FINAL PROJECT REPORT **YEAR**: 3 of 3

PROJECT TITLE: Improving food safety of fresh apples by hot air impingement drying

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COOPERATORS: Van Doren Sales, Inc., Northwest Horticultural Council, Stemilt Growers LLC., Double Diamond Fruit Co., Pace International LLC., US Syntec, Hansen Fruit Company, Symms Fruit Ranch, Washington Fruit & Produce Company, and other packing houses.

BUDGET: **Year 1**: $73,951 **Year 2**: $74,798 **Year 3**: $75,898

OTHER FUNDING SOURCES: Part of the new faculty start-up funds of Dr. Girish M. Ganjyal. Support from co-operators for some of the materials and time on their packing lines.

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Item	2015-16	2016-17	2017-18
Salaries[1]	40,000	40,000	42,000
Benefits[1]	11,960	11,960	12,558
Wages[1]	3,750	6,000	4,500
Benefits	368	132	441
Equipment[3]	4,000	2,000	0
Supplies[2]	6,873	12,706	11,399
Travel[4]	7,000	2,000	5,000
Miscellaneous	0	0	0
Plot Fees	0	0	0
Total	$73,951	$74,798	$75,898

Footnotes:
[1] Salaries, Wages and Benefits for technical and student support
[2] Supplies and analysis fees, including for microbial testing
[3] Equipment related to biosafety level two microbial analysis
[4] Travel for industrial experiments

OBJECTIVES

The objective of this proposal was to evaluate the potential of using hot air impingement drying to enhance the safety of the fresh-packed apples. The specific objectives of the proposal are as detailed below:

1) Determine the impingement drying characteristics for a broad range of wax-coated apples and the impact on the quality of the apples with in-plant testing.
2) Study the effectiveness of impingent drying in reducing the microbial levels in apples.
3) Develop scale-up strategies for commercial packing lines and complete the energy efficiency analysis.

SIGNIFICANT FINDINGS

Objective 1:

- Two types of wax (shellac and carnauba) behave differently under higher heat conditions.
- The viscosity of both waxes reduces significantly with the increase in temperature.
- Both Carnauba and Shellac waxes can be effectively dried at higher temperatures (up to 200°F), in a regular convection air dryer.
- The Shellac wax tends to have flaking issues around 100°F. However, with an increase in temperature beyond 150°F, it provides a high level of gloss on apples.
- Carnauba wax provides good performance in the temperature range of 100 to 200°F.
- In general, at a higher temperature, shorter drying time was better for maintaining gloss.
- The overall quality of the apples (as determined by measurement of total solids, moisture loss, and pH) were comparable with the control apples (without waxing, but similar drying treatment) over the 3-week storage period.
- Longer drying times at higher temperatures had negative effects on the wax quality on the apples.

Objective 2:

- Microscopy analysis revealed that apple peel surface is covered with numerous microstructures, such as lenticels, and microcracks, present mostly in calyx and stem bowl sections.
- Calyx and stem bowl sections harbored approximately 150 times more bacteria than the equatorial section of the apple.
- Drying along could not provide the microbial load reduction of more than 1 log.
- Application of surfactants combined with sanitizer followed by drying with hot temperature air helped to decrease bacterial count on the apple surface. However, bacteria are attached to the microcracks in the stem bowl cavity, which may protect them from contact with a cleaning solution for a time long.

Objective 3:

- Impingement drying method can be used effectively to reduce the current dryer footprint and provides the opportunity to use additional food safety interventions on the packing line.
- Drying times can be reduced significantly by using higher drying air temperatures for shorter times and thus increasing the production capacity.
- Overall, this drying technique can provide economic benefits to the packing house.

RESULTS & DISCUSSION

Objective 1:

It was found that higher temperatures resulted in higher gloss values. In other words, higher drying temperatures led to more shiny apples for both Carnauba and Shellac waxes. Although, for the Shellac wax in specific, the wax quality was negatively impacted when the temperature of the drying was increased from 100 to 150ºF. But, at 200ºF, the wax quality got better with increased glossiness compared to 100ºF drying temperature. But for the Carnauba wax, the glossiness increased with any increase in drying temperature. In general, the apple quality was not negatively impacted by the increase in the temperature of the drying. There was a slight increase in the weight loss for the shellac coated apples compared to the carnauba coated as well as the control samples. But all other quality parameters were not significantly different among the treatments and the control samples.

From the plant trials related to the testing for quality of the apples and the wax, we concluded that the best temperatures for the red delicious apple variety is 250°F or lower. The "golden delicious" variety of apples is not negatively impacted by high temperatures (up to 300°F).

Objective 2:

In 2016 microbial testing was performed. The maximum of 1 log CFU/apple was observed (Fig. 1 and 2).

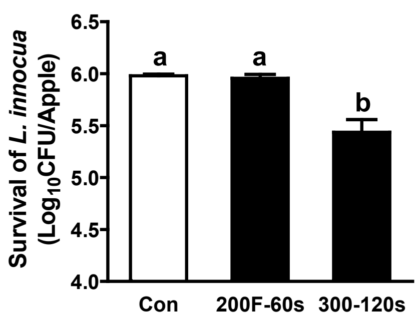

Fig. 1. Survival of L. innocua on Granny Smith apples.
Mean ± SEM, n=12, bars with different letters on the top are statistically different at P < 0.05.

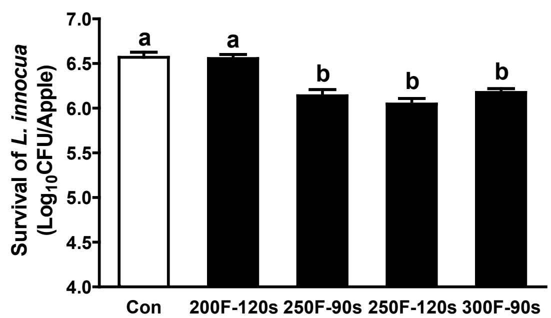

Fig. 2. Survival of L. innocua on Granny Smith apples*.*
Mean ± SEM, n=12, bars with different letters on the top are statistically different at P < 0.05.

With the results from the year 2016, we did not see more than 1 log reduction of *L. innocua* (a surrogate strain of *L. monocytogenes*) with high temperature conditions in the dyer.
This made us try to understand why we did not see the reduction even though we know from the literature that the *L. monocytogenes* cannot survive at high temperatures.

To better understand how bacteria can survive on the surface of the apple during drying at high temperature, the apple peel surface was analyzed under scanning electron microscopy. Microscopy analysis revealed that the apple peel surface is covered with numerous microstructures, such as lenticels and microcracks. Three common apple varieties were analyzed, Gala, Granny Smith, and Golden Delicious. In all varieties, microcracks were mostly present in the calyx and the stem bowl areas. These microcracks are actually big size for the *Listeria* spp. and other pathogens, but probably too small for the water or other chemicals to enter. We did more research in this matter and have published an article titled "*Apple Peel Morphology and Attachment of Listeria Innocua through Aqueous Environment as shown by Scanning Electron Microscopy"* in the Food Control journal.

Microscopy observations were followed by microbial enumeration, which confirmed that bacteria attached to the calyx and stem bowl sections primarily. Calyx and stem bowl sections harbored approximately 150 times more bacteria than the equatorial section of the apple. The *L. innocua* was well hidden in the cracks, which are hard to reach by many of the interventions typically used, including the hot air (Fig 3).

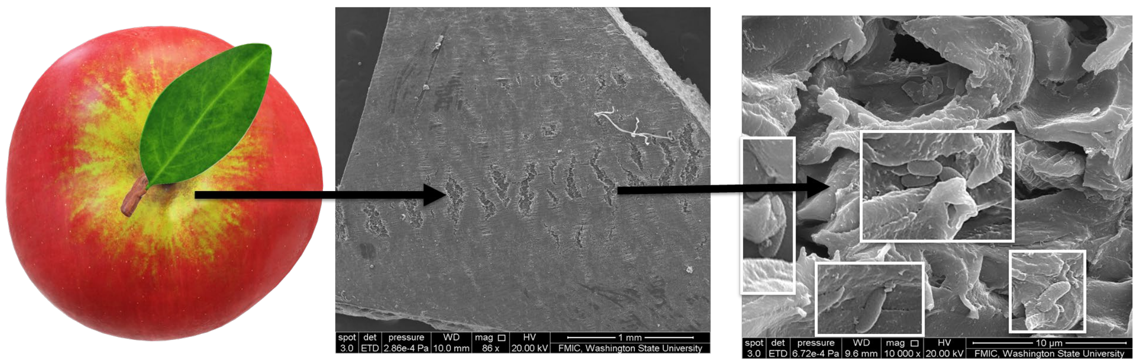

Fig. 3. Scanning electron microscopy analysis of apple peel surface. *Apple peel surface was covered with microcracks which harbored and protect bacteria.*

Furthermore, the surface of apple peel is covered with a natural layer of wax that governs hydrophobic character and water-repelling properties. The high surface tension of the water and water solution of commonly used sanitizers such as chlorine and peracetic acid prevent it from spreading on the apple surface. We found that the water or other chemicals used with water have a very high contact angle, which can suggest they don't adhere to the apple skin closely and thus may not reach the hidden *L. innocua* in microcracks.

To decrease the surface tension, we decided to add a small concentration of surfactant to water and examine if it will help to reach bacteria. Lower surface tension and a better spread of the cleaning solution on the apple surface may help reach microstructures present on the surface of the apple and aid in their decontamination. Three different food-grade surfactants at concentration 0.1%, combined with peracetic acid at concentration 80 ppm, were used to clean two different varieties of apple, Gala and Granny Smith, which were then dried at two different time/temperature conditions. **The use of a surfactant helped to reduce bacterial count (Fig. 4).**

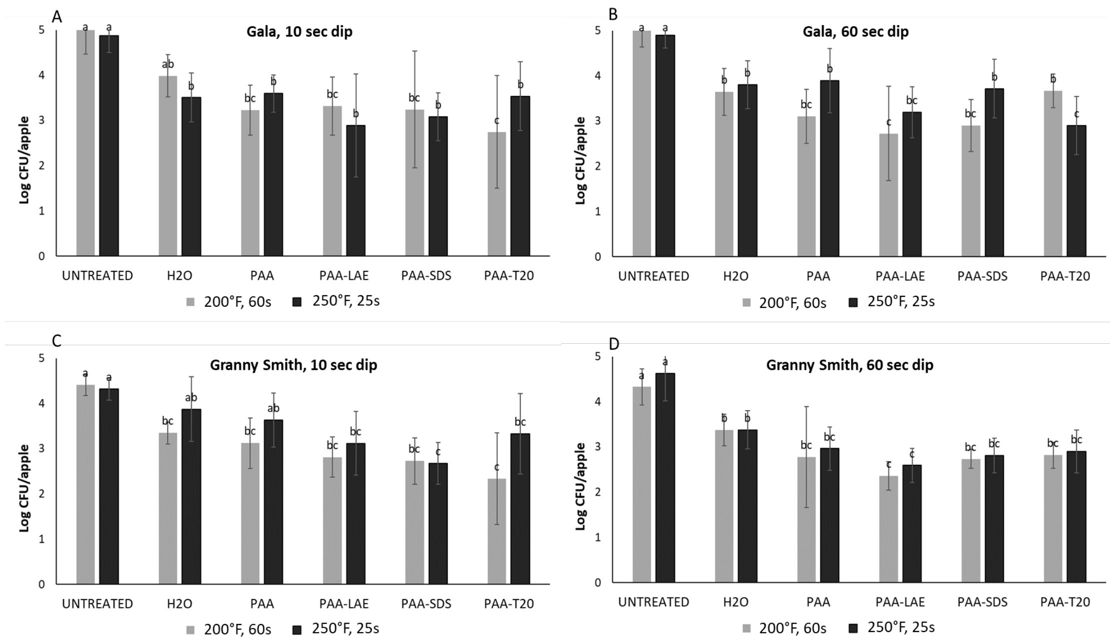

Fig. 4. Reduction of L. innocua on Gala and Granny Smith apples after surfactant dip followed by hot air drying. *Inoculated apples were dipped into cleaning solutions (H2O, PAA, PAA-LAE, PAA-SDS, PAA-T20), washed for 60 sec and hot air-dried at 93°C for 60 sec or 121°C for 25 sec. H_2O – tap water, PAA – Peracetic acid (80 ppm); LAE - lauric arginate (0.1%); SDS - sodium dodecyl sulfate (0.1%); T20 – Tween 20 (0.1%). Mean ± standard deviation; n = 9. Bars labeled with different letters indicate a significant difference ($P<0.05$) between treatments.* ***(Confidential data).***

Additionally, the application of surfactants resulted in enhanced drying of the solutions from the surface of the apples when compared with water and peracetic acid. Apples were almost dry even when the time of drying was only 25s. Applied treatments did not cause damage to the apples, such as heat burn or skin discoloration. We measured the temperature of the apple surface immediately after drying, and it did not exceed 104°F. This temperature can be normally observed during sunny summer days.

We also examined the influence of surfactant wash followed by hot air drying on apple texture over the 21-day storage (at 70°F and 40°F). Applied treatment had no significant effect on the apple texture of Gala and Granny Smith apples (Fig. 5), showing that surfactant wash combined with hot air drying did not affect apple quality.

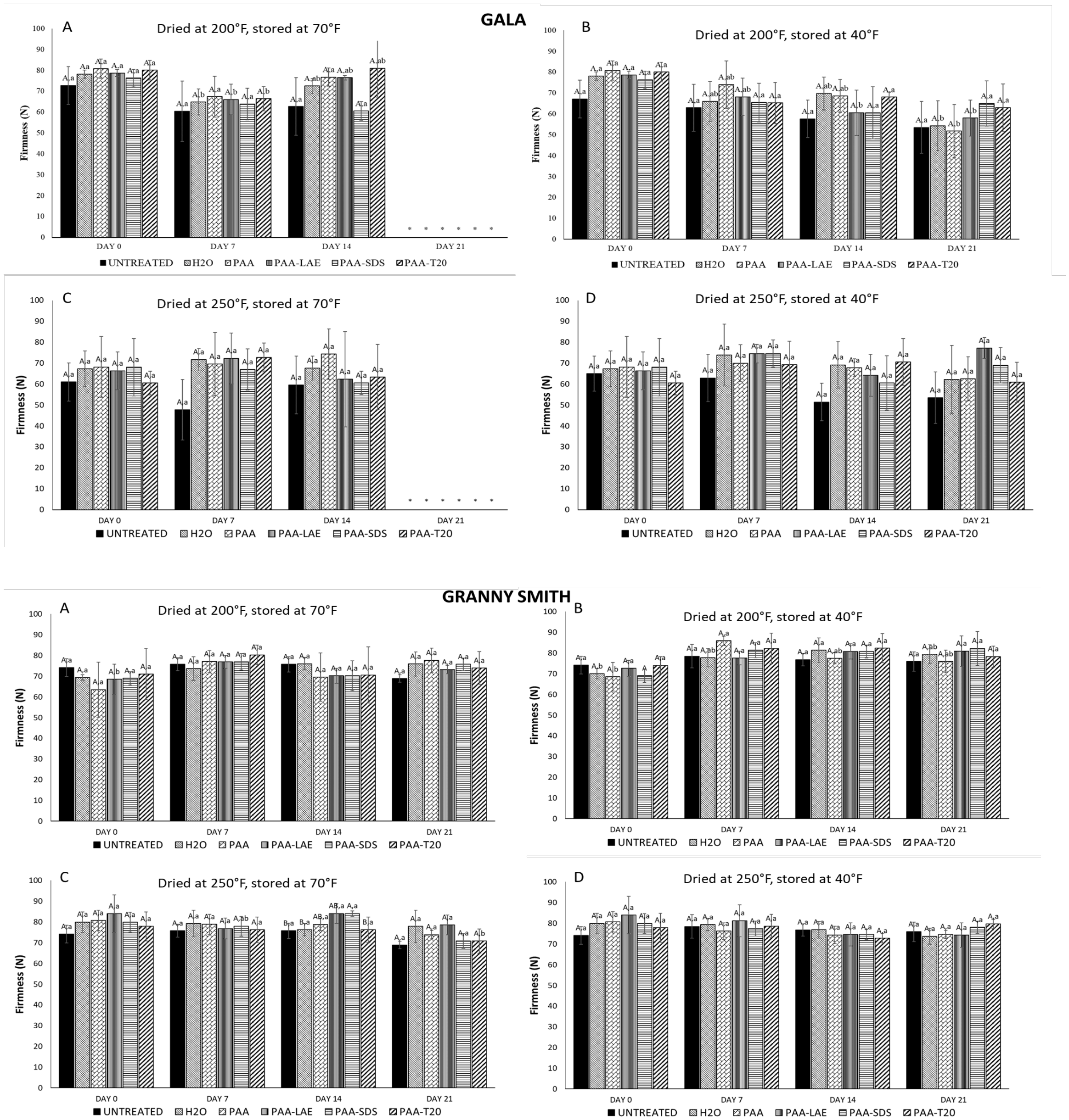

Fig. 5. Effect of the hot air drying on the firmness of the Gala and Granny Smith apples over 21-day storage. *Apples were cleaned with various cleaning solutions (H2O, PAA, PAA-LAE, PAA-SDS, PAA-T20) for 60 sec and hot air-dried at 93°C for 1 min (A, B) or 121°C for 25 sec (C, D). The firmness of the apples was measured at 0, 7, 14, and 21 days of storage at room temperature and compared with untreated apples. For each treatment and time point, 5 apples (n=5) were analyzed.*

** Apple texture was too springy, the probe could not penetrate the flesh.*

H2O – tap water, PAA – Peracetic acid (80 ppm); LAE - lauric arginate (0.1%); SDS - sodium dodecyl sulfate (0.1%); T20 – Tween 20 (0.1%).

Bars represent mean and standard deviation. Bars labeled with different uppercase letters (A, B) indicate a significant difference between apples after the same treatment at different time points (P<0.01). Bars labeled with different lowercase letters (a, b) indicate a significant difference between apples after the same treatment at different time points (P<0.01).

(Confidential data, please do not publish this online for at least 12 months).

Objective 3

The key benefit of this impingement drying method is the fact that the air is forced at a high velocity on to the fruit, which leads to drying of the surface only. Our hypothesis was that this uniqueness of the drying method would help to raise the drying temperature and reduce the drying time. This would help to increase the production capacity and potentially benefit the fruit quality and safety.

We surveyed the current drying systems in various packing houses. Some of the key observations include:

- The current drying temperatures range from 70 to 140°F for two to three minutes.
- Often much heat is lost to the surroundings.
- The dryer footprint is generally significant, relative to the packing line.
- Most packing houses do not keep track of the energy spent on this unit operation.
- From our interviews with the packing houses, they are aware that this unit operation does take a significant amount of space and money to operate.
- Most packing houses expressed that if the dryer footprint is reduced, then that will enable them to use the saved space for other interventions.

Key points from our assessments related to the scale-up of this unit operation:

- For the small scale system that we modified using off the shelf pizza oven, we were able to dry the apples with an actual dryer bed of 16 inches x 16 inches.
- The maximum drying temperature that can be used for all apples would be 225°F with the residence time of less than 25 seconds, without compromising the quality of the apples.
- Even if we are more conservative and use a temperature of less than 200°F, the residence time in the machine can be below one minute.
- This can increase the throughput through the dryer by more than double.
- From our calculations, in the scaled-up version, we can have a drying bed length of less than 3 feet, keeping the same bed width as we currently have. This will reduce the footprint by at least 50%.
- Further, the quantity of the hot air required will also be reduced significantly, as the air will be directed very close to the fruit.
- It will also be easier to maintain the environment inside the dryer at a higher temperature due to less volume inside the dryer.

We will be very happy to work with any of the packing houses if they would like to experiment with this, especially if they are planning on installing new lines or at a state where they would be replacing the existing dryer.

EXECUTIVE SUMMARY

Project Title: Improving food safety of fresh apples by hot air impingement drying

Keywords: food safety, impingement drying, *Listeria innocua,* wax

Abstract: This project explored the potential of the use of impingement drying technique in the apple packing process. The impingement drying can reduce the current dryer footprint and provide the opportunity to use as additional food safety interventions on the packing line.

The primary goal of this project was to understand the impacts of the higher drying temperatures on the quality of the wax and the fruit over the standard storage period. Tests were conducted in the laboratory using an impingement drying oven to assess the impacts of the higher drying temperature on the wax and fruit quality. Temperatures of 100, 150, and 200˚F were tested at different drying times of 1, 2, and 3 min. The wax quality (glossiness) and the fruit quality (weight loss, soluble solids, and pH) were tested on a weekly basis for three weeks of cold storage. It was found that higher temperatures resulted in higher gloss values. In other words, higher drying temperatures led to more shiny apples for both Carnauba and Shellac waxes. Although, for the Shellac wax in specific, the wax quality was negatively impacted when the temperature of the drying was increased from 100 to 150ºF. However, at 200ºF, the wax quality got better with increased glossiness compared to 100ºF drying temperature. Although, for the Carnauba wax, the glossiness increased with any increase in drying temperature.

Based on this, we conducted additional studies to assess the impact of the higher drying temperatures on the microbiological load of the apples. From the results from the initial tests, we did not see more than 1 log reduction of *L. innocua* (a surrogate strain of *L. monocytogenes*) with high-temperature conditions in the dyer. To better understand how bacteria can survive on the surface of the apple during drying in high temperature, the apple peel surface was analyzed under scanning electron microscopy, which revealed that the apple peel surface is covered with numerous microstructures, such as lenticels and microcracks that can protect the bacteria. Results of the microscopy analysis were summarized in the manuscript titled "*Apple Peel Morphology and Attachment of Listeria Innocua through Aqueous Environment as shown by Scanning Electron Microscopy"* published in the Food Control journal.

To enhance the bacterial reduction, apples were first cleaned with sanitizer combined with food-grade surfactants and then dried at temperatures below 250ºF. The use of surfactant helped to reduce bacterial count, with maximum reduction at approximately 2 log CFU/apple. Additionally, the application of surfactants resulted in enhanced drying of the solutions from the surface of the apples when compared with water and peracetic acid. Applied treatments did not cause damage to the apples, such as heat burn or skin discoloration, and had no significant effect on the apple texture over the 21-day storage (at 70°F and 40°F) of analyzed apples.