
  - Outer and inner conditions noted, such as:
    - Lenticel browning
    - Internal water soaking
    - Stem defects

- Aroma was used as a proxy for anaerobic conditions and the presence of ethanol/acetaldehyde. These chemicals are present at higher concentrations when the package residual oxygen drops below the threshold for anaerobic conditions in Mango.

- **Future Research:**
    - Pulsed light and its' antimicrobial effects. Literature showed a drastic effect, but we could not secure a unit in time for testing.
    - Anti-microbial system from Clean Works Corp (emerging technology, recently commercialized)
        - Clean Works' Clean Verification process uses ultraviolet light, vaporized hydrogen peroxide, and ozone to kill up to 99.99% of pathogens. https://cleanworkscorp.com/
        - This may be a good solution for both the whole mango, and also for fresh cut mango.
    - Viscous coatings that match the mango chemistry
        - Literature has tested some, but we think with some minor tweaks, this is a very viable solution for fresh cut mango shelf-life extension
    - CO_2 gas spray systems for the fresh cut mango surfaces (after confirming early results, but results have been stunningly positive)
        - May also be a good solution for the whole mango prior to cutting.
    - Working directly with an identified processor; that is willing to use their peeling equipment to provide peeled Mango to test.
        - Also willing to conduct tests on their full equipment. Test design would be sure to be minimally invasive to not impact production
    - Examine additional peeling equipment and techniques
        - Flexible for multiple maturities
        - Flexible for depth of peel
        - Flexible for multiple mango sizes
        - Flexible for multiple mango types
        - Topping/tailing inclusion?

Resources:

We have compiled a separate document detailing the literature we searched with summaries that guided our work. This is available and will be sent with this report.

Best Regards,

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