# Report on

# Pilot plant PEF system trials in a commercial French fries company

**Project title** : Use of Pulsed Electric Field technology to mitigate the effects of Liberibacter infections in potatoes and improve production efficiency

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**Other investigators** : Prof. Phil Bremer, Patrick Silcock, Dr. Sze Ying Leong

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**Contracting body** : Potatoes New Zealand Inc.

## Executive summary

To assess the potential advantages of PEF in New Zealand, a 3-month pilot scale Pulsed Electric Fields (PEF) trial has been carried out in a commercial French fries company using a high-throughput PEF equipment. Elea Germany provided the PEF equipment for this trial. We investigated the effect of different PEF process parameters (1 – 2.1 kV/cm, 1.8 – 50 kJ/kg) on three potato cultivars used locally for the production of French fries. The colour and texture of French fries, produced at commercial scale using untreated and PEF-treated potatoes were assessed and were compared with commercially produced fries (using pre-heated potatoes). The same PEF process parameters were also used with either uninfected or *Liberibacter*-infected potatoes to assess PEF's ability to mitigate zebra chip symptoms.

Applying PEF treatment to *Liberibacter*-infected potatoes, appears to "at least partially" ameliorate the visual impact of infection by enabling even browning across the entire fry and produced crispier fries. A cultivar effect on the effectiveness of PEF was observed and this will be further investigated by our newly-recruited PhD student Jess Fitzgerald. In addition, results from the industry trial demonstrated the potential of PEF technology to produce French fries with frying qualities similar to commercial fries without the need for the energy, time and water intensive pre-heating step. Overall, PEF-treated fries were able to maintain the same extent of browning after frying and develop a crispier crust while preserving the internal mealy texture of fries from pre-heated potatoes, i.e. commercial fries. A new PhD student, Zihan Xu, will provide a deeper understanding of the mechanisms of frying process for PEF-treated potato. Her research will involve modelling mass transfer and validating the mathematical model.

An unexpected finding from the industry trial was that PEF treatment appeared to reduce browning anomalies in fries caused by plant physiological processes (other than *Liberibacter* infection) for certain potato varieties. Therefore, fries with even browning across the entire fry can be produced after PEF pre-treatment of the tubers.

In conclusion, the industry trial provided a valuable opportunity to test the capacity of PEF technology to process potato tubers that are highly heterogeneous in terms of their physiological, chemical and microstructural properties. The trial demonstrated that pre-treating variable raw potatoes with PEF at commercial condition led to fries with a more uniform colour and crispier crust compared to untreated fries. The result was consistent across three different potato cultivars on different production days and importantly PEF treatment appeared to reduce the extent of browning in fries produced from *Liberibacter*-infected potatoes.

To facilitate knowledge transfer to Potato NZ members, we organised a workshop on 19th February 2019 in Dunedin to share the findings from this industry trial and discuss with representatives from the potato industry the potentials of PEF technology.

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## Project brief

The goal of this study was to determine the effect of different PEF conditions on three potato cultivars used for the production of French fries and to assess PEF's ability to mitigate Zebra chip symptoms.

An industrial-scale study was conducted between June and September 2018 (Table 1) at a commercial French fries production plant (Washdyke, Timaru). In this trial, a pilot scale PEF unit (provided by Elea GmbH, Germany) with a capacity of 1 tonne potatoes per hour was used. The three potato cultivars used in this study were provided on-site by the French fries company after stone washing and steam peeling. The potatoes were used immediately (without undergoing pre-heating step) for PEF treatments under four different processing intensities of electric field strength and energy input. Non PEF-treated potatoes were used as a control. The untreated or PEF-treated potatoes were processed into fries under the same process condition as commercial fries (at a continuous production flow rate of 20 tonnes per hour), i.e. cut into fries using a hydrojet cutter, blanching, surface-drying, par-frying and blast freezing. Commercial fries (preheated) were also obtained at the end of the process line as the reference control. Fries from each treatment was individually split into batches of 500 g and bagged, transported back to University of Otago (Department of Food Science, Dunedin) and stored at -20 °C until given a standard frying treatment (to fully cook the fries) and compared for colour and texture against commercial fries. PEF process parameters, which were systematically varied were also used with either uninfected or *Liberibacter*-infected potatoes to assess PEF's ability to mitigate Zebra chip symptoms.

Table 1. List of trials at the commercial French fries production plant at Washdyke, Timaru between June and September 2018

| | Visit date | Main tasks |
|---|---|---|
| 1 | 27th – 29th June* | • Industry open day (see Appendix 1)<br>• Commissioning of the pilot scale PEF unit at the commercial French fries production plant<br>• Preliminary PEF trial runs |
| 2 | 25th – 26th July* | • Preliminary PEF trial runs to screen PEF processing parameters for actual trial |
| 3 | 14th – 17th Aug | • Actual PEF trial runs produced 137 bags of sample (500 g each) |
| 4 | 28th – 29th Aug | • Actual PEF trial runs produced 35 bags of sample (500 g each) |
| 5 | 19th – 21st Sep | • Actual PEF trial runs produced 88 bags of sample (500 g each) |
| 6 | 25th – 26th Sep | • Actual PEF trial runs produced 70 bags (500 g each) |

* Actual trial runs were not conducted during the first 2 visits due to frequent plant breakdowns (e.g. fryer on 28th June, SAPP flume on 26th July) and installation of new plant (oil miser and ADR screening) was not completed on our second visit.

**Description of the samples produced in this study**

(1) Potato tubers provided on-site by the commercial French fries company

Three potato cultivars were used (Figure 1) and due to confidentiality requirements associated with accessing the factory, the cultivars are referred to as “Cultivar X”, “Cultivar Y” and “Cultivar Z”. These potatoes were harvested from paddocks in the Canterbury region and stored unwashed at the company according to their optimum storage condition (controlled temperature and relative humidity) until processing. Potato tubers containing total solids between 19.1 and 22.1% were used (graded on-site by the company QC staffs with the specific gravity method) (Table 2). Tubers with uniform size and shapes (300-450 g, 100-150 mm length) and an absence of external (cracking, misshapes, secondary growth, greening) and internal (hollow heart, fungal infection) defects were selected for the study.

Cultivar X
- White coloured flesh
- Large and long tubers that are slightly flat, with dark skin

Cultivar Y
- Cream coloured flesh
- Large and oblong in shape with a smooth skin and have shallow eyes

Cultivar Z
- Yellow coloured flesh
- Round in shape with yellow skin and few eyes

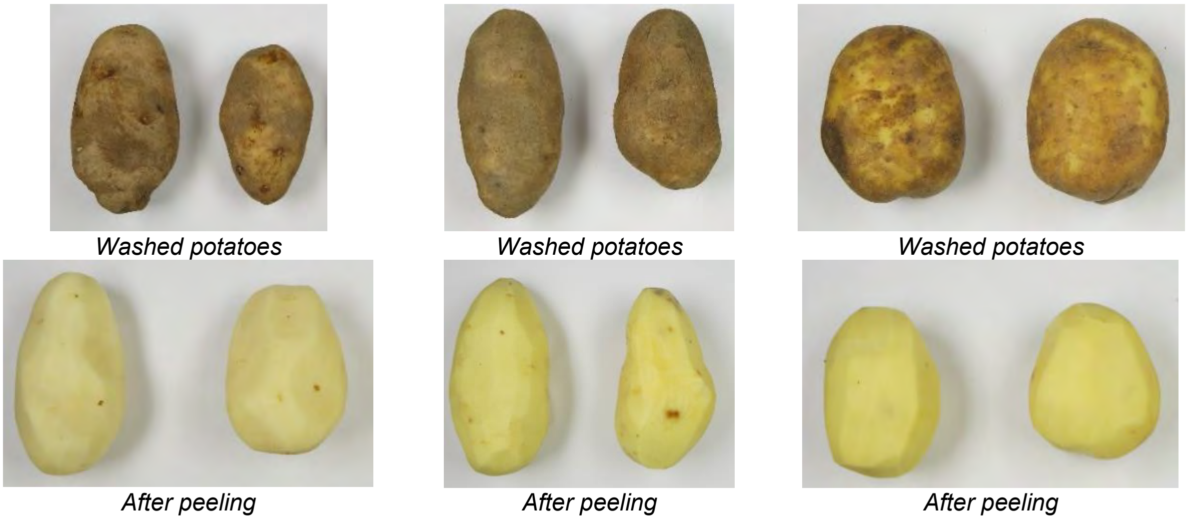



Figure 1. Three processing potato varieties used in the PEF industry trials.

Table 2. Summary of the total solids content for potatoes at different production days

| Potato | Production date | Total solids (%) | Final product cut size |
|---|---|---|---|
| Cultivar X | 14th August | 22.1 | 7 mm |
| | 16th August | 21.0 | 13 mm |
| | 19th September | 21.7 | 10 mm |
| | 20th September | 21.2 | 7 mm |
| Cultivar Y | 15th August | 20.2 | 13 mm |
| | 17th August | 19.1 | 7 mm |
| | 28th August | 19.4 | 10 mm |
| | 21st September | 19.6 | 7 mm |
| Cultivar Z | 25th September | 21.9 | 7 mm |
| | 26th September | 21.7 | 7 mm |

Note that “Cultivar X” was more prone to enzymatic browning (enzymatic action of polyphenol oxidase reacting on high levels of phenolic substrates) when exposed to air after slicing than “Cultivar Y and Z” (Figure 2). From the plant biology perspective, the higher susceptible-ness to enzymatic browning in “Cultivar X” represented a much higher ability to defend the tuber from any stress stimuli (e.g. developed higher resistance towards insects/pathogen attack) while the plant defence mechanism for other cultivars might respond poorly to these stimuli. This is an advantage for the tuber when it is growing but at least where Liberibacter is involved it is a major disadvantage for potato processors.

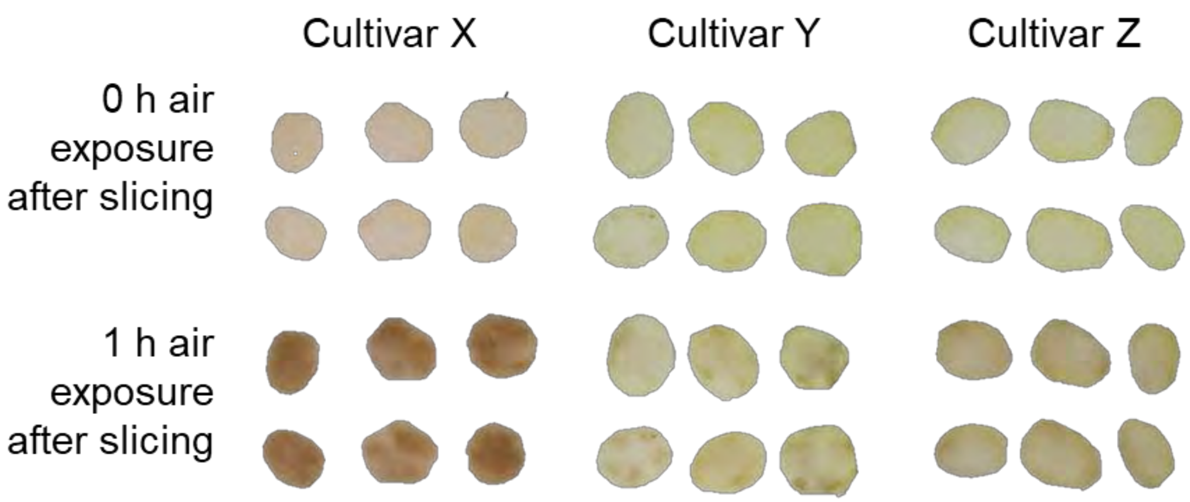



Figure 2. A comparison on the extent of enzymatic browning between three potato varieties.

(2) *Liberibacter*-infected potatoes

Potato tubers infected with *Liberibacter* typically exhibit dark brown streaking in their vascular rings (Figure 3) and they can only be visually identified when the outer skin is removed during the peeling step. From the three potato varieties provided by the company, “Cultivar X” clearly exhibited symptoms of infection after peeling and developed an uneven and intense browning upon frying (Figure 4). Therefore, “Cultivar X” was the cultivar selected to be used to investigate the effect of PEF on reducing the extent of browning in fries due to *Liberibacter* infection.


Figure 3. A comparison of the extent of enzymatic browning between uninfected and *Liberibacter*-infected “Cultivar X”.

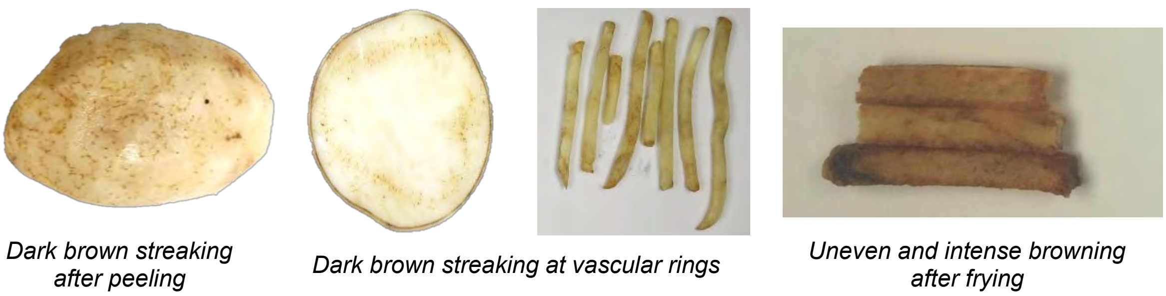



Figure 4. Visual appearance of *Liberibacter*-infected “Cultivar X” potatoes after peeling, cutting and frying.

(3) Production of French fries at commercial scale using PEF-treated potatoes

Figure 5a illustrates the important steps (washing, peeling, preheating, cutting, blanching, drying, par-frying and freezing) involved in the current commercial production of French fries. It took approximately 2 h to convert raw potatoes to French fries). The process condition for each step were adjusted by the French fries company according to the chemical properties of the raw potatoes and the intended quality of final fries on the day of production (processing conditions are kept confidential).

In our trials, potatoes were subjected to different PEF treatments immediately after peeling instead of continuing to preheating step (Figure 5b). Post PEF-treatment the potatoes were manually transferred to the cutting flume and to the remaining processes under the identical conditions as commercial fries. In the existing process line, preheating potatoes is used softened the potato texture, facilitating hydrojet cutting. However, the preheating step is an energy, time and water intensive process. Therefore, the main application of PEF on potatoes in this industry trial was to replace the existing preheating step to achieve potato softening within a short process time at reduced water and energy consumption, without affecting the colour and textural properties of the final French fries.

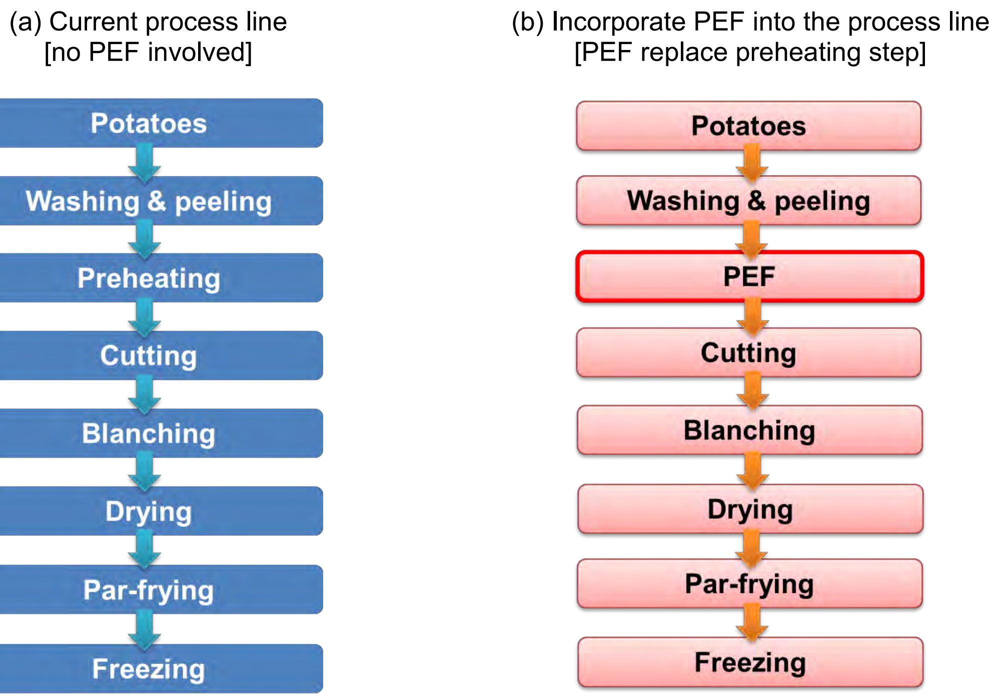



Figure 5. Simplified diagrams illustrating (a) the current process line in the French fries company and (b) how PEF technology can be incorporated into the process line by replacing the preheating step.

(4) PEF equipment and processing parameters

A pilot scale PEF unit provided by Elea GmbH (Quakenbrueck, Germany) with a capacity of continuously handling 1 tonne potatoes per hour was used (Figure 6). The PEF unit consisted of a “HVP30” generator (Serial No: 330107-150) and a “TB-140” treatment bath (Serial No: 330105-04-B140-002). The HVP30 generator created and transmitted the high voltage pulses to the treatment electrode in the TB-140 treatment bath. Peeled potatoes were dropped into the feed of the treatment bath and were conveyed past the PEF electrode (electrode gap of 130 mm). Treated potatoes were subsequently transported by hand to the hydrocutter.

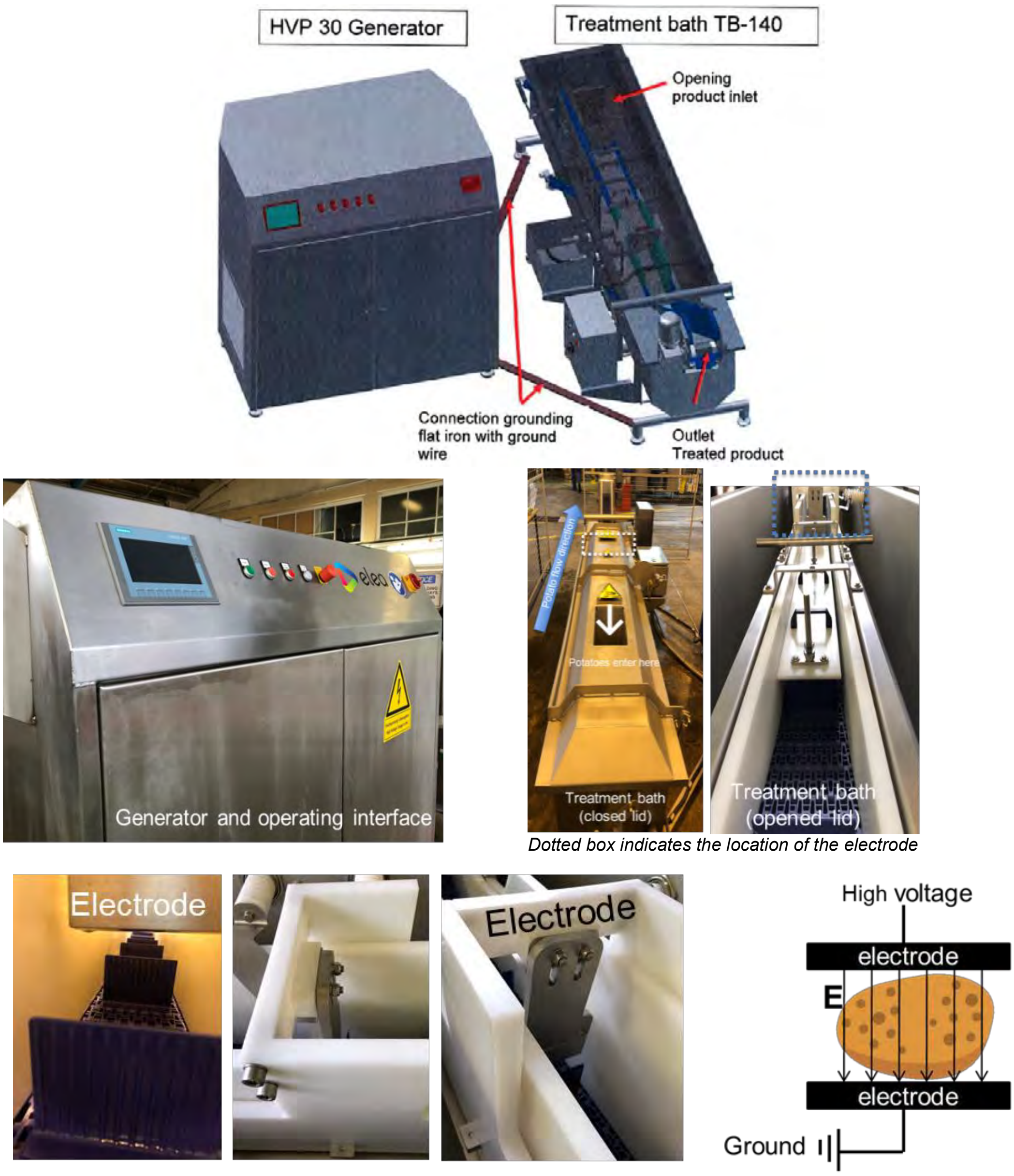



Figure 6. Pilot scale PEF unit (1 tonne/h) consisted of a “HVP30” generator and a “TB-140” treatment bath.

In these trials, potatoes were PEF-treated with varying intensities of electric field strength and total energy input (Table 3). The fixed PEF process parameters were: electrode gap, 130 mm; pulse frequency, 200 Hz; and pulse width, 20 μs.

Table 3. Summary of the range of PEF process parameters and the calculated power used in the potato industry study

| PEF setting | Electric field strength (kV/cm) | Total energy input (kJ/kg) | Calculated power (kW) |
|---|---|---|---|
| PEF A | Low (1 – 1.2) | Low (1.8 – 2.2) | 4.5 – 5.2 |
| PEF B | High (1.8 – 2.1) | Low (6.8 – 7.1) | 14.2 – 16.9 |
| PEF C | Low (1 – 1.2) | High (47 – 50) | 5.6 – 5.8 |
| PEF D | High (1.8 – 2.1) | High (47 – 50) | 15.7 – 16.9 |

<u>(5) Experimental design, sampling plan and final products produced from the trial</u>

For each PEF run, approximately 50 kg peeled potatoes were split into 2 groups (25 kg/group), where the first group was immediately treated with PEF and the second group was untreated (referred as "No PEF"). Subsequently, potatoes from both groups were put into the hydrojet-cutter to be cut into fries in the following sequence: PEF → No PEF. Meanwhile, approximately 2 kg of cut fries from the current process line (after passage through the preheater) were collected to be used as reference control (referred as "Commercial reference A"). Each type of cut potatoes was divided equally into nylon laundry bags. In total, 9 laundry bags were prepared per run: 4 bags for PEF, 4 bags for No PEF, and 1 bag for Commercial reference A and put back into the process line where they proceeded to blanching, drying, par-frying (fries moved from laundry bag to stainless steel frying basket) and blast-freezing (fries returned to laundry bag from stainless steel frying basket), under the same condition as commercial fries in the process line. When retrieving the 9 laundry bags at the end of the freezing tunnel, approximately 2 kg of frozen fries from the process line were collected as another reference control for the experiment (referred as "Commercial reference B"). It took approximately 1.5 h to process the PEF-treated potatoes into fries and the same procedure described above was repeated for all PEF settings for both "Cultivar Y" and "Cultivar Z" potatoes.

For “Cultivar X”, approximately 100 kg peeled potatoes either without or with visible *Liberibacter* symptom (see Figure 4) were obtained for each PEF run. These potatoes were then divided into 4 groups (25 kg/group), where:

- The first group consisted of potatoes with no visible symptom to be PEF-treated (referred as uninfected-PEF),
- The second group consisted of potatoes with visible symptom to be PEF-treated (referred as infected-PEF),
- The third group consisted of potatoes with no visible symptom to be untreated (referred as uninfected-No PEF), and
- The fourth group consisted of potatoes with visible symptom to be untreated (referred as infected-No PEF).

Both PEF treated or untreated potatoes were put into the hydrojet-cutter to be cut into fries in sequence: infected-PEF → uninfected-PEF → infected-No PEF → uninfected-No PEF. Meanwhile, approximately 2 kg of cut fries from the current process line (went through the preheater) were collected to be used as reference control (referred as “Commercial reference A”). For each sub-treatment type (e.g. infected-PEF, uninfected-PEF), the cut potatoes were recovered after cutting and divided equally into nylon laundry bags. In total, 17 laundry bags were prepared per run: 4 bags for uninfected-PEF, 4 bags for infected-PEF, 4 bags for uninfected-No PEF, 4 bags for infected-No PEF, and 1 bag for Commercial reference A. All samples were all put into the process line to proceed to blanching, drying, par-frying (fries moved from laundry bag to stainless steel frying basket) and blast-freezing (fries returned to laundry bag from stainless steel frying basket), under the same condition as commercial fries in the process line. When retrieving the 17 laundry bags at the end of the freezing tunnel, approximately 2 kg of frozen fries from the process line were collected as another reference control for the experiment (referred as “Commercial reference B”). It took approximately 1.5 h to process PEF-treated potatoes into fries and the same procedure described above was repeated for all PEF settings on “Cultivar X” potatoes.

At the end of each PEF run, fries were individually packed into polyethylene bags, sealed, transported back to the University of Otago (Department of Food Science, Dunedin) and stored at -20 °C.

A summary of the experimental design and sampling plan is illustrated in Figure 7. It is important to note that our experimental design have these types of reference samples (No PEF, Reference A and Reference B) for every PEF setting tested to ensure that the impact of PEF on the fries quality can be confidently postulated.

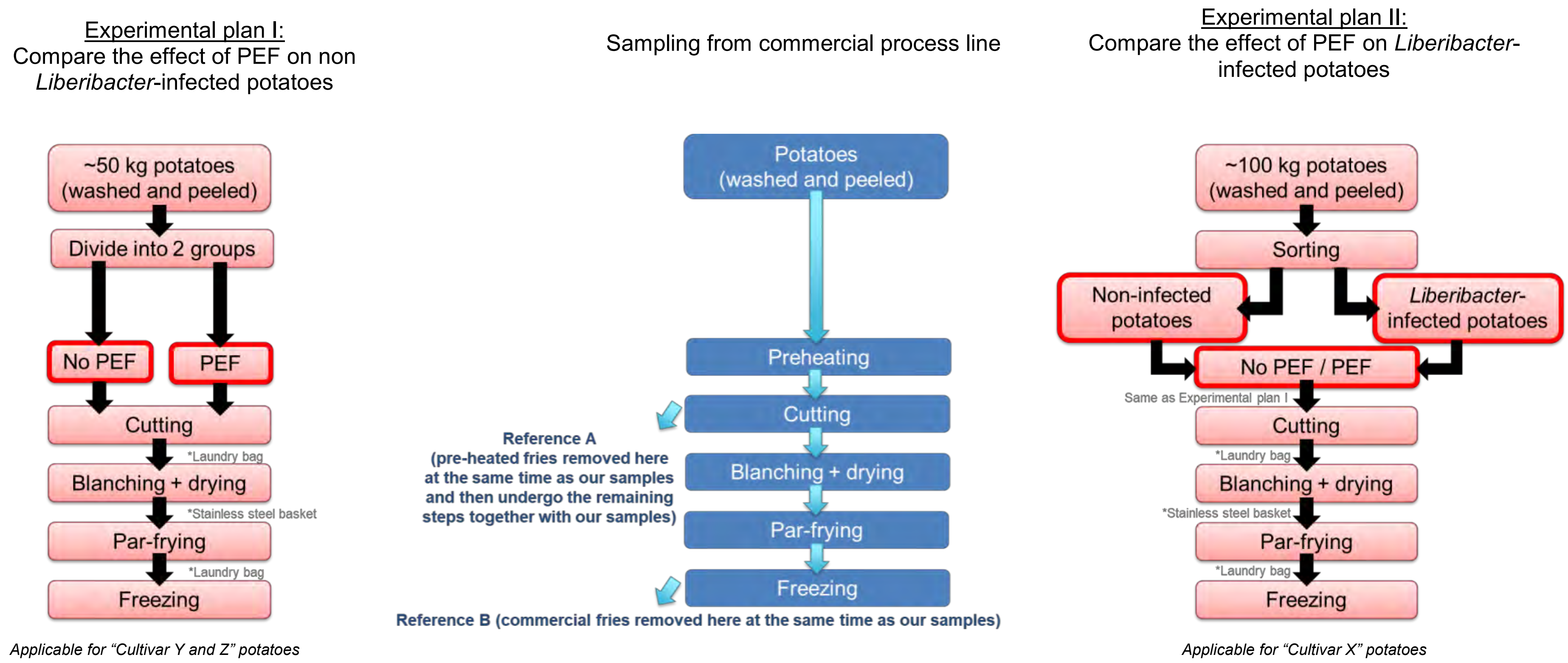



Figure 7. Experimental plan for each PEF run and sampling plan from the commercial process line.

**Finished frying in Dunedin and evaluation of fries' colour and texture**

<u>(1) Justification of the analysis on fries</u>

The processing quality of potatoes for French fries is largely determined by the colour obtained after frying (Marquez & Anon, 1986). During frying, non-enzymatic browning, known as the Maillard reaction, occurs as a result of the reaction between reducing sugars and amino acids at high temperatures. Therefore, a frying test followed by colour measurement of the French fries was used to evaluate the processing quality of PEF-treated potatoes.

Processing steps (i.e. pre-heating, blanching, drying and frying) involved during the production of French fries play key roles in influencing the textural properties of the final product (Lisińska & Gołubowska, 2005). Evaluation of the fries included examining the appearance inside the fries (ideally a mealy core and reduced hollow air space) and the following texture parameters maximum peak force, crispiness, etc. (Miranda & Aguilera, 2006). In this study, PEF technology was incorporated into the existing French fries process line by replacing the pre-heating step, therefore texture profiles for French fries produced using commercial process line (with preheating step) and those from PEF-treated potatoes (without preheating) were compared.

*Liberibacter*-infected potatoes are reported to contain higher levels of sugars than uninfected potatoes owing to the upregulation of a plant defence response mechanism that favours the breakdown of starch to sugars during tuber development (Kumar, Knowles, & Knowles, 2017). The high sugar content in the tubers subsequently contributes to excessive browning during frying. In this trial it was postulated that the ability of PEF to induce electroporation in the potato's cell membrane (Faridnia, Burritt, Bremer, & Oey, 2015) would result in a more controlled leakage of intracellular compounds (e.g. reducing sugars) involved in the Maillard reaction and reduce the tendency of potatoes to brown during deep frying. With this in mind, a frying-colour test was a straightforward approach to investigate the potential of treating *Liberibacter*-infected potatoes with PEF technology in order to prevent excessive browning of the fries.

(2) Finished frying experiment

Prior to frying, frozen fries were sorted according to their length (short <50mm, medium and long >100mm). Medium length fries (varied between 50-100 mm depending on the fries cut size and potato cultivar) in 300 g were then equilibrated at -20 °C for 1 h in an Irinox Shock Freezer to ensure that the fries were at the same initial temperature before frying. A Blue Seal electric fryer (Evolution series E44E – 450 mm) filled with 13 L of canola oil was used. Once the oil reached 178 ± 3 °C, fries (300 g) in a fryer basket were placed into the oil. Depending on the cut size, a small amount of fries were removed at predefined time points, drained of excess oil and cooled. 7 mm fries, were removed after 3, 3.5 or 4 min of frying. 10 mm fries, were removed after 4, 4.5, 5 or 5.5 min frying. 13 mm fries, were removed after 4, 5, 6 or 7 min of frying.

(3) Evaluation of surface colour and internal appearance of fries

Fries at different frying time points were cut in half to evaluate their internal appearance. The surface colour of each fry was measured using a Hunterlab colorimeter (five measurements per sample). Colour coordinates of L*, a* and b* were measured with the colorimeter in order to calculate the browning index (BI) of the fries (see Equations (1) and (2)).

$$\text{Browning index (BI)} = \frac{[100\ (X - 0.31)]}{0.17} \qquad \text{Equation (1)}$$

$$X = \frac{(a + 1.75\ L)}{5.645\ L + a - 3.012\ b} \qquad \text{Equation (2)}$$

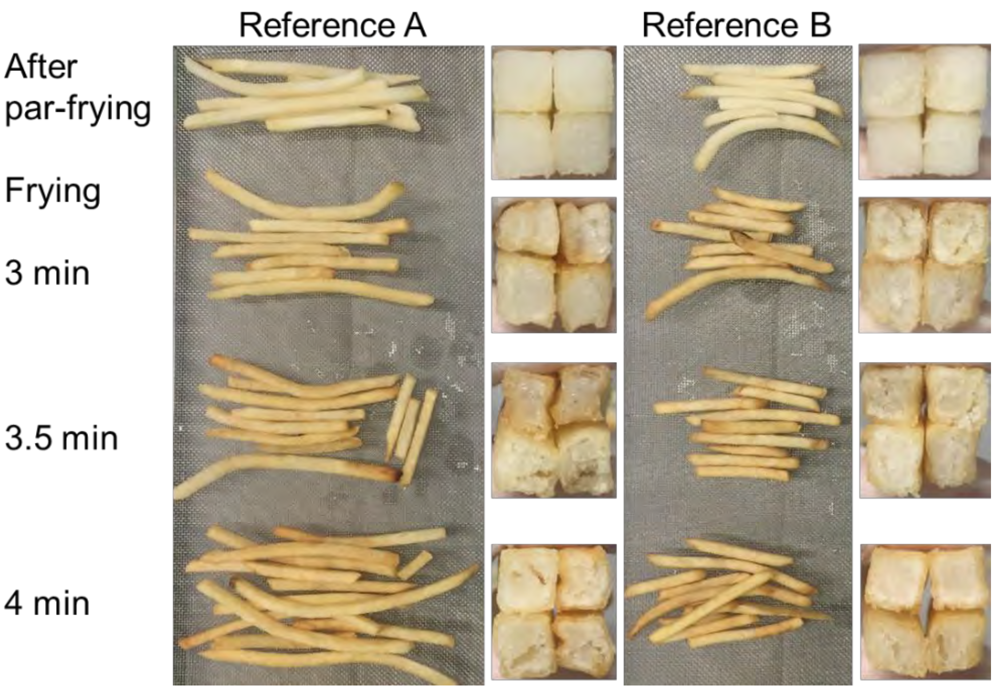
(4) Evaluation of crust hardness

The maximum cutting force through each fry was measured using a texture analyser (Stable Micro Systems) (Appendix 2). Fries fried for 3.5 min for 7 mm fries and 5 min for 10 and 13 mm fries were prepared. A compression test involving a cutting blade with guillotine edge (Blade 11054, 90 mm height, 70 mm width, 3 mm thickness) was used. The operating parameters for the crust hardness measurement were: 5 kg load, 2 mm/s pre-test and test speed, 10 mm/s post-test speed, 5 g trigger force, 15-20 mm cutting distance. The maximum peak force was read from the force vs. cutting distance curves. Duplicate measurements were taken per fry and a total of 10 fries were measured from each treatment group.

**Key findings**

<u>(1) Untreated fries produced in the experimental setup (Reference A) were similar to commercial fries (Reference B)</u>

- Surface colour and internal appearance of fries as a function of frying duration for Reference A and B samples were similar
    - o Reference A = Pre-heated fries collected at the cutter and bagged into laundry bags, then proceed to the entire processing line together with PEF samples (this sample mimic our experimental design)
    - o Reference B = Fries collected at the freezing tunnel (no bagging into laundry bag during the entire process) (this sample mimic commercial French fries)
- Conclusion: Our experimental setup (i.e. bagging into laundry bags) had a negligible impact on the browning development of fries upon frying. Therefore, it is reasonable to use Reference A samples can be used as a reference control to investigate the effect of PEF treatment on potatoes during French fry production.

<table>
<tr><td>Evidence 1</td><td>Visual observation on the surface colour and internal appearance<br>Sample: “Cultivar X” 7 mm<br>
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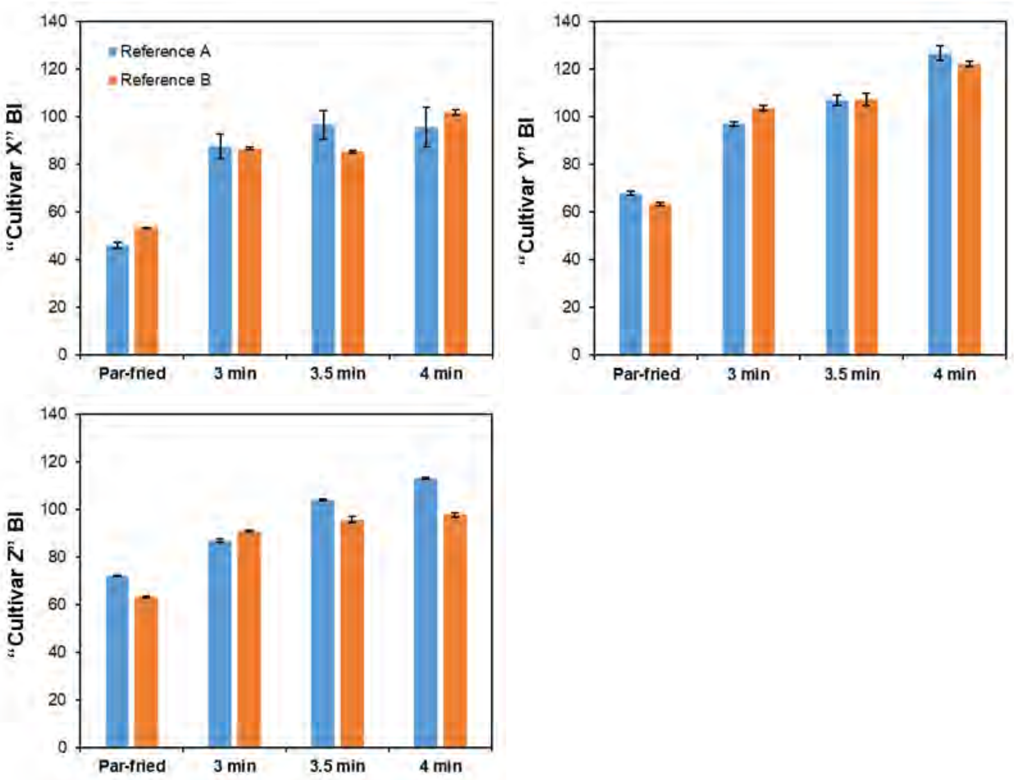
| Evidence 2 | Fries had a similar browning index (BI) between Reference A and Reference B samples<br>Sample: “Cultivar X”, “Cultivar Y”, “Cultivar Z” 7 mm<br> |

(2) Fries produced from pre-heated (Reference A) or non pre-heated (No PEF) potatoes differed in their internal appearance

- Reference A and No PEF fries had a similar browning index (BI) as a function of frying duration but the internal appearance of fries for Reference A and No PEF samples differed. No PEF treated fries had excessive hollow internal air spaces within the fries.
    - Reference A = Pre-heated fries collected at the cutter and bagged into laundry bags, then added to the processing line together with PEF samples
    - No PEF = Peeled potatoes immediately cut without going through the preheating step, placed into laundry bags and added to the processing line together with PEF samples
- Conclusion: Reference A samples were reliable reference controls to investigate the effect of PEF treatment on the quality of French fries.

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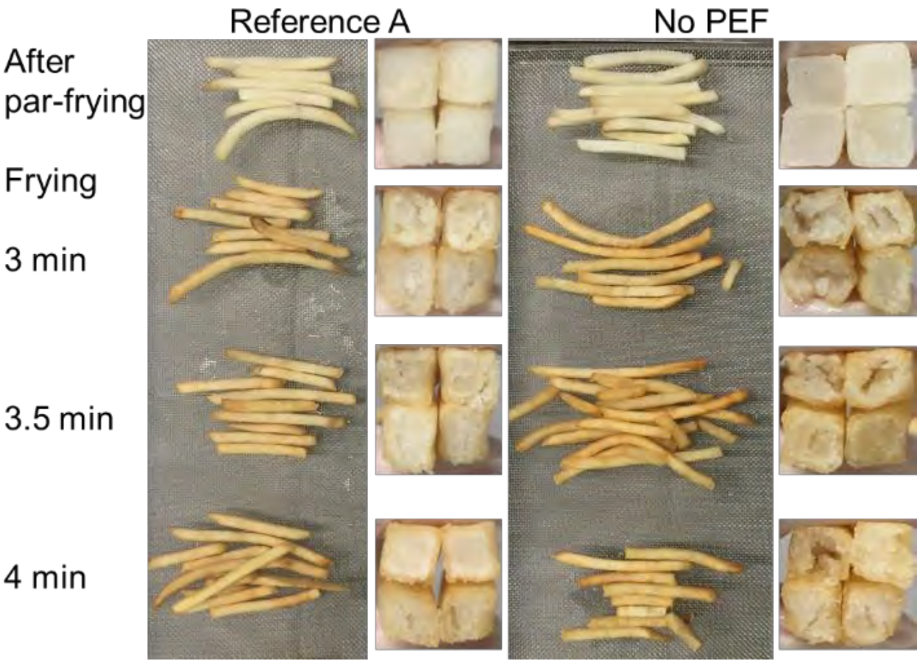
<tr><td>Evidence 1</td><td>Visual observation on the surface colour and internal appearance<br>Sample: “Cultivar X” 7 mm<br>
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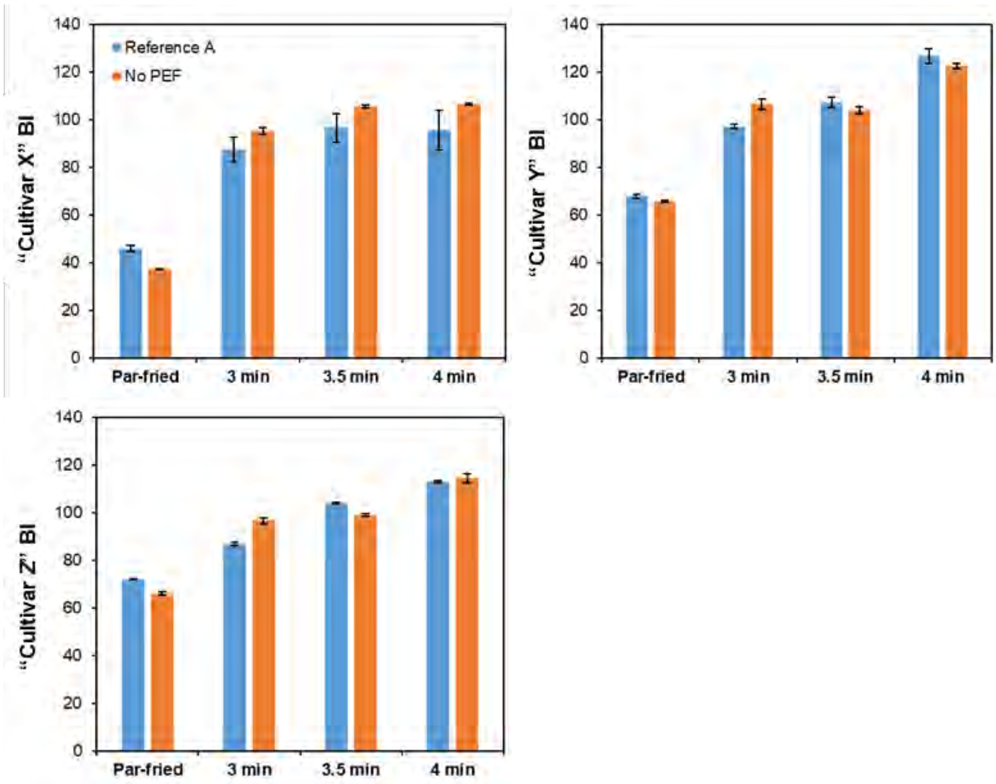
<tr><td>Evidence 2</td><td>Fries have similar BI between Reference A and No PEF samples<br>Sample: “Cultivar X”, “Cultivar Y”, “Cultivar Z” 7 mm<br>
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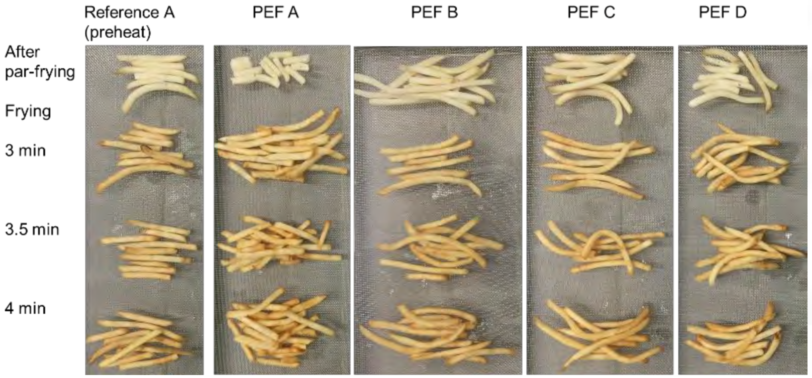
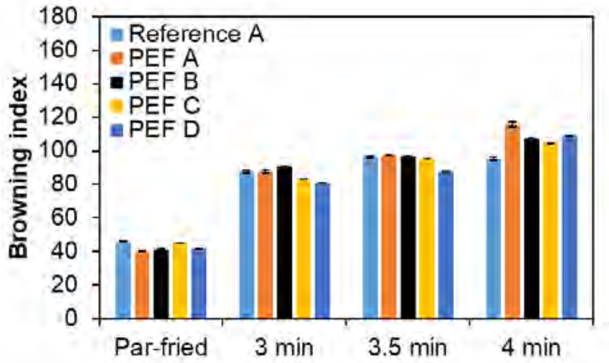
<u>(3) Application of PEF treatment on potatoes was able to maintain the extent of browning in fries</u>

- Reference A samples (preheated commercial fries) were used as reference controls to determine whether PEF influenced the extent of browning for fries.

<table>
<tr>
<td>Evidence 1</td>
<td>An application of PEF treatment on potatoes was able to maintain the browning of fries during frying<br>Sample: “Cultivar X” 7 mm



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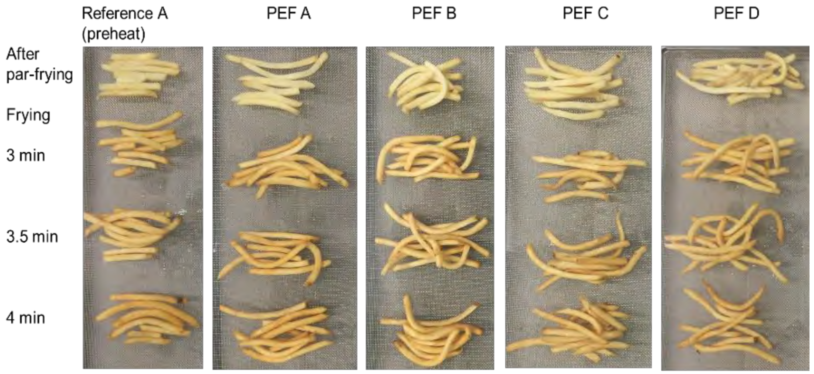
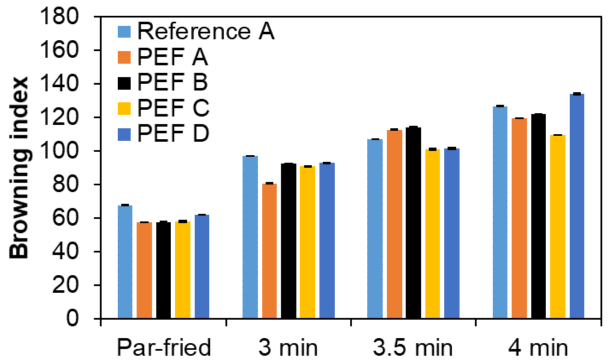
<td>Evidence 2</td>
<td>An application of PEF treatment on potatoes was able to maintain the browning of fries during frying<br>Sample: “Cultivar Y” 7 mm



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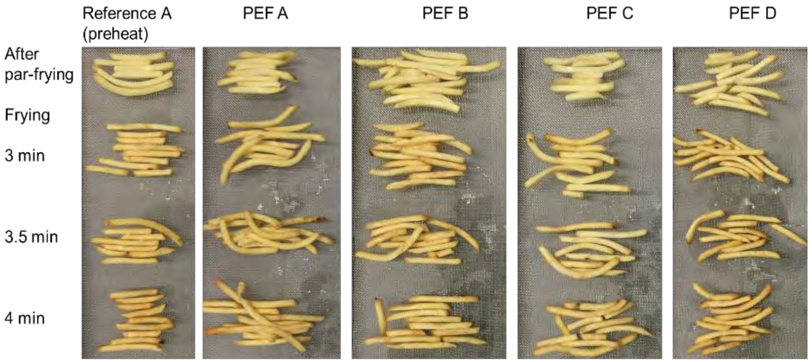
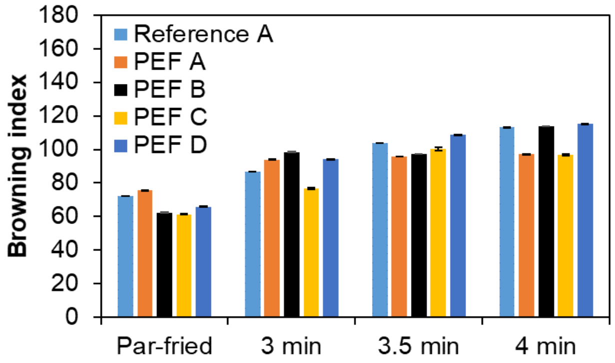
| Evidence 3 | An application of PEF treatment on potatoes was able to maintain the browning of fries during frying<br>Sample: “Cultivar Z” 7 mm<br><br> |
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- Conclusion: On each of the three potato cultivars studied, the range of PEF parameters tested in this study (see Table 2) resulted in similar browning as seen in fries made from pre-heated potatoes (commercial fries).

(4) PEF produced crispier fries

- Reference A samples (preheated commercial fries) were used as reference controls to determine whether PEF reduced the extent of browning of fries.
- Due to the high variability in the texture profile between fries from the same treatment group (see Appendix 2), the range (minimum and maximum value) of the maximum cutting force from 20 texture measurements (duplicate readings for 10 individual fries) is reported in the tables below.

Sample: “Cultivar X” 7 mm fried for 3.5 min

| Sample | Maximum cutting force (N) | | | Internal appearance |
|---|---|---|---|---|
| | Mean ± SD (n=20) | Minimum | Maximum | |
| Reference A (preheat) | 913.77 ± 353.18 | 419.33 | 1806.45 |  |
| PEF A | 1344.20 ± 514.27 | 630.18 | 2685.59 |  |
| PEF B | 1219.91 ± 386.70 | 721.95 | 2136.63 |  |
| PEF C | 1222.39 ± 462.57 | 505.83 | 2092.50 |  |
| PEF D | 1085.50 ± 328.41 | 520.44 | 1783.96 |  |

- Findings: A higher cutting force was needed to cut through the crust of the PEF-treated “Cultivar X” fries compared to commercial fries (pre-heated). In other words, PEF-treated fries had a crispier crust. The internal appearance of PEF-treated fries was also similar (i.e. mealy core) to the pre-heated fries.

Sample: “Cultivar Y” 7 mm fried for 3.5 min

| Sample | Maximum cutting force (N) | | | Internal appearance |
|---|---|---|---|---|
| | Mean ± SD (n=20) | Minimum | Maximum | |
| Reference A (preheat) | 807.13 ± 338.49 | 365.87 | 1633.34 |  |
| PEF A | 1223.96 ± 301.66 | 618.64 | 1708.57 |  |
| PEF B | 1110.84 ± 238.10 | 790.28 | 1613.25 |  |
| PEF C | 961.15 ± 282.32 | 415.35 | 1377.28 |  |
| PEF D | 1259.59 ± 481.32 | 525.44 | 2149.68 |  |

- Findings: As found for “Cultivar X” fries, a higher cutting force was needed to cut through the crust of the PEF-treated “Cultivar Y” fries compared to commercial fries (pre-heated). PEF-treated fries had a crisper crust. The internal appearance of fries treated with lower PEF intensity were similar (i.e. mealy core) to commercial fries. However, PEF D (i.e. high intensity electric field strength and total energy) resulted in a dry appearance and hollow air spaces inside the fries.

Sample: “Cultivar Z” 7 mm fried for 3.5 min

| Sample | Maximum cutting force (N) | | | Internal appearance |
|---|---|---|---|---|
| | Mean ± SD (n=20) | Minimum | Maximum | |
| Reference A (preheat) | 974.72 ± 427.60 | 339.79 | 1744.02 |  |
| PEF A | 1029.83 ± 306.02 | 518.87 | 1497.49 |  |
| PEF B | 1319.32 ± 368.41 | 500.29 | 2035.12 |  |
| PEF C | 1219.62 ± 400.61 | 200.86 | 1735.89 |  |
| PEF D | 1663.69 ± 730.67 | 488.10 | 3177.61 |  |

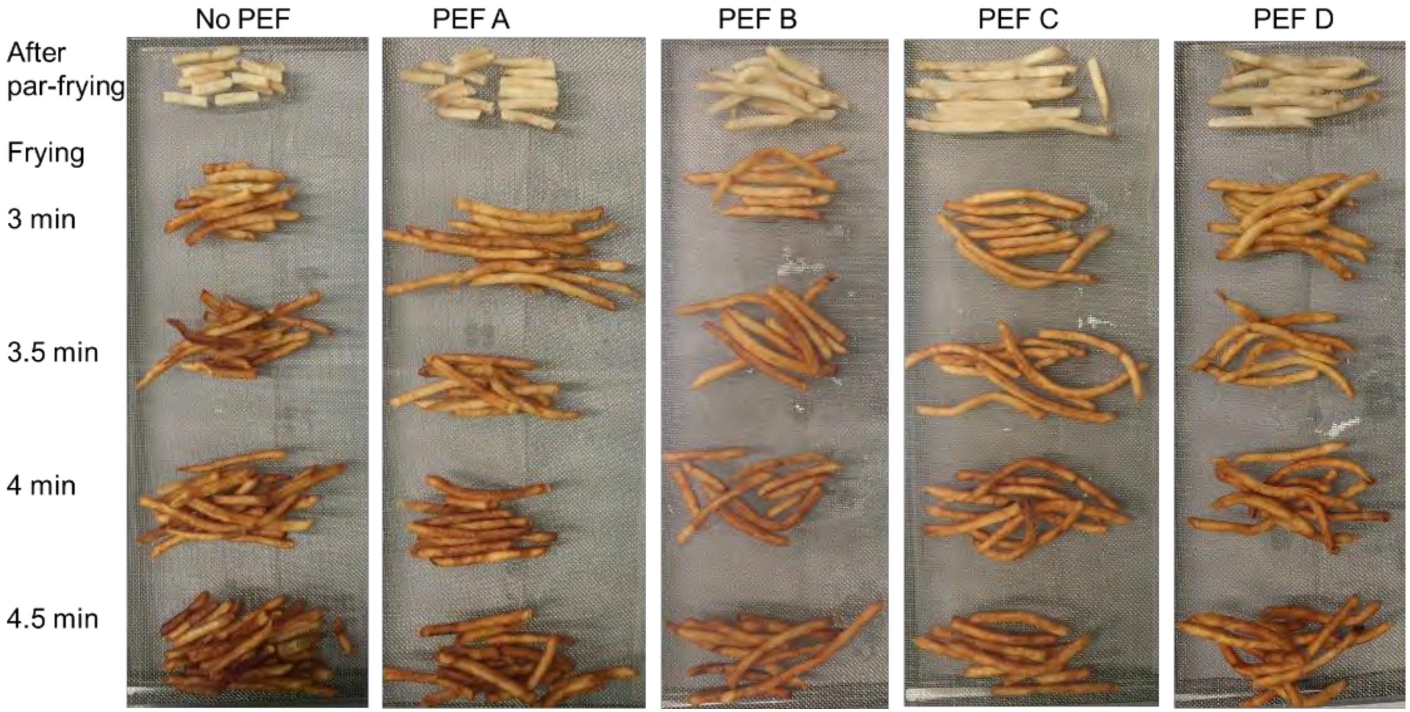
- Findings: “Cultivar Z” fries from PEF-treated tubers were also shown to be crispier than commercial fries (pre-heated). The internal appearance of commercial “Cultivar Z” fries had severe hollow air spaces inside but this occurrence appeared to be improved in PEF-treated fries, except for those treated with PEF D (i.e. high intensity electric field strength and total energy).

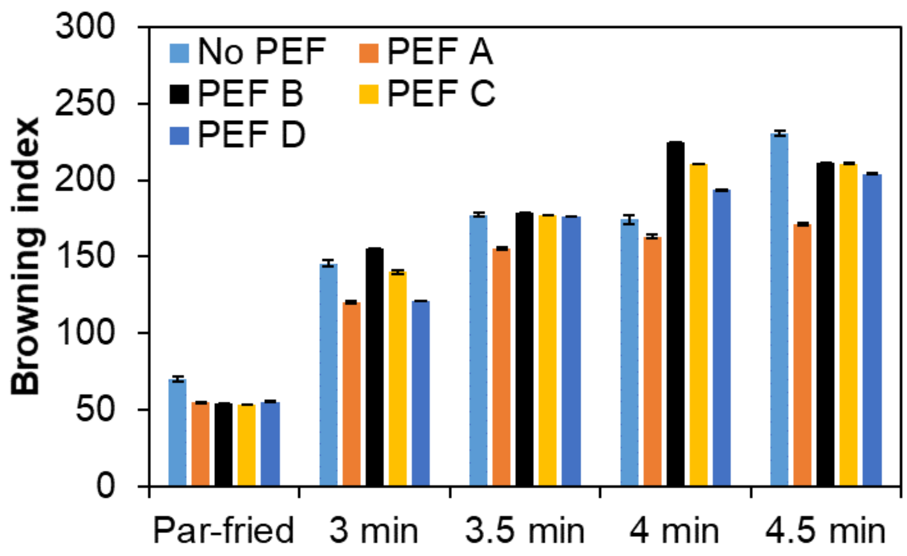
- Conclusion: PEF treatment was able to produce fries with a crispy crust while preserving a desirable internal texture. The internal appearance of PEF-treated fries was very similar to that of commercial fries. Note, high intensity PEF treatment should be avoided.

(5) Application of PEF treatment on *Liberibacter*-infected potatoes was able to reduce the extent of browning in fries

- From the three potato varieties provided by the company, “Cultivar X” clearly exhibited symptoms of infection after peeling and developed an uneven and intense browning upon frying (see Figure 4).
- Infected-No PEF samples were used as reference controls to determine whether PEF could reduce the extent of browning in fries from *Liberibacter*-infected potatoes.

| | |
|---|---|
| Evidence 1 | Visual observation on the surface colour<br>Fries developed even browning across the entire fries during frying<br>Sample: “Cultivar X” 7 mm |

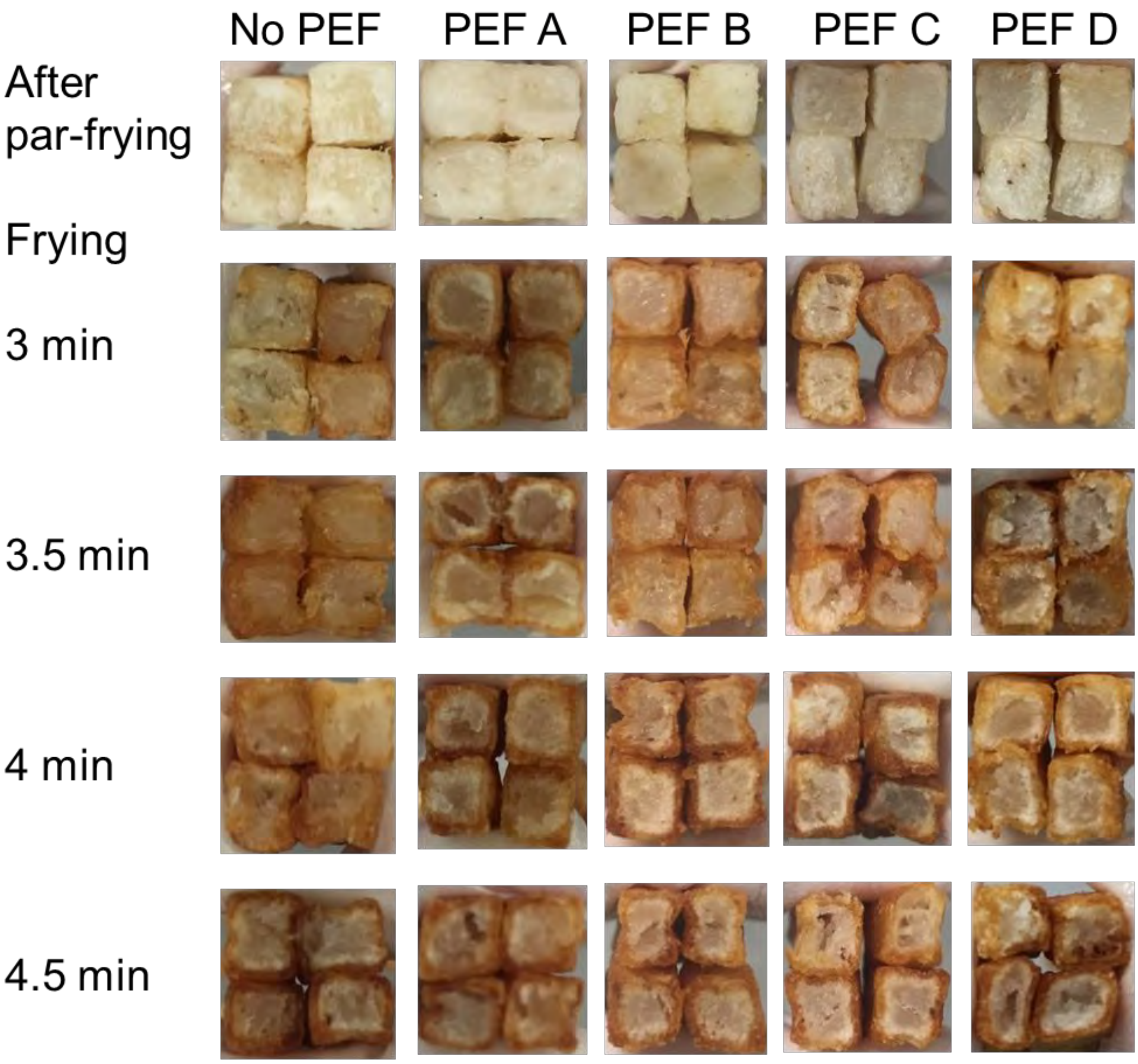


| | |
|---|---|
| Evidence 2 | PEF treatment of *Liberibacter*-infected potatoes was able to reduce the browning of fries.<br>Sample: “Cultivar X” 7 mm<br><br> |

- Conclusion: Applying a PEF treatment to *Liberibacter*-infected potatoes could “at least partially” ameliorate the visual impact of infection in fries. For instance, an even browning across the entire fry has been observed for *Liberibacter*-infected potatoes subjected to PEF treatment. Moreover, PEF-treated fries did not brown further if frying was prolonged. The findings also suggested that PEF treatment decreased the reducing sugar concentration in *Liberibacter*-infected potatoes probably owing to the leaching of reducing sugars during subsequent cutting and blanching being accelerated from the PEF-treated potato tissue. Overall, the four different PEF parameters tested in this study were able to control the Maillard reactions in *Liberibacter*-infected potatoes, and reduce brown colour formation during frying.

(6) Application of PEF treatment on *Liberibacter*-infected potatoes influenced the internal appearance and crust crispiness

- From the three potato varieties provided by the company, "Cultivar X" clearly exhibited symptoms of infection after peeling and developed an uneven and intense browning upon frying (see Figure 4).
- Infected-No PEF samples were used as reference controls to determine whether PEF influenced the internal appearance and crust crispiness of fries from *Liberibacter*-infected potatoes.
- Findings: Fries from *Liberibacter*-infected potatoes appeared to develop thicker crust, with a glassy texture and a more moist appearance.



- Findings: PEF-treated fries from *Liberibacter*-infected potatoes had a higher cutting force compared to non PEF-treated fries, which was attributed to a crisper crust. This is consistent with the findings in uninfected “Cultivar X” fries, PEF-treated *Liberibacter*-infected fries which had a crisper crust. PEF treatment of *Liberibacter*-infected potatoes reduced the glassy appearance of the resulting fries, improving their appearance.

Sample: *Liberibacter*-infected “Cultivar X” 7 mm fried for 3.5 min

| Sample | Maximum cutting force (N) | | | Internal appearance |
|---|---|---|---|---|
| | Mean ± SD (n=20) | Minimum | Maximum | |
| No PEF | 959.30 ± 339.81 | 300.52 | 2369.96 |  |
| PEF A | 1337.78 ± 393.43 | 596.93 | 2400.11 |  |
| PEF B | 1293.59 ± 361.80 | 937.37 | 2329.41 |  |
| PEF C | 1211.43 ± 294.77 | 612.28 | 1658.91 |  |
| PEF D | 1068.95 ± 301.88 | 534.30 | 1677.87 |  |

- Conclusion: PEF treatment was able to produce fries from *Liberibacter*-infected potatoes with a crispy crust and improved final quality as indicated by internal appearance of the fries. Informal sensory indicated improvements to the texture and a reduction in the bitterness of the fries.

(7) PEF treatment has the potential to reduce the browning anomaly in fries caused by plant physiological process and potato variety

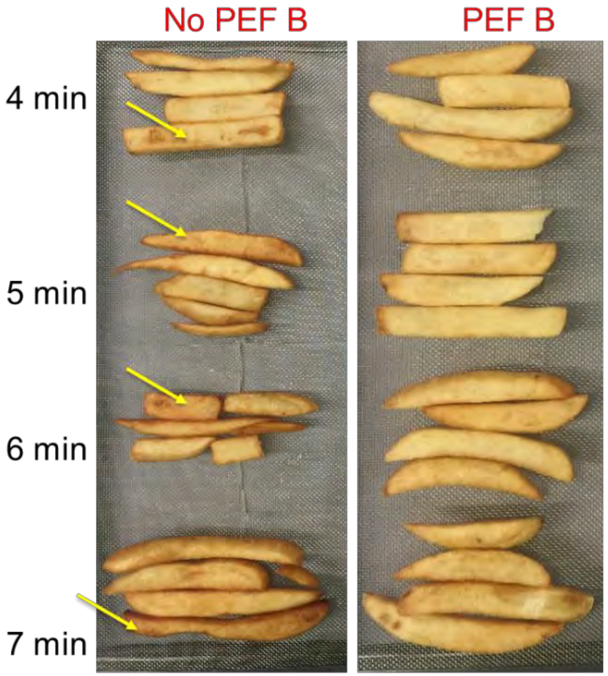
EXAMPLE 1: "Cultivar Y" potato

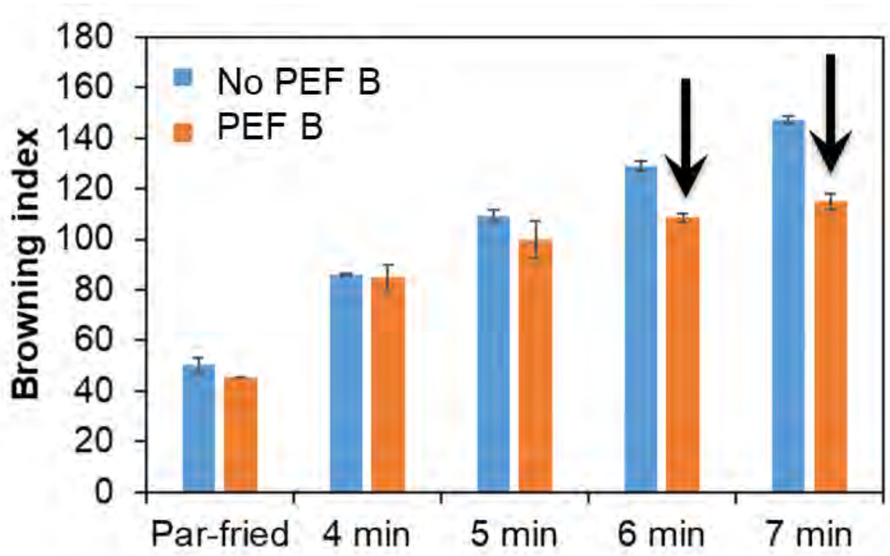
- In this study, we encountered tubers with no visible symptoms of *Liberibacter* infection from which the resulting fries developed uneven browning upon frying.
  - Possible cause: Potatoes are living tissue even after harvest. This batch of potatoes were probably not handled appropriately at harvest or not correctly stored prior to processing, putting the tubers under oxidative stress though *Liberibacter* infection cannot be eliminated as the cause. Oxidative stress in plant can trigger an upregulation of plant defence responses, leading to starch breakdown into sugars and accumulation of sugar in the potato.

<table>
<tr><td>Evidence 1</td><td>"Cultivar Y" tubers did not demonstrate dark brown streaking at the vascular rings but fries developed localised browning upon frying (indicated by the yellow arrows).<br>Sample: "Cultivar Y" 13 mm (15th August 2018 production date) No PEF<br><br><br></td></tr>
</table>

<table>
<tr>
<td>Evidence 2</td>
<td>

Under the same processing batch of potatoes and similar processing conditions, “Cultivar Y” tubers subjected to PEF treatment produced fries with even browning across the entire fry with reduced browning at the fries’ edges.
Based on the colour analysis, a reduction in the BI for PEF-treated fries compared to the untreated fries.
Sample: “Cultivar Y” 13 mm (15th August 2018 production date)




</td>
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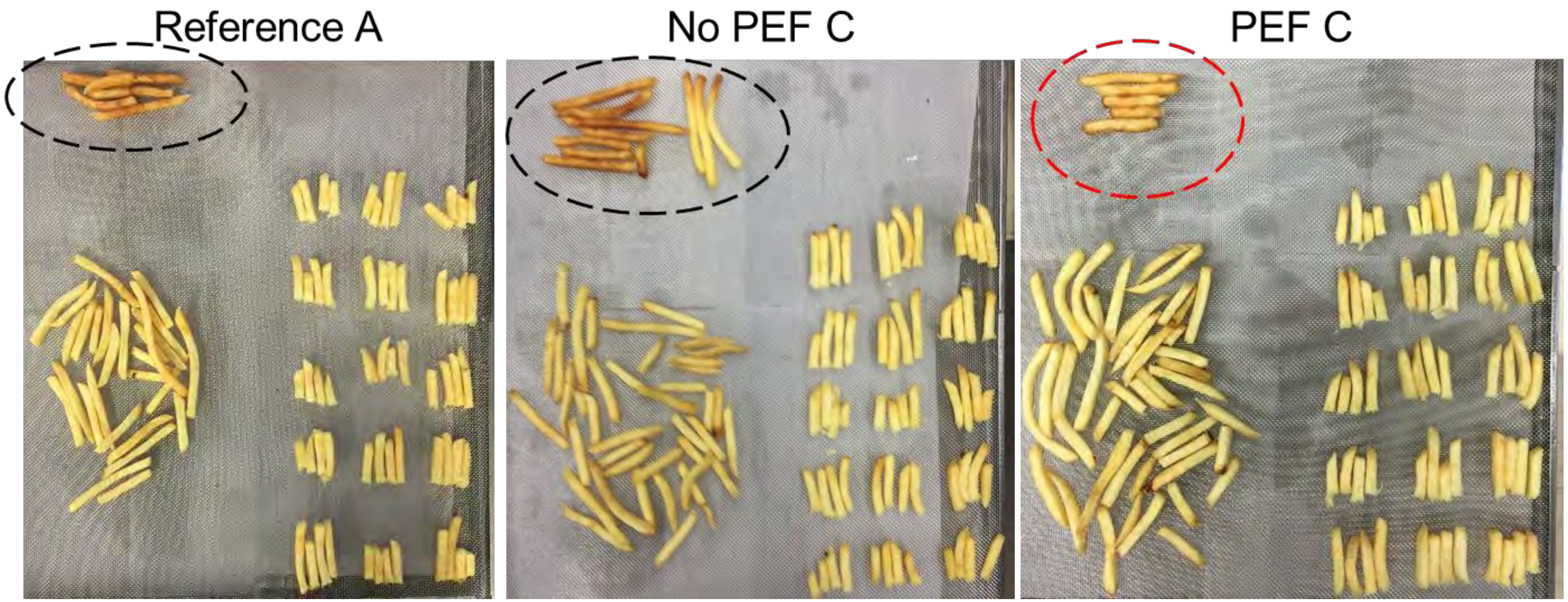
</table>

EXAMPLE 2: “Cultivar Z” potato

- Compared to “Cultivar X” and “Cultivar Y”, we found inconsistency in the frying quality of “Cultivar Z” potatoes. Specifically, a small number of fries from the same frying batch exhibited excessive browning at their edges and intense browning across the entire fry.

| | |
|---|---|
| Evidence 1 | A small amount of commercial and experiment fries from the same processing batch of potatoes exhibited excessive browning at the edges and dark browning across the entire fry (dark circled) but the browning reduced and uniform in colour for PEF-treated fries (red circled).<br>Sample: “Cultivar Z” 7 mm (25th September 2018 production date) No PEF<br> |

- Conclusion: Visual defect such as uneven browning in French fries can be influenced by physiological process (e.g. “Cultivar Y”) and potato variety (e.g. “Cultivar Z”). Therefore, applying a PEF treatment on these potatoes or specific variety offers the opportunity to reduce their sugar concentration in order to control Maillard reactions, and reduce brown colour formation during frying.

## Outputs and engagements with potato industry

1. Industry open day on 27th June 2019 at Washdyke, Timaru to commission the pilot scale PEF unit at the commercial French fries production plant (see Appendix 1).

2. A short magazine report in "Food New Zealand Vol. 18 (No. 4), year 2018, pages 21-23" entitled "Pulsed electric field technology offers new potential for New Zealand potato processing and wine making industries" by SY Leong, P Bremer, P Silcock, I Oey.

3. A joint workshop between Potatoes New Zealand and the University of Otago on 19th February 2019 in Dunedin (see Appendix 3), with the following objectives:
    a. To discuss the potentials of using PEF as pre-treatment for potato processing
    b. To share project findings with potato industry representatives from McCains, Talleys and Mr Chips
    c. Hands-on demonstration of PEF unit

4. Two oral presentations at the "4th FIET Colloquium" on 13th June 2019 at Palmerston North entitled "FIET project 9 updates" and "Updates on the industry trial on potatoes" by SY Leong, P Bremer, P Silcock, I Oey.

## Citing literatures


Faridnia, F., Burritt, D. J., Bremer, P. J., & Oey, I. (2015). Innovative approach to determine the effect of pulsed electric fields on the microstructure of whole potato tubers: Use of cell viability, microscopic images and ionic leakage measurements. *Food Research International, 77*(3), 556-564.

Kumar, G. M., Knowles, L. O., & Knowles, N. R. (2017). Zebra chip disease enhances respiration and oxidative stress of potato tubers (*Solanum tuberosum* L.). *Planta, 246*(4), 625-639.

Lisińska, G., & Gołubowska, G. (2005). Structural changes of potato tissue during French fries production. *Food Chemistry, 93*(4), 681-687.

Marquez, G., & Anon, M. (1986). Influence of reducing sugars and amino acids in the color development of fried potatoes. *Journal of Food Science, 51*(1), 157-160.

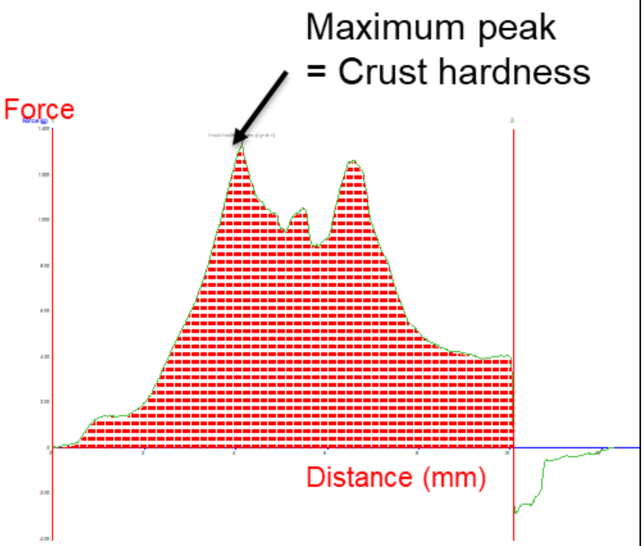
Miranda, M. L., & Aguilera, J. M. (2006). Structure and texture properties of fried potato products. *Food Reviews International, 22*(2), 173-201.

**Appendix 1: Industry open day on PEF unit at Washdyke, Timaru on 27th June 2018**

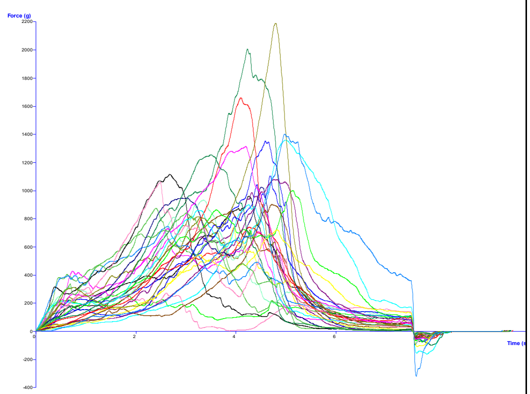
Left to right: Katy Bluett (FIET board member), John Jackson (McCain Foods), Gordon Gillies (McCain Foods), Jimmy Kinsella (Elea, Germany), Prof. Indrawati Oey (University of Otago – UO), Chris Claridge (Potatoes New Zealand), Dr. Sze Ying Leong (UO), Zhihao Hu (UO), Ian Ross (UO), Pat Silcock (UO) and Prof. Phil Bremer (UO).

**Appendix 2: Evaluation of crust hardness from the texture profile obtained from texture analyser**

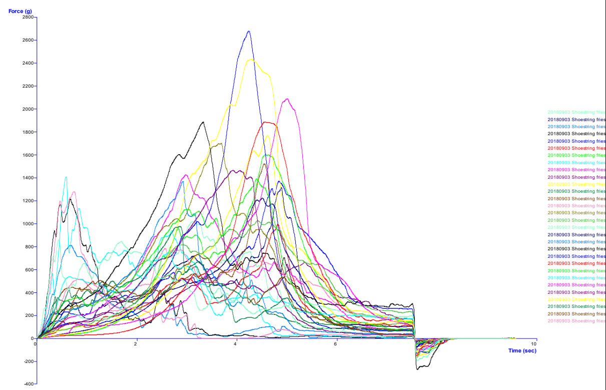
Cutting blade with guillotine edge (Blade 11054, 90 mm height, 70 mm width, 3 mm thickness)




Example of the texture profile (cutting force vs. distance travelled through the fries by the cutting blade). The maximum cutting force through the fries is defined as the crust hardness.



Collective texture profiles from 10 fries (duplicate measurements) from the same treatment group (Reference B, “Cultivar X”). This shows a high variability in the texture profile between fries.



Collective texture profiles from 10 fries (duplicate measurements) from the same treatment group (PEF A, “Cultivar X”). This shows a high variability in the texture profile between fries.

**Appendix 3: Joint workshop between Potatoes New Zealand and the University of Otago on 19th February 2019 in Dunedin**

(1) Workshop agenda and list of presentations

Potatoes NEW ZEALAND

FIET Food Industry Enabling Technologies

UNIVERSITY OF OTAGO

# FIET - PotatoesNZ Workshop

## 19 February 2019 - 10 am to 4 pm

### Otago Business School Room LG04, University of Otago, Dunedin

| | |
|---|---|
| 10.00 – 10.10: | Welcome, introduction to the team and the scope of the workshop<br>*by Prof. Indrawati Oey (University of Otago)* |
| 10.10 – 10.20: | FIET research programme: A brief overview<br>*by Prof. Richard Archer (Massey University)* |
| 10.20 – 10.30: | Overview of PotatoesNZ's business and research needs<br>*by Dr. Iain Kirkwood (PotatoesNZ)* |
| 10.30 – 12.00: | Understanding the impact of Pulsed Electric Field (PEF) technology on potato processing<br>*by Prof. Indrawati Oey and Dr. Sze Ying Leong (University of Otago)* |
| 12.00 – 13.00: | Lunch and networking |
| 13.00 – 14.30: | PEF processing and zebra chip defects<br>*by Dr. Sze Ying Leong (University of Otago)* |
| 14.30 – 15.00: | Automated *Liberibacter* damage detection in whole potato tubers on a grading line<br>*by Prof. Richard Archer and Dr. Abhimanyu Garhwal (Massey University)* |
| 15.00 – 16.00: | Demonstration of PEF technology for potato processing and tasting of PEF-treated products |

Please send RSVP to sze.leong@otago.ac.nz
by Wednesday, 13 February 2019
(This is a free workshop)
For more information, please contact Prof. Oey at indrawati.oey@otago.ac.nz

## (2) Group photo with the workshop attendees

Workshop attendees were Otago University staffs (Prof. Indrawati Oey, Pat Silcock, Associate Prof. David Burritt, Sze Ying Leong, Ian Ross) and students (Zihan Xu and Jess Fitzgerald) involved in the potato project, Dr. Iain Kirkwood from Potatoes New Zealand, potato industry representatives from McCains, Talleys and Mr Chips, Plant and Food Research collaborator for FIET project 9 (Dr. Samantha Baldwin) and FIET members (Dr. Peter Fennessy, Prof. Richard Archer and Dr. Ross Holland).

## (3) Hands-on demonstration of PEF unit

*Dr. Fennessy (FIET) and Mr. Chudleigh (Talleys) were discussing on the potato slices after PEF treatment.*

*Dr. Baldwin (Plant and Food Research) was assessing the potato tubers after PEF treatment.*

*Dr. Kirkwood (Potatoes New Zealand) and Mr. Haigh (Mr Chips) were assessing PEF-treated potato.*

*Dr. Leong was demonstrating the fries produced from untreated and PEF-treated potatoes to Mr. Haigh (Mr Chips)*