TECHNICAL POSITION PAPER ON AIR INJECTION

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DEFINITION

The use of air injection technology in the maple industry can be defined as: the forced introduction of air through a series of perforated pipes submerged in the boiling sap in the front and /or back pan of a maple syrup evaporator.

Several studies conducted in recent years have investigated aspects of the use of air injection technology in the process of maple syrup production. This technology was designed primarily to produce lighter-colored syrup which procured a higher market price for producers. No single study can encompass the wide range of conditions found among maple producers (different evaporators, size and design of equipment and maple operation, varying sap composition, varying air injector design and air flow rate, etc.), and it is not practical to scientifically replicate each of these different sets of conditions. Each of the studies had different objectives and was designed to answer a limited number of questions under certain conditions and constraints, and thus cannot be extrapolated beyond certain limits. In some instances, results of these different studies may appear to be contradictory; however each simply reflects the particular set of experimental conditions and emphasis on a specific question of interest. In most cases the perceived discrepancies can be explained. This document is an attempt to provide an overview of the key results that have been found to this point and to point out where the results are similar, and where they are not. Questions which require further research to answer are also identified.

COMPARISON OF SYRUP ATTRIBUTES PRODUCED WITH AND WITHOUT AIR INJECTION

Light Transmittance (Color)

All studies indicate that there is a strong effect of air injection on the color of maple syrup. Air injected syrup is generally significantly lighter in color (it has a higher light transmittance) than syrup produced without air injection. The increase in light transmittance appears to be influenced by a large number of factors. The effect is generally greatest in the early and mid-season, but may be reduced or absent in the late-season.

Light Transmittance Changes in Storage

Air injected syrup that is packed in retail containers behaves similarly to syrup produced without air injection over a storage period of one year. Color deterioration of both air injected and non air injected syrups proceed at the same rate in a given container type.

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pH

Maple syrup made with air injection has a significantly lower pH compared to syrup made without air injection, although this is not consistent across all studies. When observed, differences typically occur in early to mid-season, but not in the late-season, although the tendancy for a lower pH in air injected syrup is still often observed. During processing, sap pH tends to be slightly elevated in all partitions of air injected pans compared to non-air injected pans. In all cases, pH of syrup made with or without air injection was within the established range of pure maple syrup.

Conductivity

The conductivity of maple syrup produced with air injection is not significantly different from that produced without air injection.

Carbohydrate Composition

There were no significant differences in sucrose concentration between air injected and conventionally made syrup (without air injection). Some, but not all studies revealed a tendency for air injected syrup to have a slightly elevated level of invert sugars (glucose and fructose). When observed, differences in invert sugar levels did not fall outside the range documented for pure maple syrup.

Mineral & Metal Composition

In general, few differences were observed in the bulk mineral composition of maple syrup made with or without air injection. In some studies significant differences in some elements were observed, however these tended to be small and inconsistent, and in all cases the concentrations found were within the range of pure maple syrup.

Organic Acids

In a laboratory-level study, air injection resulted in reduced levels of oxalacetic acid in syrup, but did not significantly affect the concentration among the five other organic acids examined.

Phenolic Compounds

In a laboratory-level study, syrup made with air injection had significantly lower levels of syringaldehyde than syrup made without air injection. A tendency for higher level of vanillin with the use of air injection was observed, although the results were not statistically different. The coniferol content did not differ.

Qualitative monitoring during the production process showed that phenolic acid content decreased when air injection was used. This decrease seemed to be more important as the season progressed towards the end of the season.

Bioactivity

In the laboratory scale study, parameters such as the total soluble phenolic acid content, total antioxydant activity and oxydo-reduction potential were used to assess the impact of air injection on the bioactive properties of maple syrup. Preliminary results pointed to an alteration of these properties.

Production Factors (Defoamer, Niter, Temperature)

In a study using a standard type of maple evaporator, the amount of defoamer

required did not vary with or without air injection. Similarly, there was no difference in the rate of scale (niter) accumulation on pan surfaces, nor in the amount of loose scale (sugar sand) that was filtered from syrup.

In the same study, the temperature of the boiling sap was consistently and significantly lower in all partitions except the draw-off partition (where the air injection tubes were shortest). The liquid temperature averaged 7.7°C cooler (range 3.3 - 14.3°C) in air injected pans than in an evaporator without air injection.

Flavor and Volatile Compounds

The effects observed of air injection on syrup flavor varied somewhat between the different studies. This is due to the different manner by which the maple syrups were produced as well as the different sensorial analysis techniques used.

In a survey of commercial syrups made with and without air injection, the preliminary results on sensorial analysis based on the Maple Flavor Wheel, revealed a modification to the overall flavor profile with an increase in the tendency for foreign flavors due to air injection. A more complete study of the impact of air injection on sensory properties of maple syrup confirmed the previous tendencies. In the laboratory scale study, it was demonstrated, based on the Maple Flavor Wheel, that air injection modified the maple syrup flavor profile by increasing the level of the Vanilla flavour, while the level of the other flavor attributes were lower. The maple syrup samples were also evaluated by accredited inspectors from the Quebec industry in order to characterize them using the official standardized quality grading system. Out of 6 categories of off-flavors, the results indicated that air injection samples had more than twice as many unidentified origin off-flavors (R4) as compared to the non-injected syrup samples (31% R4 versus 12% R4, respectively), although these results were not statistically significant. No other category of off-flavor was detected. The inspectors also recorded 31% Good, 38% (slight taste of caramel, bud or wood) for the air injected maple syrup samples and 38% Good, 50% (slight taste of caramel, bud or wood) for the non-injected syrups. Of these, only the R4 category results in a price penalty to the producer. Similar results were observed in a parallel study with industrial evaporators. In general all the panellists of this study described air injected maple syrup global flavor using the following descriptors: honey, vanilla, acidic, chemical and oil taste. The total proportion of all off-flavors did not vary between air injected and non-air injected syrups.

In syrup produced simultaneously in paired identical evaporators boiling from a common sap source, there was no evidence of an increased frequency of total off-flavors resulting from air injection. The total concentration of volatile flavor compounds was significantly greater in syrup produced without air injection compared to syrup produced with air injection in both evaporator and laboratory studies. Several volatile compounds typical of maple syrup were significantly reduced or wholly absent in syrup produced with air injection, although this finding is not inconsistent with the fact that the syrup produced with air injection was significantly lighter in color.

Product Safety

This aspect was not directly addressed in any of these studies. However, the consensus is that to the best of our collective knowledge, there is no evidence for concern. It is understood that food safety measures and maple equipment manufacturers' operational guidelines, such as the use of an appropriate air filter, an appropriate air

uptake positioning and the use of equipment made of appropriate material for contact with food, must be respected while using the air injection technology

POTENTIAL MECHANISM(S) OF AIR INJECTION ON MAPLE SYRUP ATTRIBUTES

Overall mechanism(s)

The physical and chemical reactions involved in the production of maple syrup are very complex and not that well understood. Air injection adds yet another complicating factor in the understanding of the color and flavor development processes. The development of the characteristic amber color and flavor profile of maple syrup (composed of a mixture of a number of flavor compounds) is, to a large extent, a result of the intricate interplay of the caramelisation and Maillard processes and the polymerization of phenolic compounds. The different studies have been conducted to measure the effects of air injection during the production of maple syrup and to elucidate some of the mechanisms that may be responsible for the changes observed. It has not been clearly demonstrated that these mechanisms are causal in the changes observed in the resultant syrup color and flavor. The introduction of air injection technology as documented in these studies may affect these processes in a number of possible ways such, including:

A) Reduction in processing temperature

Air injection resulted in substantial reductions in sap and syrup processing temperatures within a commercial evaporator system. These reduced temperatures could produce a reduction or delay in carmelization and Maillard reactions, resulting in reduced color and flavor development.

B) Chemical oxidation

An increased level of oxygen introduced by air injection (ambient air contains 21% oxygen) through sap in a laboratory setting produced higher levels of oxidizing compounds *in situ*, with a concomitant decrease in color precursors and/or colored polymers. This oxidation could result in lighter-colored maple syrup, a reduced flavor profile, and a tendancy for syrup to contain elevated levels of specific off-flavors (R4-unidentified origin).

C) Altering the alkaline degradation phase

Substantial color and flavour development in maple syrup can occur during the 'alkaline degradation phase' of processing maple sap into syrup. Reductions in sap and syrup pH are typically observed with air injection. The lower pH levels found during sap processing with air injection could reduce the time sap spends in the alkaline degradation phase, thereby resulting in reduced color and flavour development in finished syrup.

D) Mechanical agitation of sap

The mechanical action of bubbling air may increase the surface area of sap exposed to the air. This could lead to a loss in volatile compounds that are involved in flavor development, resulting in reduced flavor/aroma in finished maple syrup produced with air injection. This mechanical action may also provide a better distribution of heat during the processing of sap.

To summarize, the effects produced by all the above processes, including the reduction of processing temperature, the chemical action of oxygen, alterations in the extent of the alkaline degradation phase, and probably to a lesser extent, the mechanical agitation as a result of air injection, are all operating simultaneously. Depending on the

specific operating conditions and the specific portion of the process, one mechanism may predominate over the others. The precise contribution of each possible mechanism to the overall effects observed is currently unknown. A survey conducted amongst producers using air injectors suggest that the full range of conditions and effects might be expected.

CONCLUSION

The overview of the results obtained from these studies demonstrates that some maple syrup attributes may differ as a result of the use of air injection during maple syrup production. Even though the occurrence of several phenomenons was observed in these studies, results have well demonstrated the reduction of color and flavor development due to lower processing temperatures, as well as the alteration of maple syrup chemical components through oxidation reactions. It is important to note that these phenomena are not well understood and, even if they occur simultaneously during processing, their relative contribution to the observed modifications in maple syrup properties were not evaluated and may greatly depend on the wide range of processing parameters.

The results from the various studies may be reconciled with the following hypothesis: When the processing conditions are such that the processing temperature is significantly lowered, then the normal color formation may be retarded due to a delay in the carmelization and Maillard reactions. The flavor profile is similarly less developed, thereby providing less masking of certain flavors. The intense air flow responsible for important temperature lowering also leads to a loss of the volatile compounds.

When the temperature lowering is not as extreme, oxidation of the color precursors which are being formed at a relatively normal rate may become more important. The oxidation of components such as the phenolic compounds is concomitant with changes in the flavor profile (namely diminished characteristic flavors and increased in off-flavors) and bioactivity.

The processing conditions may favour one mechanism over the other, although these mechanisms could all be operating simultaneously. No one mechanism can be expected to explain the full spectrum of phenomena observed, given the range of equipment set-ups and operating conditions that exist in the field.

Although the majority of syrups produced with air injection may be considered to fall within the normal range of limits of composition of maple syrup, they are decidedly skewed towards lighter colored syrup with considerably less developed taste.

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Table 1 Comparison of results of air injection studies at Centre Acer and the UVM Proctor Maple Research Center. **Legend:** + = significant increase with air injection, - = significant decrease with air injection, 0 = no significant change in syrup attribute. No symbol indicates that measurement was not taken in that study.

Parameter	Centre Acer (Lab Scale)	Centre Acer (Survey)	CARA (Evaporator)	PMRC Sap (Evaporator)	PMRC Concentrate (Evaporator)
Light Transmittance (%)	+	+	+	+	+
pH	-	-		0	0
Conductivity (μS/cm2)				0	0
Carbohydrate Composition					
Sucrose (%)	0			0	0
Glucose (%)	0			+	+
Fructose (%)	0			0	+
Galactose (%)	0				
Maltotriose	0				
Total invert sugar (%)				+	+
Mineral/Metal Composition					
Aluminum (ppm)					+
Calcium (ppm)	0			0	0
Copper (ppm)					0
Iron (ppm)				0	0
Magnesium (ppm)	0			+	+
Manganese (ppm)	0			+	+
Nitrogen (ppm)				0	+
Phosphorous (ppm)					0
Potassium (ppm)	0			+	0
Sodium (ppm)	0			-	0
Sulfur (ppm)				+	0
Zinc (ppm)	0				0
Organic Acids (%)					
Oxalacetic	-				
Gluconic	0				
Malic	0				
Succinic	0				
Fumaric	0				
Lactic	0				
Phenolics (ppm)					
Vanillin	0(tendency↑)				
Conyferol	0				
Syringaldehyde	-				
Production Factors					
Total defoamer used (g)					0
Filtered Niter (g/kg syrup)				0	0
Scale Thickness (μm)				0	0
Liquid Temperature				-(3 to14°C)	-
Evaporation Rate				-	0
Flavors / Off-Flavors					
Volatile Flavor Compounds	-			-	-
Flavor (organoleptic)	+Vanilla, -others			-	
Off-flavors (organoleptic)	0 (+R4)			0	0

Table 2 Air injection study at Centre Acer. **Legend:** + = increase with air injection, - = decrease with air injection, 0 = no change in syrup attribute. No symbol indicates that measurement was not taken in that study.

Parameter measured	Increasing the level of O2	Notes
Total antioxidant activity (%)	-	
Dissolved Oxygen (% saturation)	+	Only at early season
Oxydo-reduction potential (mV)	+	0 in late season
UV-Visible spectra (AU)	-	
Temperature (ºC)	0 (gas injection)	∆4ºC gas injected-no injection
Monitoring during production of air-injected and non-injected maple syrups		
Total soluble phenolic acids content (g/L)[1]	-	
Hydrogen peroxide (mg/L)	+	0 in late season
Oxydo-reduction potential (mV)	+	0 in late season
Absorbance at 420, 342, 284, 277nm (AU)	-	

APPENDIX - ABSTRACTS/PAPERS

The following collection of abstracts and papers are not part of the technical consensus summary, but are included here for completeness.

Air injection in evaporators: impact on maple syrups quality

Adaption by N. Martin from: Boutin, J. 2005. "Injection d'air dans les évaporateurs: impact sur la qualité du sirop d'érable", Coopérative acéricole régionale des Appalaches (CARA), 163, rang du Nord, St-Pamphile, QC, G0R 3X0

In 2004, the Coopérative acéricole régionale des Appalaches (CARA), a group of organic maple producers, carried out a project aimed to evaluate the impact of air injection on maple syrup. The objectives of the project were: to verify the effects of air injection on maple syrup color, to determine the stability of these effects upon time and to evaluate the impact on maple flavor. The first experiment was done with four evaporators one equipped with air injection and three without. The second experiment was meant to evaluate the performance of a processing plant using air injection for the first time comparing it with the previous years. In both experiments, the results show that air injection has a great impact on light transmission producing lighter colored maple syrup. Maple syrup from the first experiment was packaged in small containers after conditioning and pasteurization treatments and stored for 8 months at room temperature. No difference was observed between air injected maple syrup and non-injected maple syrup. Results also showed that maple syrup flavors are greatly affected with use of air injection. From both experiments, sensory analysis showed a lost in the characteristic maple flavor and an increase in honey, vanilla and sugar flavors with the use of air injection along with a unpleasant mouth and throat sensation.

Air injectors for maple syrup production

N. Martin, S. Guay, M. Cournoyer, C. Charron, R. Gaudy, R. Desruisseaux, M. Cartier Centre ACER inc., 142, Rang Lainesse, St-Norbert d'Arthabaska, QC, G0P 1BO

In 2002, the maple syrup industry asked Centre ACER to carry out a research project allowing the documentation of the effects related to the use of this new technology. The work was done in 2003 when maple syrup samples were taken from 35 maple syrup producers half of whom were using the air injection technology. The objectives of the project

were: to determine if there was a color change in maple syrup produced with the use of the technology, when compared to the traditional process; to evaluate the differences through out the season; and to follow the color changes during storage. The study was not made for the purpose of understanding one system over another but to give an overall evaluation of the technology. Based on the results, we observed a lighter color in maple syrup samples made with the air injection technology, mostly at the beginning of the season. Stored for nine months in ideal conditions, maple syrup samples, produced at the beginning of the season, showed similar color conservation profile, when a better color conservation was observed for air injection samples produced from mid to the end of the season. However, the use of air injection seems to produce maple syrup with lower pH and flavour defects.

Study of the impact of air injection on maple syrup chemical and sensory properties

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Recently, maple producers have sought to produce syrup with a lighter color for its higher commercial value. Air injection during maple sap evaporation has been introduced to achieve this. The current research was meant to investigate the effect of this technology on maple syrups physical and sensory attributes and to see if air injection contravenes Quebec's provincial regulation forbidding the use of decoloring, bleaching or refining processes. The hypothesis upon which the research was based was that oxygen introduced into maple sap during evaporation causes oxidation of color/flavor precursors and colored polymers. Maple syrup was thus produced at lab scale under controlled conditions to ensure that all effects measured were directly attributable to the air injector process. Maple sap was concentrated using different levels of oxygen injected (without injection, $0\%O_2/100\%N_2$, $10\%O_2/90\%N_2$ and "air" $21\%O_2/79\%N_2$). The results showed that syrups produced with "air" injected were significantly lighter in color and lower in pH than the controls (without injection and $0\%O_2/100\%N_2$) and that this is proportional to the level of oxygen injected. While, these effects were significant in sap acquired in early and mid tapping season, there was no significant difference observed at the end of the season suggesting a link with sap composition. The monitoring of other parameters (DO, oxydo-reduction potential, H_2O_2, HMF and furfural content) also suggests that oxidation reactions may be involved. In parallel to these observations, the study showed that there was also an unfavourable impact of air injection on maple syrup flavor. Considering all these aspects, the use of air injection during maple syrup production is to be reconsidered.

At this point, it is worth noting that some important aspects of the technology weren't covered by our work such as the evaluation of the potential risks of maple syrup contamination, related to the use of the air injection, and of the conformity level with safety and sanitary rules in food transformation, should also be addressed.

Effects of air injection on syrup chemistry and flavor.

van den Berg[1], A.K., T.D. Perkins[1], M.L. Isselhardt[1], M.A. Godshall[2] and S.W. Lloyd[3].
Ontario Maple Syrup Producers Association Conference, Richards Landing, Ontario. July 2007.

Air injection is reported to have a variety of effects, including the production of lighter-colored syrup and reductions in the amount of sugar sand developed and deposited as nitre on pans. These effects, and whether air injection yields other effects on the chemistry and flavor of maple syrup, have not been rigorously tested. Thus, during the 2006 and 2007 production seasons we conducted experiments in the Maple Production Research Facility at the Proctor Maple Research Center to test the effects of air injection on the chemistry and flavor of maple syrup. The studies compared the chemistry, flavor,

sugar sand formation and nitre deposition of syrup produced with and without air injection simultaneously from a common sap source.

Effects of air injection combined with reverse osmosis on maple syrup chemistry and flavor.

van den Berg[1], A.K., T.D. Perkins[1], M.L. Isselhardt[1], M.A. Godshall[2] and S.W. Lloyd[3].

Ontario Maple Syrup Producers Association Conference, Owen Sound, Ontario. July 2008.

Air injection is reported to have a variety of effects, including the production of lighter-colored syrup and reductions in the amount of sugar sand developed and deposited as nitre on pans. Experiments were conducted during the 2006 and 2007 production seasons in the Maple Production Research Facility at the Proctor Maple Research Center to test the effects of air injection on the chemistry and flavor of maple syrup. The 2006 experiment first examined the basic effects of air injection by comparing syrup produced with and without air injection simultaneously from a common sap source. The 2007 experiment sought to investigate the effects of combining the use of air injection with the use of reverse osmosis (RO), as many producers often employ both types of technology. This presentation will report results from this experiment, which compared the chemistry and flavor of syrup produced with and without air injection simultaneously from a common source of sap pre-concentrated to 8% sugar by RO.

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[2]Sugar Processing Research Institute, Inc., 1100 Robert E. Lee Blvd., New Orleans, LA 70124

[3]United States Department of Agriculture Agricultural Research Service Southern Regional Research Center, 1100 Robert E. Lee Blvd., New Orleans, LA 70124

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