FINAL PROJECT REPORT **PROPOSED DURATION**: 1 Year

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

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Cooperators: Laura Grunenfelder – Northwest Horticultural Council, Van Doren Sales, Inc., Stemilt Growers LLC., Double Diamond Fruit, Co., Pace International LLC., US Syntec, Hansen Fruit Company, Washington Fruit & Produce Company and many others packing houses.

Total Project Request: Year 1: $56,743

Note: A new 3-year proposal was funded to continue the work on this idea. This report is the conclusion of the 1-year project that was funded in 2014. The continuing report for the 3-year proposal has been submitted separately.

Other funding sources: Part of the PI's new faculty start-up funds were used to support this project for covering part of the equipment, supplies and salaries.

Budget 1
Organization Name: WSU **Contract Administrator:** Ben Weller
Telephone: 509-335-0052 **Email address:** wellerb@wsu.edu

Item	**2014-15**
Salaries	$32,295
Benefits	$4,945
Wages	$4,291
Benefits	$416
Equipment	$5,000
Supplies	$6,796
Travel	$3,000
Miscellaneous	$0
Plot Fees	$0
Total	$56,743

Footnotes:
The majority of the funding requested was to cover graduate student wages and part time technician wages. Funds are also requested for wages to support an undergraduate student to help with the experiments. Some funds were requested to cover part of the cost for impingement dryer, supplies for using analytical equipment and other laboratory supplies to accomplish the various planned experiments. Travel funds were requested to cover travel costs related to the project work, such as trips to the packing facilities in Wenatchee and Yakima.

RECAP OF ORIGINAL OBJECTIVES

The objective of this proposal was to conduct a feasibility study on the potential of hot air impingement technology for drying waxed apples. ***Specifically we wanted to investigate if the high drying air temperature will maintain the quality of the wax coating and does not negatively impact the fruit quality.***

The more specific objectives of the proposal were:

1) Develop a thorough understanding of the current drying process and properties of the waxes commonly used in the apple packing process.
   - Specifically, to understand the upper limits of the wax drying in terms of temperature.

2) Determine the impingement drying characteristics of wax coated apples and the impact on quality of the apples.
   - Identify the effects of the temperature and drying time on the wax and apple quality.
   - Design and build a pilot scale hot air impingement dryer and test it to determine if this technology has the potential to dry the waxed apples at higher temperature without negatively affecting the quality.

SIGNIFICANT FINDINGS

All the objectives set forward for this project have been completed. Below are the list of key tasks completed and the key findings from the work.

- Rheological properties of two kinds of waxes (Carnauba and Shellac) were studied.
- An assessment of the current drying conditions in different packing houses was conducted by more than 12 plant visits.
- Drying characteristics of apples coated with both Carnauba and Shellac waxes with convection air drying method were thoroughly studied at a drying air temperature range of 100 to 200^{o}F and drying times of 1 to 3 minutes, as determined by assessment of current packinghouse conditions.
- Quality assessments were conducted for apples dried with the (conventional) convection drying method over a three week period.
- An impingement dryer was purchased after thoroughly researching the options available in the market.
- The new impingement dryer purchased was modified to:
  - Increase the clearance for drying bigger apples
  - Conveyor belt was modified to suit the apple drying process
- Plant trials were conducted in a packing facility to determine the potential effectiveness of the impingement drying of waxed apples.
- Both types of wax (shellac and carnauba) behave differently under higher heat conditions.
- Viscosity of both waxes reduces significantly with increase in temperature.
- Both Carnauba and Shellac waxes can be effectively dried at higher temperatures (up to 200^{o}F), in a regular convection air dryer.
- The Shellac wax tends to have flaking issues around 100^{o}F. However, with an increase in temperature beyond 150^{o}F, it provides a high level of gloss on apples.
- Carnauba wax provides good performance in the temperature range of 100 to 200^{o}F.
- In general, at 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.
- In-plant impingement drying tests provided very encouraging results on the drying of waxed apples.

- We observed that the drying temperatures could be increased to 300ºF for both the Carnauba and Shellac waxes without negatively affecting the glossiness on the dried apples.
- With higher temperatures of 250ºF and 300ºF, shorter drying times (less than 1 min) was found to be more beneficial.
- Longer drying times at higher temperatures had negative effects on the wax quality.

Overall, we had very encouraging results from the first year of the project. A new 3 year project was funded during last year to explore this idea further. A continuing report for the first year of the work has been submitted for that project separately. In that project we have done extensive testing of the apples in the plant for the quality assessment and some preliminary work on the impacts on the microbiological load has been started.

METHODS

All the materials (apples and waxes) were obtained from the various co-operators.

For the first objective, initially visits were made to different packing facilities and data collected. The drying temperature and times were recorded. Along with this the temperatures of the apples surface and core were also recorded. These measurements were taken with standard temperature recorders and thermocouples.

Waxes were tested using a rheometer to understand the effects of their viscosity behaviour as an effect of temperature. Viscosity and melting characteristics helped us to understand the spread-ability of the waxes. The drying characteristics of the waxes were also tested using the waxing sheets. These drying characteristics of the waxes helped us to determine the best drying conditions for the impingement drying system.

Initial drying studies were conducted using a convection oven (Model 414004-568, VWR International, LLC, Bridgeport, NJ). The details of the experiments are as described below in the results section. The already cleaned apples were obtained from the packing house. Wax was applied by hand and dried at different conditions. The quality of the apples (glossiness before and after drying, pH, ºBrix, weight loss, as well as assessments of wax quality, such as dripping, flaking, and cracking) were monitored over a period of 3 months. Standard procedures were followed.

For the Impingement drying studies, a new oven was purchased (PS628E, WOW^2, Middleby Marshall, Elgin, IL). The oven was disassembled to understand the air flow mechanisms. Air flow ducts were redesigned and the oven was modified to have about 6 inch clearance for drying apples of all sizes. The oven was further modified by removing the original metal mesh conveyor belt with a conveyor belt similar to that in the packing house dryers. Plant trials were conducted to understand the performance of the newly modified dryer. Apples were waxed using a wax brush system and dried in the modified dryer at different settings. The glossiness of the apples were measured using a Glossmeter. The waxed and dried apples were stored over a period of 4 weeks to study the glossiness changes.

RESULTS & DISCUSSION

i) Current drying conditions in packing houses:

We visited various apple packing houses and assessed the drying conditions (more than 15). Thanks to all the packing houses that provided tours of their facilities and helped us with drying temperature readings and information regarding drying conditions. We found that the drying conditions range very broadly, with the air temperatures ranging from 80ºF to 150ºF. The drying times were narrow, ranging from 2 ½ minutes to 3 minutes.

ii) Convection air drying of waxed apples:

A study was conducted to understand the drying characteristics of the Carnauba and Shellac waxes using a convection dryer in the laboratory.

Cleaned and un-waxed Fuji apples (one pallet) were hand-collected from an apple packing line. The apples were transported to Pullman for testing with the convection drying process. Two kinds of waxes (Carnauba and Shellac) were obtained from Pace International LLC and US Syntec (each) for testing. Drying studies were conducted in a convection oven (Model 414004-568, VWR International, LLC, Bridgeport, NJ). Drying temperature of 100 to 200ºF were studied along with drying times of 1, 2 and 3 minutes. Apples were hand waxed following the procedures described to us by our co-operators. After hand waxing, the apples were dried at various conditions of temperature and time combinations. After drying, the Apples were tested for Gloss, ºBrix and pH. Further, the apples were stored for three weeks in a walk-in cooler in the pilot plant facilities in Pullman. Apples were pulled out every week and the quality parameters were tested.

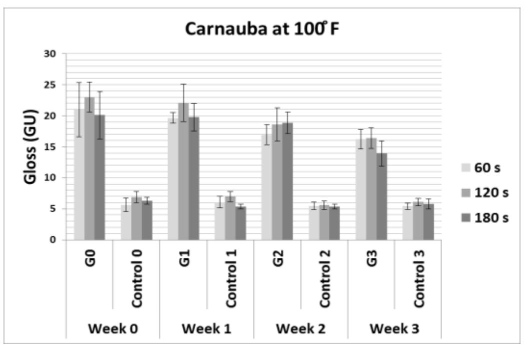

Fig 1. Gloss data for Fuji Apples coated with Carnauba.

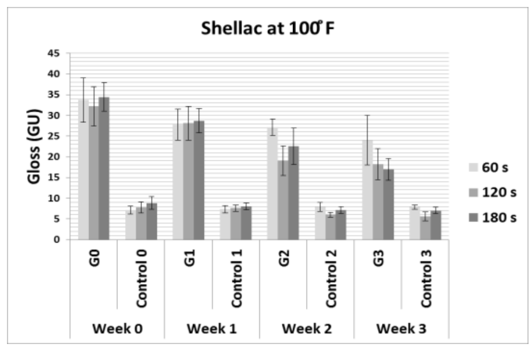

Fig 2. Gloss data for Fuji Apples coated with Shellac.

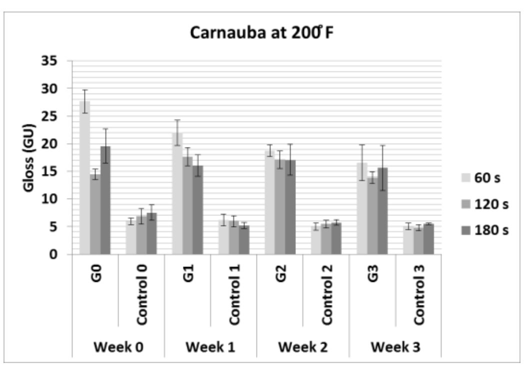

Fig 3. Gloss data for Fuji Apples coated with Carnauba.

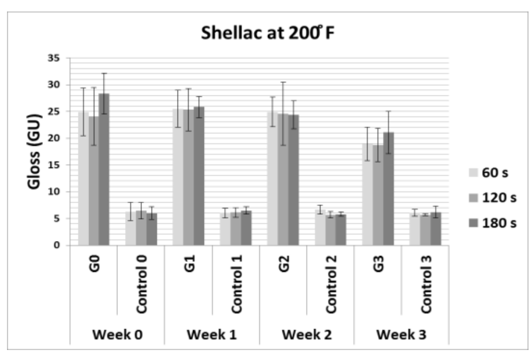

Fig 4. Gloss data for Fuji Apples coated with Shellac.

Figures 1 through 4 show the gloss results of the apples coated with either Carnauba or Shellac wax and dried at different drying conditions. From these results we saw that there were no statistically significant differences in the Apple glossiness at different temperatures and times of drying.

However, we generally observed that the Shellac wax has more glossiness at higher temperatures than the Carnauba wax. “G” in the figures above represent the wax treated samples.

Shellac was found to be more sensitive to drying temperatures at 100°F. At this temperature, the wax coated well, but during storage started to deteriorate. The apples pulled out of the storage at the end of the first week showed lot of flaking of the coating (Fig 5). This phenomenon was observed only for the Shellac wax, at lower temperatures (100°F) and longer drying time of 2 minutes or greater. This phenomenon was not present at higher drying temperatures for this wax. This result was encouraging for the use of higher temperature drying with this wax. Carnauba wax did not show any issues in these drying experiments.

Fig 5. Shellac wax showing flaking at 150°F.

Figures 6 through 9, show the data of the °Brix of the apples dried at 100 and 200°F for 1, 2 and 3 minutes. The figures show the data for both Carnauba and Shellac coated apples. We did not see any significant differences in these apples, suggesting that the higher temperature drying did not have any negative impacts for this quality parameter, although additional studies are warranted.

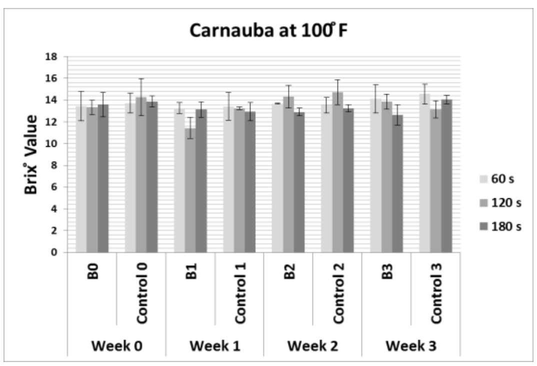

Fig 6. °Brix data for Fuji Apples coated with Carnauba.

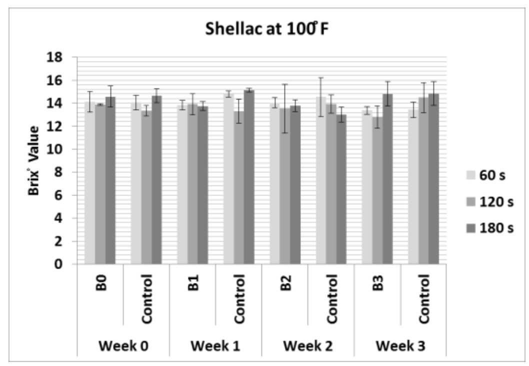

Fig 7. °Brix data for Fuji Apples coated with Shellac.

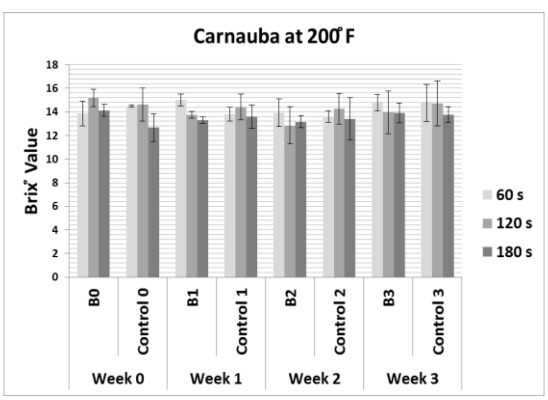

Fig 8. °Brix data for Fuji Apples coated with Carnauba.

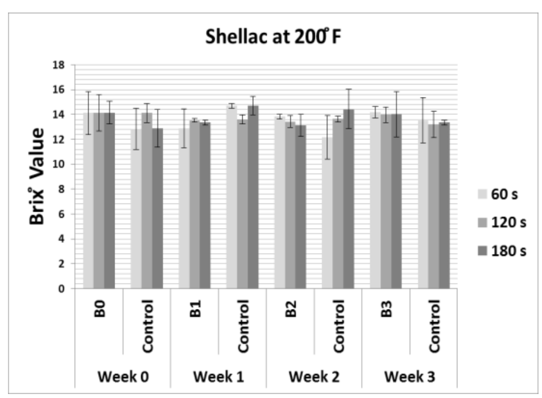

Fig 9. °Brix data for Fuji Apples coated with Shellac.

The results for the pH of the apples were also consistent among all the treatments. We did not see any visual deterioration of the apples for all the treatments.

Overall, from this experimental work we learned that higher drying temperatures (up to 200ºF) can be used without negatively impacting the quality of the wax and the apples in general. We also did trials with two other varieties (red delicious and gala) of the apples, although not as broad of study as completed for Fuji. We saw similar results for other varieties of the apples, although additional, in-depth studies are needed.

iii) Impingement air drying of waxed apples:

During the last year, we simultaneously started working on the impingement drying process. Initially, we had thought to buy a small unit that can fit in the laboratory. After conducting a lot of research on different off-the-shelf impingement drying units, we purchased the Hot Air Impingement Oven (PS628E, WOW^2, Middleby Marshall, Elgin, IL). This unit was more flexible and had the range of air velocities and temperatures needed.

This unit had a wire mesh conveyor with a clearance of only 3 inches. If the conveyor was modified to resemble current apple dryers, the clearance would be even more limited.

This forced us to take close look at the dryer design. The dryer air flow paths were modified, and the clearance increased to 6 inches. Further, we replaced the conveyor belt with the roller belt conveyor, similar to what is currently used in the packing lines. Please see Fig. 10, for the modified impingement dryer.

Fig 10. Modified impingement dryer in use in packing house

Following the completion of the modifications, we took the dryer to a packing house. One of our co-operators was very helpful and welcoming to us, so we could test the dryer in their facility.

During the first trials, we used the dryer to test the upper limits of the drying temperatures for drying of the apple waxes, testing both the Carnauba and Shellac waxes with drying air temperatures ranging from 150 to 300ºF. ***Interestingly, the higher drying temperatures were found to be more favourable for efficient drying of the waxes in terms of the wax finish and glossiness.***

For Carnauba wax, the drying temperature of 250ºF was found to be optimum from this preliminary testing. The appearance of the wax was still good up to 300ºF, beyond which the wax became too thin and started to flow away from the apple surface. We completed a experimental design to study the gloss of the apples coated with Carnauba wax. Fig. 11 shows the gloss data of the Carnauba coated apples at different impingement drying conditions. We can see the glossiness of the apples immediately after drying and after a week of storage time.

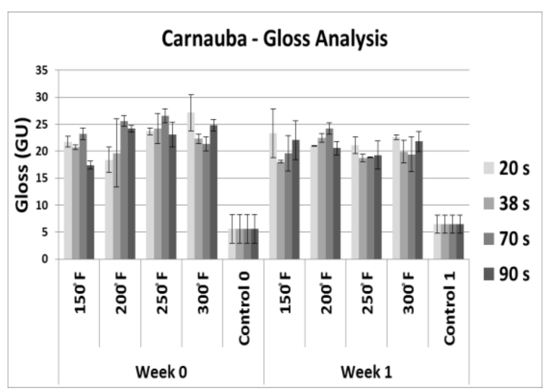

Fig 11. Glossiness data of Apples coated with Carnauba and dried by hot air impingement dryer.

As indicated in Fig. 11, the glossiness of the apples did not change significantly after one week of storage at 40ºF. We will continue to monitor these apples for a total of 5 weeks.

For Shellac wax, the impingement drying temperature of 300ºF proved to be more effective. At this high temperature of drying, only 20 seconds of drying time was required. In general we observed that the Shellac wax performed better at higher temperatures. However, the Shellac wax did not perform well above 300ºF, similar to Carnauba wax.

Plant Trial Results:

Further during the initial part of the year 2015, another study was conducted to assess the impact of impingement drying on the glossiness of the apples through the storage period of 5 weeks. Weks 1 through 4 were in cold storage conditions and week 5 was when the apples were kept in the room conditions.

Golden delicious variety of apples was selected for testing, based on the availability in the plant at the time. The apples were coated with carnauba wax and dried in the impingement dryer at 4 different temperature settings of 150, 200, 250 and 300ºF at their respective optimum drying times. The optimum drying time was determined by making sure the wax was fully dried and the apples were shiny visually without any damage to the typical wax quality.

Table 1. Gloss data of the impingement dried "golden delicious" apples over the storage period of 5 weeks.

Wax Type	Drying Temp (ºF)	Drying Time (sec)	Gloss Data (GU)							
			Week 1	Week 1	Week 3	Week 3	Week 4	Week 4	Week 5	Week 5
			AVG	Std. Dev.	AVG	Std. Dev.	AVG	Std. Dev.	AVG	Std. Dev.
Un-Waxed	N/A	N/A	6.78	1.19	N/A	N/A	N/A	N/A	N/A	N/A
Carnauba	150	20	23.30	4.56	18.62	1.75	19.56	3.36	16.61	1.31
Carnauba	150	38	18.01	0.25	12.95	0.46	12.00	0.14	11.05	1.20
Carnauba	150	70	19.61	3.32	17.38	0.81	15.65	2.75	14.00	4.69
Carnauba	150	90	22.06	3.59	17.00	1.46	16.53	0.20	14.82	1.38
Carnauba	200	20	20.96	0.10	13.63	0.66	14.54	3.51	10.72	1.80
Carnauba	200	38	22.46	0.81	14.06	0.24	14.88	2.66	13.99	3.25
Carnauba	200	70	24.20	1.05	15.45	0.05	16.04	3.37	14.05	1.17
Carnauba	200	90	20.57	1.27	14.82	0.18	15.84	0.57	14.46	0.18
Carnauba	250	20	21.06	1.58	16.44	0.78	15.98	0.41	14.80	3.56
Carnauba	250	38	18.76	0.67	15.66	0.23	16.46	1.92	13.81	1.25
Carnauba	250	70	18.88	0.06	17.08	0.95	16.25	2.08	15.11	2.10
Carnauba	250	90	19.24	2.64	DNR	DNR	DNR	DNR	DNR	DNR
Carnauba	300	20	22.56	0.40	16.37	0.29	16.69	3.05	14.63	2.56
Carnauba	300	38	19.87	2.13	17.19	1.85	16.61	1.81	16.53	0.62
Carnauba	300	70	19.41	3.18	DNR	DNR	DNR	DNR	DNR	DNR
Carnauba	300	90	21.77	1.87	DNR	DNR	DNR	DNR	DNR	DNR

(Note for the table: N/A means not applicable; DNR means did not run, as the apple got heat damage)

From the Table 1, we can observe that the drying temperatures up to 300ºF, did not lead to any loss in the glossiness. Although, it should be noticed that the glossiness of the apples dried at 300ºF and drying time of greater than 38 sec, led to decrease in the glossiness. Further, this high temperature and increased drying time, led to loss of the overall quality of the apple. Thus these samples were discarded.

<u>iv) Internal temperature of the apples during impingement drying process:</u>

During the impingement drying tests, the surface and internal core temperatures of the apples were recorded. We found that with the complete range of the impingement drying tests conducted, the core temperature did not significantly change compared to the untreated control apple. Please see Fig. 12, showing the data of the surface and core temperatures of apples at various drying conditions.

These results are encouraging not only because of apple quality, but also for the positive impact it can have on the energy requirements for downstream cooling of the apples.

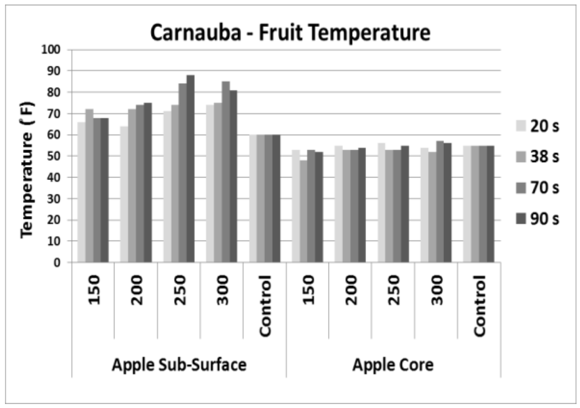

Fig 12. Temperature data of apples coated with Carnauba and dried by hot air impingement dryer.

SUMMARY:

The high temperature drying has shown the potential to dry the waxes (Carnauba and Shellac) effectively. Typically, it has been found that the higher temperature enhances the glossiness of the wax. The impingement drying method, in which the hot air is forced on to the apples, helps to dry the apples faster. With our experiments we consistently found that with the higher temperatures the drying time reduces very significantly. For example with 300ºF drying temperature, the drying time reduced to 30 seconds or less and at 250ºF, the drying time reduced to 60 seconds or less.

The next steps are to evaluate the effectiveness of the higher drying temperatures in reducing the microbiological loads of the fresh apples. Our hypothesis is that this high temperature on the surface of the fruit with the moisture present in the wax can help reduce the microbial loads. This can be shown with the help of the Fig 13a and 13b.

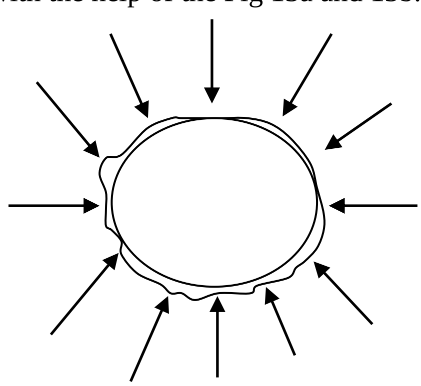

Fig 13a. Schematic of the apple before heating the surface

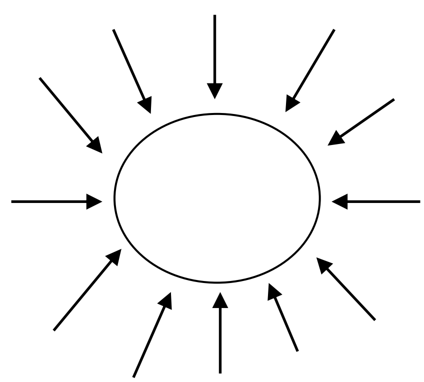

Fig 13b. Schematic of the apple after heating the surface

In the Fig 13a, we have shown the apple in the center with a thin layer of the wax solution on the surface. The wax is formulated with about 60 to 70% moisture (this is what we learnt from our conversations with the industry experts) which will evaporate during the hot air drying. In the Fig 13b, we show the layer of wax solution disappeared, suggesting that the water vapor in the wax has evaporated by creating a micro steam environment. This micro steam environment would help in reducing the microbial load.

Although, it is possible that when the apples are prepped for the waxing process the surface becomes fairly dry and the moisture present in the wax may not be enough to provide the micro steam environment that is needed to help reduce the microbial load.

Thus it may be necessary to test this hot air drying, while the excess moisture is present on the apple surface. We do know from the literature that the microorganisms are more resistant to heat in dry conditions than in moist conditions.

Because of the above reasoning and as a result of our preliminary microbiology studies that were conducted during this year (see the continuing project report); we are planning to modify the approaches for the microbiological experiments during this year's proposed work. Mainly, we will conduct inoculation studies in the laboratory with excess moisture on the apple surface and with the wax, to evaluate the effectiveness of the hot air drying on the microbial load reduction.

As it is we can confidently conclude that this drying technique if implemented in the packing lines can help with,

1. Reducing the footprint of the current dryer and thus providing more space for additional food safety interventions, such as additional chemical spray bars.
2. With the aid of the impingement drying process, the wax quality can be improved without sacrificing the fruit quality.
3. This drying method can help reduce the current drying times to less than a minute, if higher drying temperatures are used. This can help increase the product throughput.

OTHER OUTPUTS:

Two manuscripts as detailed below have been prepared from this research work and submitted to the peer reviewed journals for review.

1. Thapa BB, Behnam S, Wijesekara I, Aluwi NA, Kallu S, and Ganjyal GM. 2016. Impacts of convection drying temperatures and times on the postharvest quality of fresh waxed Fuji apples. *Postharvest Biology and Technology*. (In review).

2. Gu BJ, Behnam S, Wijesekara I, and Ganjyal GM. 2016. Characterization of glossiness of shellac and carnauba waxes under different drying conditions. *Postharvest Biology and Technology*. (In review).

We will be more than happy to share these manuscripts and all the data we have from this project with the WTFRC and all its members.

Executive Summary

The major 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. Along with this, we had proposed to develop a pilot scale impingement drying unit that can be used to test the feasibility of this drying technique.

Tests were conducted in the laboratory using a convection 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 the higher temperatures resulted in higher gloss values. In other words, higher drying temperature 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 150°F. But, at 200°F the wax quality got better with increased glossiness compared to 100°F 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.

This helps us conclude that higher temperatures up to 200°F can be used for drying of the waxed apples. Based on this, we do recommend that further studies need to be conduct to assess the impact of the higher drying temperatures with the current plant dryers on the microbiological loading of the apples.

Further, to test the concept of the impingement drying process, an off the shelf dryer was purchased and modified. The dryer was modified to increase the clearance of the drying zone to fit wide range of the apple sizes. With the assistance of one of the co-operators, we also replaced the mesh conveyor to the roller belt conveyor. This enabled us to have an impingement dryer as close as possible to the dryers currently used in most of the packing houses.

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 will 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.

The goal for this project was to see if the impingement drying will help increase the drying temperature without compromising the wax and fruit quality. We conducted a few plant trials with the dryer to determine the highest temperature that we can dry the fruit without compromising the wax and fruit quality. From this work, we found that depending on the variety of the fruit the drying temperature can be raised up to a maximum of 300°F. With the drying temperature at 300°F, the drying time was reduced to less than 30 seconds. We did find from our studies that some fruits cannot withstand this high temperature. For example, the red delicious variety, can withstand only up to 250°F, compared to the Fuji variety that can withstand up to 300°F.

As a results of this 1 year project work, we were funded a 3 year project to further evaluate the feasibility of this drying method to effectively dry the fruit and increase the food safety of the fresh packed apples.

We have completed the first year of the 3 year project where we have tested this dryer on few varieties and completed the studies on the wax and apple quality over the standard storage periods. Now we have started the work to evaluate the impacts of the impingement drying on the microbiological loads on the apples.