Characterization of blanching water from the potato processing industry and the influence of processing conditions

Akram Sayed[1], Michael Chys[1], Imca Sampers[1*]

[1]*Research Unit VEG-i-TEC, Department of Food Technology, Safety and Health, Faculty of Bioscience Engineering, Ghent University, Campus Kortrijk, Graaf Karel de Goedelaan 5, 8500 Kortrijk, Belgium*

---

* **Corresponding author:** Imca Sampers. Mailing address: Research Unit VEG-i-TEC, Department of Food Technology, Safety and Health, Faculty of Bioscience Engineering, Ghent University, Campus Kortrijk, Graaf Karel de Goedelaan 5, 8500 Kortrijk, Belgium. Phone: +32 56 29 26 00.

Electronic mail address: imca.sampers@ugent.be

Word count: 8040

Abstract

The move towards a circular economy pushes (Belgian) potato processing companies to direct water reuse in high water-consuming processing steps such as blanching. To design a robust treatment for this stream, it is important to know the composition and variability through different seasons, companies and processing conditions. An extensive physicochemical and (limited) microbial characterization was done on samples taken from four different blancher types at seven companies for 1.5 years. High concentrations of organic matter, represented as chemical oxygen demand (9032±4349 mg O_2/L), glucose (0.26±0.32 g/L) or starch (1.40±1.22 g/L) and dissolved ions (348±142 mg Cl^-/L and 1279±510 mg potassium/L) were found, at constant ranges independently of the season. This is probably due to the occurrence of a steady state over time for the physicochemical parameters in the water. Concentrations at this steady state or equilibrium could change depending on the used potatoes-to-water ratio used at the blanchers, which is specific to the company and blancher and hence influences the aforementioned equilibrium. From this study, the blanching water shows a high potential for reuse with the (potential) recuperation of thermal energy and by-products. In the case of membrane filtration as a treatment method (ultrafiltration and/or reverse osmosis), the implementation of a pre-treatment to eliminate an excess of solids is recommended together with a possible disinfection or heat exchanger as post-treatment.

1 Introduction

The Belgian potato processing industry is responsible for delivering more than 2 Mt processed potato products (e.g. fries, croquettes, hash browns) on an annual basis (Keijbets, 2008; VILT, 2021). This induces a large water consumption considering the multiple water-demanding processing steps such as washing, (steam) peeling, water-propelled cutting and blanching (Sayed et al., 2021; Zhang et al., 2021). On average a potato processing company uses 1.25 – 4.3 m^3 water/t finished product with blanching claiming to be responsible for ± 21% of the total water consumption (VITO, 2015) as one of the most water-consuming processing steps.

Industrial blanching is a heat treatment where the washed, peeled and cut potato products are immersed in hot water or exposed to steam for a certain period and, in the (Belgian) potato processing industry, often applied in two subsequent blanching steps for the production of (frozen) fries (Tajner-Czopek et al., 2008). Conventionally, a first 'high temperature, short time' blanching step to achieve a.o. enzymatic deactivation (70 – 100 °C for <1 – 15 minutes) is followed by a second 'low temperature, long time' step, mainly to leach out carbohydrates (55 – 75 °C for 10 – 60 minutes) (Abu-Ghannam and Crowley, 2006; Ngobese et al., 2017). Nonetheless, one-step (or three-step) blanching could also be used (Tajner-Czopek et al., 2008). Other advantages of blanching are the removal of pesticides and other undesired residues, reduction of oil uptake while baking or texture improvement/softening (Reis, 2017; Xiao et al., 2017).

The processing step 'blanching' requires freshwater of potable quality (conform 2020/2184/EC and Belgian royal decision 14/01/2002) at the inlet as described by the self-checking guide G-014 'Guide for self-checking in the potato, vegetable and fruit processing and trade' (VITO, 2015). Treating the process water for recirculation may reduce the pressure on local water sources and result in a shift towards a circular economy. However, too little information is available on the exact composition of blanching water. This makes it difficult to apply certain treatments and estimate their efficiency. Until today (to the best of the authors' knowledge) no (extensive) physicochemical or microbial characterization of industrial potato blanching water has been published.

In some studies, the quality of effluent wastewater after (conventional) treatment from potato processing companies was determined showing a.o. pH, chemical oxygen demand (COD), starch and protein ranges of 3.9 – 7.5, 27.4 – 30 000 mg O_2/L, 19.47 – 25 g/L and 2.88 – 4 g/L respectively (Abeling and Seyfried, 1993; Huang et al., 2003; Mishra et al., 2004; Rintala and Lepistö, 1997). However, this is no reliable representation of water from potato blanchers. Only a limited amount of studies were published measuring a few physicochemical characteristics of blanching water (with or without water from cutting / washing) from potato processing companies, confirming the highly loaded water streams coming from these processing steps, with ranges for parameters such as pH (4.7 – 6.2), nitrogen (0.131 – 0.305 mg N/L), COD (650 – 10 000 mg O_2/L), glucose (0.369 g/L) and starch (0.0145 – 0.849 g/L) (Catarino et al., 2007; Lemmel et al., 1979; Wang et al., 2005). However, from the small amount of studies covering potato blanching water research, samples taken are very limited in quantity and analysed characteristics. Furthermore, in these studies, the processing conditions at the moment of sampling are not mentioned.

In the blanching process, operating at a constant potato input rate, freshwater is continuously or periodically added due to the increasing number of soluble components (e.g. carbohydrates) or microbial growth in the blanching water. These water refreshments should depend on the changing state of the blanching water quality, i.e. the velocity or quantity of diverse components such as carbohydrates leaching out of the potatoes (Arroqui et al., 2001), with the retainment of the right potato product quality. However, in practice, this refreshment rate is (visually) determined by rules of thumb or based on operators' experience without any specific (online) measurement or control of water characteristic parameters. Also, different factors could be influencing this process: differences between potato varieties (such as Bintje, Fontane, Challenger) as mentioned by Morales-Fernández et al. (2015) and Veerman (2003), the difference in early-, mid- or late-season potatoes (i.e., depending on the days needed to reach maturity) with the latter type having a higher starchiness compared to the early season potatoes (Leo et al., 2008; Lisinska and Leszczynski, 1989; Volkov et al., 2022), pre-harvest conditions (KUMAR et al., 2004) or storage conditions (time & temperature) inducing sweetening processes with changing sugar concentrations in the potatoes as a result (Blenkinsop et al., 2002; Carvalho, 2017; De Wilde et al., 2005).

As the process water coming from a blancher may be rich in sugars and starch, a water treatment urges when recirculation is considered to reduce the consumption of valuable fresh water of potable quality. Because of the limited information in the literature regarding the potato blanching water quality and influences coming from the processing conditions , it is very difficult to select a suitable treatment for the recuperation of the water, (thermal) energy and interesting by-products such as starch. To counter this, the objectives of this research were (i) to provide an extensive physicochemical characterisation of blanching water in different Belgian potato companies combined with a brief microbiological screening, taking into account varying (ii) process parameters, (iii) seasons and (iv) companies. The outcome of this study should enable possibilities for future research to conduct proper selection of water treatment technologies by highlighting the specific characteristics of the blanching water and the points of attention when treating it.

2 Materials and methods

2.1 Experimental set-up and sampling methodology

Water samples (n=68) from 17 full-scale operating horizontal hot water screw blanchers in seven different companies (further denoted from A to G) located in Belgium were collected throughout all seasons between February 2020 and April 2021. The hot water-filled screw blanchers all consisted of a rotating screw moving the product while either steam or heated water was used for temperature control and as water refreshment. For a full screening of real industrial blanching water and all its different influences such as the impact of different blanching conditions on the water quality, samples were collected from a 'high temperature, short time' blancher (further referred to as BL1) and subsequent 'low temperature, long time' blancher (further referred to as BL2) in the same processing line of producing (frozen) fried fries. Company A occasionally included a third blancher in the same processing line (as a matter to extend the 'low-temperature, short-time' blancher) which was also sampled when operational, (further referred to as BL3). This blancher is only used in the period between March – June, when processing late-season and longest stored potatoes (since the harvesting period September – October) to compensate for the usually higher sugar concentrations by extending the time for carbohydrate leaching (Carvalho, 2017; Volkov et al., 2022). At companies B, C, E, F and G an (additional) blancher type was sampled processing larger potato parts (further referred to as BLS) used for the production of other potato products than fries (e.g. wedges, croquettes, hash browns). For these products, only one blanching step is commonly used. A summary of minimum and maximum blancher settings (i.e. temperature, time, water refreshment rates, etc.) for the different blanchers is given in Table 1. Note that due to the industrial setting, not all processing conditions could be obtained for every sample as some companies do not monitor or log every parameter. Companies A & B were sampled at different seasons with an increase in sampling frequency during the seasonal shift from processing stored to freshly harvested potatoes (typically) in the summer period. Other companies were sampled at least once for mutual comparison. A complete overview of the collected samples at any moment is displayed in Table S1.

Clean HDPE containers, pre-rinsed with the deliberate sample, were used to collect the water at the blancher sampling taps or if not available by grab sampling. At every sampling moment, the specific available processing conditions were noted.

2.2 Analysis methods

Analyses were performed within 12h after sampling or frozen for later analysis to avoid (microbial) changes in the water affecting the water quality. The water was cooled to ambient temperature (± 22 °C) for uniform measurement conditions and analysed following the 'Standard Methods for the Examination of Water and Wastewater' (Rice et al., 2017). Hanna Instruments (portable) meters were used to measure pH (HI2002-02) and turbidity (HI98703-02). Conductivity (EC) was measured using a HACH multi-meter (HQ40D) and probe (CDC401). Also dry matter (VENTI-Line), ash content (Carbolite ESF12/10), Kjeldahl nitrogen (Büchi, K436 & K350), particle size distribution (Malvern Panalytical, Particle Size Analyser 2000), multi-element analysis using an ICP-OES (Thermo Fisher, iCAP 7000 Series) and titrimetric measurement of water hardness (expressed in mg $CaCO_3$/L) were determined/performed using the same standard methods (Rice et al., 2017). A Shimadzu 1800 spectrophotometer was used to collect absorption data between 200 – 800 nm (1 cm path length), i.e. in the UV-VIS (ultraviolet-visible light) area. COD (LCK 014), orthophosphates (LCK 350), total phosphorous (LCK 350), chlorides (LCK 311) and nitrates (LCK 339) were spectrometric determined using HACH cuvettes and a DR6000 spectrophotometer. Viscosity was measured using the falling-ball principle (Ali et al., 2019). Reducing sugars and starch content were determined using the method of Luff-Schoorl (Matissek et al., 2014).

Total Psychotropic Aerobic Count (TPAC) was conducted on Plate Count Agar (Thermofisher CM0325) and incubated for 72 h at 22 °C, *Escherichia coli* (*E*. *coli*) were determined using RAPID'*E.coli* 2 Medium (BIO-RAD 3564024) and incubated for 24 h at 37 °C (ISO 9308-1), lactic acid bacteria (LAB) were plated on MRS broth (Thermofisher CM0359) with incubation on 30 °C for 72 h (ISO 15214) and thermophilic aerobic spores were determined by heating the samples at 80 °C for 10 min in a water bath followed by incubation on Plate Count Agar (Thermofisher CM0325) at 55 °C for 48 h (Kent et al., 2016).

The collected data were processed using SPSS statistics 24 for all statistical analyses (www.spss.com). Principal Component Analysis (PCA) was used for parameter reduction by applying pattern recognition following the procedure described by Chys et al. (2018).

3 Results and discussion

3.1 Blanching water composition

Characterization results of all samples are presented in Table 2, indicating that the blanching process is strongly affecting the water matrix considering potable water is used as starting water. The most notable characteristics are concerning the organic load and the presence of dissolved ions in the water. Concentrations of 9032 ± 4349 mg O_2/L COD, 5117 ± 3070 mg O_2/L Biological Oxygen Demand (BOD), 0.264 ± 0.323 g/L glucose and 1.40 ± 1.22 g/L starch were detected on average. Dissolved ions such as potassium (1279 ± 510 mg potassium/L), chloride (348 ± 142 mg Cl^-/L) and magnesium (126 ± 65 mg magnesium/L) were detected with the highest concentrations of the dissolved ions. These ions are also most probably responsible for the high conducting capacity of the blanching water (4.56 ± 1.39 mS/cm on average). These results emphasize the importance of a well-selected treatment technique, or combination of techniques aiming to reduce both the organic load and dissolved ions until the drinking water limit is met, as described in KB 14/01/2002 (i.e. Belgian drinking water legislation). A (physical) separation as pre-treatment could help reduce the particulate organic load, e.g. centrifugation before membrane filtration.

Potato tubers consist of approximately 76.3 % water, 17.5% carbohydrates, 2% of proteins, 0.7% of fibres and 0.4% of potassium (Sablani and Mujumdar, 2006). Leaching of these components from the potatoes during blanching will contribute to the increasing (organic) load in the water. The water turbidity and dry matter content of 744 ± 641 NTU and 1.06 ± 0.51 m% on average will mainly be determined by the present proteins, carbohydrates and fibres. The latter two are probably also responsible for the largest part of the measured particles as fibres could have particle sizes of 105 µm (Dhingra et al., 2012) and starch granules sizes between 1 – 110 µm (Singh et al., 2016), depending on the potato itself and gelatinization while glucose, proteins and ions are smaller than 0.30 µm (David and Livney, 2016; Minoli, 2005). Micronutrients such as potassium, calcium or phosphorous, present in potatoes, were also detected in the blanching water. Chlorides in the blanching water were detected in concentrations up to 786 mg Cl^-/L, while the maximum limit in potable water is 250 mg Cl^-/L (2020/2184/EC). Only ± 0.07 % of the potato composition is covered by chlorides (White et al., 2009) indicating that the high chloride concentrations could be the result of the leaching effect from the potato tubers, potentially combined with residual concentrations in the blancher from chlorine-based cleaning or disinfection products and/or the salty buffers/additives used during processing (e.g. to operate the 'pulsed electric field' treatment). The addition of salts such as $CaCl_2$ and $Ca(OH)_2$ at the blanching step is mentioned in the literature as a possible microbial inhibitor (Reis, 2017) or as an improvement to fries quality (Gökmen and Şenyuva, 2007), but this is not confirmed by the sampled companies as used techniques. The acidic to neutral pH of the blanching water is in line with the common pH of potatoes of 5.9 – 6.2 (Hyde and Morrison, 1964), due to the presence of organic acids, e.g. ascorbic acid, present in the tubers.

The average concentrations of pH (6.34 ± 0.72), Kjeldahl nitrogen (0.052 ± 0.022 m/V%) and glucose (0.264 ± 0.323 g/L) in this study are similar to the literature (Catarino et al., 2007; Lemmel et al., 1979; Wang et al., 2005), while COD and starch values are much higher compared to those studies (on average: 1060 to 9032 mg O_2/L COD and avg. 0.432 to 1.4 g/L starch). Although these few sources indicate some important physicochemical or biochemical components in potato blanching water, currently none of these publications specifies the exact origin (type of processing plant and step) and circumstances (type of blanched potato product and conditions) of the blanching water samples. Hence, differences between this research and the literature could be due to different conditions.

The microbiological parameters of interest were chosen based on screenings by cooperating companies and the microbiological standards mentioned in the Belgian royal dicision of 14/01/2002. Results from the microbial screening showed no detection (<LOD) of coliforms and *Escherichia coli* which are eliminated from the food products and water by the high temperatures (> 60 °C) in the blanching process and good hygienic operation. However, thermophilic aerobic spores and lactic acid bacteria are present in the blanching water with respectively 2.7 ± 1.1 and 2.6 ± 0.8 logs CFU/ml detected in the water. The latter could be of importance in terms of acidification and odour pollution of the blanching water and product. Acidification is now suppressed by continuous water refreshment inside the blanchers. In the case of treating the blanching water for reuse, attention should be paid to microbial safety. As microbial growth is likely to occur, a post-treatment disinfection step will be necessary if the selected water treatment technology fails to restrain this growth.

3.2 The impact of blanching process conditions on the water composition

Figure 1 shows the results of BL2 as a percentage of BL1 for most monitored physicochemical parameters. The pH, nitrates, spectrometric parameters (absorbances) and parameters constituting the organic matrix such as turbidity, COD, glucose and starch concentrations are visually lower in BL2 compared to BL1. This was statistically confirmed by a one-way ANOVA on a 5% significance level.

The high(er) concentrations in BL1 might seem contradictory as the ‘low temperature, long time’ blancher (i.e. BL2) is commonly used for carbohydrate leaching. However, the differences could be explained by the relative water consumption for both blanchers. BL1 blanchers are usually smaller (<10 m^3) compared to the BL2 types (>20 m^3), while an equal amount of potatoes is processed in both types. In addition, water refreshments of 1.8 – 10 m^3/h are maintained in BL2 compared to the 1 – 2.5 m^3/h in BL1, this results in a much higher potato-to-water ratio for BL1 than BL2 (respectively 5.52 up to 34.35 t/m^3 vs. 0.38 up to 6.17 t/m^3).

Figure 1 also shows that organic components, which are most abundant in potatoes, lead to a fast saturation in the blanching water of BL1 while mono and divalent ion concentrations are more evenly distributed through different blanching steps. Different diffusion rates between the larger organic molecules and small mono or divalent ions will probably be the reason why only a selection of parameters is more concentrated in BL1. This was stated by Pedreschi et al. (2009) claiming that sugars could have variable diffusivities in the function of the blanching time.

Including a third blancher (BL3), as occasionally done by company A, reduces the average product residence time to 9.7 ± 3.1 min in BL2 and BL3 compared to 12.8 ± 5.3 min at BL2 during other moments in the year. As a result, a (small) decrease in almost all parameters is noticed when comparing the means of BL2 (Table 3) and BL3 (Table S2), as expected considering that the fries entering BL3 already contain a lower number of components which could be leached out. Only the particle sizes of BL3 (D4.2 = 284 ± 50 µm) seem to be larger on average compared to BL2 (D4.2 = 207 ± 100 µm). This suggests the presence of larger particles, coming from the higher starchiness, in late-season and/or long-stored potatoes. When comparing D4.2 of the three BL2-samples taken at the same moment as BL3, 242 ± 43 µm is still smaller than 284 ± 50 µm of BL3, indicating that larger particles take longer to leach out of the potatoes. However, differences are small and statistically not confirmed.

The water characteristics from the blancher in the production line for potato products (BLS) are difficult to compare with other types considering the differences in products (fries vs potato parts) and processing conditions (Table 1). Overall, concentrations are similar to those for BL1 as, with BLS as a single-blanching step, both enzymatic deactivation and carbohydrate leaching should be accomplished, resulting in an accumulation of an equivalent (organic) load coming from the potatoes which are usually divided over multiple blanchers at processing lines with multi-stage blanching steps.

Considering all results, no direct relations could be drawn between the blanching water composition and the blanching process conditions at the moment of sampling. Further exploration at the companies revealed that between two moments of cleaning and disinfection, processing conditions and potato varieties could vary daily and are now not always (correctly) monitored. Companies will strive for uniform product quality, so processing parameters will be adjusted in function of that. For example, water refreshments will be increased if microbial acidification and odour pollution increase or the fries' residence time at the blanchers will be increased if quality control measures too high sugar contents. So in addition, more frequent monitoring on shorter periods (i.e. between two cleaning & disinfection moments) will be necessary for further elaboration on the correlation analysis between the processing conditions and physicochemical composition of blanching water. This should be combined with pre-installed monitoring sensors/systems to accomplish exact logging of important processing parameters.

3.3 The seasonal variation influencing the blanching water composition

During July, August and September, potatoes are processed immediately after harvesting. These are mostly early- and mid-season potato types. However late season potato types could also be processed upon harvest but are usually stored through the year to provide continuous input to the processing plants. As an increasing maturity of the potatoes (during storage) involves an increasing amount of starch in the tubers (Volkov et al., 2022), it also benefits sweetening processes, i.e. increasing sugar concentrations (Mestdagh et al., 2008a). Hence, it is important for the companies processing the potatoes to adjust their processes to maintain a uniform end product. Currently, it is not known if this seasonal shift (and changing concentrations of carbohydrates in potatoes) induces a difference in blanching water quality or if the quality will be more stable as it follows the changes made in the process to maintain a uniform end product.

Figure 2 shows the COD, turbidity and starch concentrations in different blanchers (from companies A & B) followed up for multiple seasons. However, no visual or statistical (one-way ANOVA, Sig.=0.05) confirmation could be found when verifying this hypothesis, as concentrations seem to be in the same range throughout the year. As mentioned before, processing conditions are being changed to maintain a uniform end product. Another possible reason for these constant concentrations in the water could be the potential presence of a state of equilibrium during blanching. This phenomenon was already mentioned in studies of Mestdagh et al. (2008b) and Tomasula et al. (1990), indicating that sugars will diffuse from the potato products to the water with the constant velocity of the equilibrium under fixed blanching conditions. However, both situations were not based on full-scale operating industrial blanchers accounting for all processing conditions or evaluating the complete blanching water matrix.

To study the occurrence of the equilibrium, a simulation is made where the mass of blanched fries per volume of water used is plotted over time, starting from the moment the blancher is drained, cleaned, disinfected and filled again (Figure 3**Fout! Verwijzingsbron niet gevonden.**). The curves were plotted using the minimum and maximum values of BL1 & BL2 mentioned in Table 1 and function (1), with t = processing time (h) since the last cleaning and refill of the blancher.

$$f(t) = \frac{\text{processing rate } (\frac{t}{h}) * t\ (h)}{\text{blancher volume } (m^3) + \text{water refreshment rate } \left(\frac{m^3}{h}\right) * t\ (h)} \quad (1)$$

Since most samples were taken of BL1 and BL2, two scenarios were plotted for these both blanchers, one simulation with the lowest processing rates recorded during sampling (i.e. 6 t/h for both) at the largest water refreshment rates (i.e. 2.5 m^3/h for BL1 and 10 m^3/h for BL2) and vice versa. Figure 3**Fout! Verwijzingsbron niet gevonden.** shows that in both cases for all blanchers most changes happen in the first 24 to 48 hours after start-up before reaching a certain level of equilibrium. It is expected that this "plateau" also induces a blanching water quality with minimal variations. For this research, only 10% of the samples were taken within the first 48 hours after start-up. 18% were taken between 48 – 100 hours after start-up and 72% after that, explaining the continuity of the blanching water composition through the year based on simulated process data. A small increase is noticeable when comparing the physicochemical parameters of samples taken at company A or B in the first hours after start-up to samples taken later. But with the other companies excluded, too few samples taken in the first 100 hours are available to draw any conclusions on the exact trend in the first hours after start-up. Regarding possible treatment technologies, the consistent composition and load of the blanching water throughout the year will facilitate possible treatment selection and handling.

3.4 Variability of blanching water composition between companies

Two different potato processing companies were monitored frequently over 1.5 years for which average concentrations and the variance for BL1 and BL2 are given in Table 3. For all 49 monitored parameters except calcium, no (statistical) differences are found (one-way ANOVA, Sig.=0.05) between the companies for BL1, which could imply that the blanching water composition is company-independent. However, for BL2 the results are less clear as 18 of the 49 measured parameters showed statistical differences between the companies (one-way ANOVA, Sig.=0.05). Despite the similar ranges, the sizing and processing conditions in a company are most likely to be decisive for the quality of the blanching water, despite the common ranges in which the concentrations usually remain. For BL1 an average of 20.0 ± 8.8 and 12.8 ± 5.7 "tonnes of processed potatoes/cubic meter water used" was maintained for companies A and B respectively. For BL2, this was 4.8 ± 0.6 t/m³ for company A and 1.75 ± 0.6 t/m³ for company B. When considering the overlap or no overlap of the standard deviations, this data confirms the possible (in)differences between companies due to their specific processing conditions, i.e., possibly inducing different levels of equilibriums (**Fout! Verwijzingsbron niet gevonden.**). Also, company A includes the third blancher as an extension of BL2 to balance the 'pollution' of the load of the water. This is not the case in company B resulting in changes in water refreshments and other processing conditions of BL2 to compensate for fries with higher carbohydrate concentrations.

3.5 Principal Component Analysis for further evaluation of (post-)processing conditions on the dependency of the blanching water composition

Principal component analysis (PCA) was applied as research development to study the general (in)dependency of the studied potato blanching water composition with (pre-)processing conditions such as the storage (time) of potatoes processed or type of blancher. Based on a significant Barlett's test of sphericity ($\chi2$ (210) ≈ 1633.0; p= <0.001), KMO value > 0.5 (KMO = 0.779) and an Eigenvalue > 1 for each PC, a "five principal component (PC) model" could be obtained representing the used physicochemical parameters with an explained cumulative total variance of 88%. Starting with the complete data set, parameters were one by one excluded, starting with the parameter with the lowest available data points until the above-mentioned criteria were met for the evaluation of the PC. Eventually, viscosity, BOD, total phosphorus, water hardness and micro-elements such as iron, potassium and calcium were not used. The rotated principal component matrix is presented in the supplementary data (Table S3).

Based on the correlations in this matrix it is clear that PC1 has an affinity for the spectral (determined) parameters (UV-VIS absorbance and turbidity), while PC2 represents the information about particle sizes. PC3 is most related to the general water quality with parameters such as dissolved ions, conductivity, dry matter and ash. PC4 and PC5 are more focussed on the organic matter, with PC4 retaining most information on the COD and nitrogen and for the last PC carbohydrates and pH are best related.

Data plots using the PCs were studied to find further interactions between parameters. Figure 4 shows the data plot of PC1 and PC2 with the differentiation by type of potato being processed at the time of sampling. From this graph, a trend is observed showing that when processing stored potatoes, the blanching water will have more particles of larger size compared to when processing fresh potatoes. This could confirm the earlier mentioned statement that more starch (i.e. larger particles) are present in the water because the stored potatoes have elevated starch concentrations. Between other PCs, some groups are noticed supporting the slightly higher presence of organic compounds in BL1 blancher types, though the distinction is overlapping and vague. Further absence of clear grouping shows that these PCs are less dependable to different conditions. This fits with earlier observed lack of correlations, meaning that the physicochemical composition is constant over different seasons (excluding particle sizes) and different companies.

4 Conclusion

An extensive characterisation of blanching water originating from different potato processing companies in Belgium was performed for 1.5 years. Results exposed that the water matrix was highly loaded with both organic matter and dissolved ions leached from the potatoes, making the water challenging to treat. Microbial activity is still ongoing with the presence of lactic acid bacteria and thermophilic spores in the water.

Small differences were observed between subsequent ‘high temperature, short time’ or ‘low temperature, long time’ blanchers in the production line for (frozen) fries. Variations in the organic load are mainly affected by the differences in the potato-to-water ratio in the blancher and the different diffusion rates of different components. A third blancher in the same line can be used as an extension to the second blancher (‘low temperature, long time’) to have an increased leaching effect when processing (long) stored potatoes with higher carbohydrate content.

No direct relations were observed between processing conditions and blanching water composition due to the frequent change of processing conditions between two moments of cleaning & disinfection to maintain the uniform quality of fries. An intensive water sampling and monitoring of process conditions between these two moments should be performed to expand correlation analysis. Also, a hypothesis was developed to explain the consistent water quality through time/seasons. A possible level of equilibrium (i.e. steady state) is assumed to occur in the blancher where the number of leached-out components and water refreshment are constant, inducing an equal constant blanching water composition. Further research should investigate the possible accuracy of this hypothesis.

Differences between seasons, i.e. when processing different potato types, did not result in different sugar or starch concentrations in the water due to compensation by the companies and the proposed steady-state level. The blanching water composition for similar types of blanchers between different companies will also depend mainly on the potato-to-water ratio used. Principal component analysis

(PCA) was used as a parameter-reduction method to further investigate earlier made hypotheses on the influence of (post-)processing conditions on the blanching water quality. Results revealed a higher presence of large particles in the blanching water when processing (long) stored potatoes. Further, PCA showed no clear grouping of parameters based on season, company or blancher type confirming the observations (lack of correlations) and the possible steady-state resulting in the constant composition of the blanching water.

The average concentrations of the prevalent components in the blanching water and the range given in this study provide better insights into the blanching process. This induces possibilities for valid water management, treatment and by-product valorisation as future estimation of the blanching water quality will be more convenient. In case of possible water treatment for reuse, the high organic load will be of importance when advanced water techniques would be used such as membrane filtration (e.g. ultrafiltration or reverse osmosis) aiming for the effluent to be of potable water quality. Therefore, the implementation of a pre-treatment step would be recommended to lower the suspended solids concentration and possibly dissolved organic load which will improve complex water treatment processes. If the selected treatment fails to deliver microbial-safe water, disinfection as post-treatment will also be necessary.

Acknowledgements

This work was supported by a project fund from Flanders Innovation & Entrepreneurship (Agentschap Innoveren & Ondernemen (VLAIO)): HBC.2018.0517 (Sucr'eau: Water reuse and valorization of the by-product at the second blanching step in the potato processing industry) and companies from the potato processing industry in Belgium with partners Flanders' FOOD; Belgapom; Watercircle.be and Ghent University. The cooperation and commitment of the participating Belgian potato processing companies were greatly appreciated as well as the support of the Interreg FWVl VEG-i-TEC project (supported by the European Fund for Regional Development).

Appendix A. Supplementary data

Supplementary material: Table S1 – Table S3.

References

Abeling, U., Seyfried, C.F., 1993. Anaerobic-Aerobic Treatment of Potato-Starch Wastewater. Water Sci. Technol. 28, 165–176. https://doi.org/10.2166/wst.1993.0098

Abu-Ghannam, N., Crowley, H., 2006. The effect of low temperature blanching on the texture of whole processed new potatoes. J. Food Eng. 74, 335–344. https://doi.org/10.1016/j.jfoodeng.2005.03.025

Ali, S.H., Al-Zuky, A.A.D., Al-Saleh, A.H., Mohamad, H.J., 2019. Measure liquid viscosity by tracking falling ball Automatically depending on image processing algorithm. J. Phys. Conf. Ser. 1294. https://doi.org/10.1088/1742-6596/1294/2/022002

Arroqui, C., Rumsey, T.R., Lopez, A., Virseda, P., 2001. Effect of different soluble solids in the water on the ascorbic acid losses during water blanching of potato tissue. J. Food Eng. 47, 123–126. https://doi.org/10.1016/S0260-8774(00)00107-2

Blenkinsop, R., Copp, L., Yada, R., Marangoni, A., 2002. Changes in Compositional Parameters of Tubers of Potato (Solanum tuberosum) during Low-Temperature Storage and Their Relationship to Chip Processing Quality. J. Agric. Food Chem. 50, 4545–4553. https://doi.org/10.1021/jf0255984

Carvalho, C., 2017. Final Report Understanding mechanisms and identifying markers for the onset of senescent sweetening. Warwickshire.

Catarino, J., Mendonça, E., Picado, A., Anselmo, A., Nobre da Costa, J., Partidário, P., 2007. Getting value from wastewater: by-products recovery in a potato chips industry. J. Clean. Prod. 15, 927–931. https://doi.org/10.1016/J.JCLEPRO.2005.12.003

Chys, M., Demeestere, K., Nopens, I., Audenaert, W.T.M., Van Hulle, S.W.H., 2018. Municipal wastewater effluent characterization and variability analysis in view of an ozone dose control strategy during tertiary treatment: The status in Belgium. Sci. Total Environ. 625, 1198–1207. https://doi.org/10.1016/J.SCITOTENV.2018.01.032

David, S., Livney, Y.D., 2016. Potato protein based nanovehicles for health promoting hydrophobic bioactives in clear beverages. Food Hydrocoll. 57, 229–235. https://doi.org/https://doi.org/10.1016/j.foodhyd.2016.01.027

De Wilde, T., Meulenaer, B., Mestdagh, F., Govaert, Y., Vandeburie, S., Ooghe, W., Fraselle, S., Demeulemeester, K., Peteghem, C., Calus, A., Degroodt, J.-M., Verhé, R., 2005. Influence of Storage Practices on Acrylamide Formation during Potato Frying. J. Agric. Food Chem. 53, 6550–6557. https://doi.org/10.1021/jf050650s

Dhingra, D., Michael, M., Rajput, 2012. Physico-Chemical Characteristics of Dietary Fibre from Potato Peel and its Effect on Organoleptic Characteristics of Biscuits. J. Agric. Eng. 49.

Gökmen, V., Şenyuva, H.Z., 2007. Acrylamide formation is prevented by divalent cations during the Maillard reaction. Food Chem. 103, 196–203. https://doi.org/https://doi.org/10.1016/j.foodchem.2006.08.011

Huang, L.P., Jin, B., Lant, P., Zhou, J., 2003. Biotechnological production of lactic acid integrated with potato wastewater treatment by Rhizopus arrhizus. J. Chem. Technol. Biotechnol. 78, 899–906. https://doi.org/10.1002/jctb.877

Hyde, R.B., Morrison, J.W., 1964. The effect of storage temperature on reducing sugars, pH, and phosphorylase enzyme activity in potato tubers. Am. Potato J. 41, 163–168. https://doi.org/10.1007/BF02855318

Keijbets, M., 2008. Potato Processing for the Consumer: Developments and Future Challenges. Potato Res. 51, 271–281. https://doi.org/10.1007/s11540-008-9104-3

Kent, D.J., Chauhan, K., Boor, K.J., Wiedmann, M., Martin, N.H., 2016. Spore test parameters matter: Mesophilic and thermophilic spore counts detected in raw milk and dairy powders differ significantly by test method. J. Dairy Sci. 99, 5180–5191. https://doi.org/https://doi.org/10.3168/jds.2015-10283

KUMAR, D., SINGH, B.P., KUMAR, P., 2004. An overview of the factors affecting sugar content of potatoes. Ann. Appl. Biol. 145, 247–256. https://doi.org/https://doi.org/10.1111/j.1744-

7348.2004.tb00380.x

Lemmel, S.A., Heimsch, R.C., Edwards, L.L., 1979. Optimizing the continuous production of Candida utilis and Saccharomycopsis fibuliger on potato processing wastewater. Appl. Environ. Microbiol. 37, 227–232.

Leo, L., Leone, A., Longo, C., Lombardi, D.A., Raimo, F., Zacheo, G., 2008. Antioxidant Compounds and Antioxidant Activity in “Early Potatoes.” J. Agric. Food Chem. 56, 4154–4163. https://doi.org/10.1021/jf073322w

Lisinska, G., Leszczynski, W., 1989. Potato Science and Technology. Springer Netherlands.

Matissek, R., Steiner, G., Fischer, M., 2014. Lebensmittelanalytik, 5th ed. Springer Spektrum, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-34829-7

Mestdagh, F., De Wilde, T., Fraselle, S., Govaert, Y., Ooghe, W., Degroodt, J.-M., Verhé, R., Van Peteghem, C., De Meulenaer, B., 2008a. Optimization of the blanching process to reduce acrylamide in fried potatoes. LWT - Food Sci. Technol. 41, 1648–1654. https://doi.org/https://doi.org/10.1016/j.lwt.2007.10.007

Mestdagh, F., De Wilde, T., Fraselle, S., Govaert, Y., Ooghe, W., Degroodt, J.M., Verhé, R., Van Peteghem, C., De Meulenaer, B., 2008b. Optimization of the blanching process to reduce acrylamide in fried potatoes. LWT - Food Sci. Technol. 41, 1648–1654. https://doi.org/10.1016/J.LWT.2007.10.007

Minoli, D., 2005. Nanotechnology Applications to Telecommunications and Networking. Wiley.

Mishra, B.., Arora, A., Lata, 2004. Optimization of a biological process for treating potato chips industry wastewater using a mixed culture of Aspergillus foetidus and Aspergillus niger. Bioresour. Technol. 94, 9–12. https://doi.org/10.1016/J.BIORTECH.2003.11.020

Morales-Fernández, S.D., Mora-Aguilar, R., Salinas-Moreno, Y., Rodríguez-Pérez, J.E., Colinas-León, M.T., Lozoya-Saldaña, H., 2015. Growth, yield and sugar content of potato tubers at different physiological ages . Rev. Chapingo. Ser. Hortic. .

Ngobese, N.Z., Workneh, T.S., Siwela, M., 2017. Effect of low-temperature long-time and high-temperature short-time blanching and frying treatments on the French fry quality of six Irish potato cultivars. J. Food Sci. Technol. 54, 507–517. https://doi.org/10.1007/s13197-017-2495-x

Pedreschi, F., Travisany, X., Reyes, C., Troncoso, E., Pedreschi, R., 2009. Kinetics of extraction of reducing sugar during blanching of potato slices. J. Food Eng. 91, 443–447. https://doi.org/10.1016/j.jfoodeng.2008.09.022

Reis, F.R., 2017. New Perspectives on Food Blanching, 1st ed. Springer International Publishing, Jacarezinho. https://doi.org/10.1007/978-3-319-48665-9

Rice, E.W., Baird, R.B., Eaton, A.D., 2017. Standard methods for the examination of water and wastewater, 23rd ed. American Public Health Association (APHA), Washington D.C.

Rintala, J.A., Lepistö, S.S., 1997. Pilot-scale thermophilic anaerobic treatment of wastewaters from seasonal vegetable processing industry. Water Sci. Technol. 36, 279–285. https://doi.org/10.1016/S0273-1223(97)00399-5

Sablani, S., Mujumdar, A., 2006. 27 Drying of Potato, Sweet Potato, and Other Roots. Handb. Ind. Drying, Fourth Ed. https://doi.org/10.1201/9781420017618.ch27

Sayed, A., Chys, M., De Rop, J., Goeteyn, L., Spanoghe, P., Sampers, I., 2021. Pesticide residues in (treated) wastewater and products of Belgian vegetable- and potato processing companies. Chemosphere 280, 130619. https://doi.org/10.1016/J.CHEMOSPHERE.2021.130619

Singh, J., Colussi, R., McCarthy, O.J., Kaur, L., 2016. Potato Starch and Its Modification. Adv. Potato Chem. Technol. Second Ed. 195–247. https://doi.org/10.1016/B978-0-12-800002-1.00008-X

Tajner-Czopek, A., Figiel, A., Carbonell-Barrachina, Á.A., 2008. Effects of potato strip size and pre-drying method on french fries quality. Eur. Food Res. Technol. 227, 757–766. https://doi.org/10.1007/s00217-007-0784-8

Tomasula, P.M., Kozempel, M.F., Craig Jr., J.C., 1990. Simulation and Control of Glucose Concentration in Hot-Water Blanching of Potatoes. Biotechnol. Prog. 6, 249–254. https://doi.org/https://doi.org/10.1021/bp00004a003

Veerman, A., 2003. Teelthandleiding consumptieaardappelen, Praktijkonderzoek Plant & Omgeving

B.V. Wageningen.
VILT, 2021. Belgische aardappelindustrie verwerkt 4 pct minder aardappelen in 2020 [WWW Document]. Vilt. URL https://vilt.be/nl/nieuws/belgische-aardappelindustrie-verwerkt-4-pct-minder-aardappelen-in-2020 (accessed 11.15.21).
VITO, 2015. Beste Beschikbare Technieken (BBT) voor aardappel-, groente- en fruitverwerkende nijverheid (AGF).
Volkov, D., Kim, I., Klykov, A., Matsishina, N., 2022. Comparative Evaluation of Different Potato Varieties for Their Suitability for Starch Processing BT - Fundamental and Applied Scientific Research in the Development of Agriculture in the Far East (AFE-2021), in: Muratov, A., Ignateva, S. (Eds.), . Springer International Publishing, Cham, pp. 443–450.
Wang, L.K., Hung, Y.T., Lo, H.H., Yapijakis, C., 2005. Waste Treatment in the Food Processing Industry. CRC Press.
White, P.J., Bradshaw, J.E., Finlay, M., Dale, B., Ramsay, G., Hammond, J.P., Broadley, M.R., 2009. Relationships Between Yield and Mineral Concentrations in Potato Tubers. HortScience horts 44, 6–11. https://doi.org/10.21273/HORTSCI.44.1.6
Xiao, H.W., Pan, Z., Deng, L.Z., El-Mashad, H.M., Yang, X.H., Mujumdar, A.S., Gao, Z.J., Zhang, Q., 2017. Recent developments and trends in thermal blanching – A comprehensive review. Inf. Process. Agric. 4, 101–127. https://doi.org/10.1016/J.INPA.2017.02.001
Zhang, Z., Hennebelle, M., Emami, S., Taha, A.Y., 2021. Effects of Potato Processing and Frying on Oxylipin Concentrations. ACS Food Sci. Technol. 1, 1436–1443. https://doi.org/10.1021/acsfoodscitech.1c00139

Figures

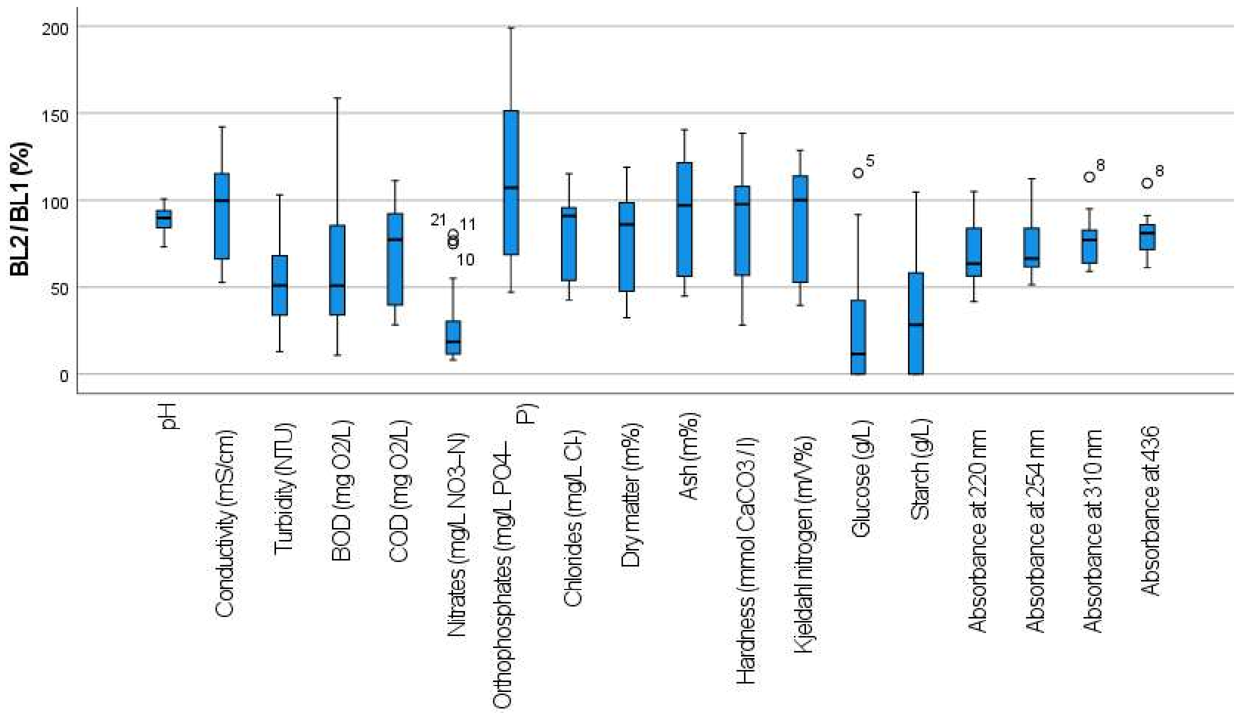

Figure 1: Average concentrations of BL2 (n=24) as a percentage of average concentrations of BL1 (n=24) from companies A and B, for a selection of physicochemical parameters.

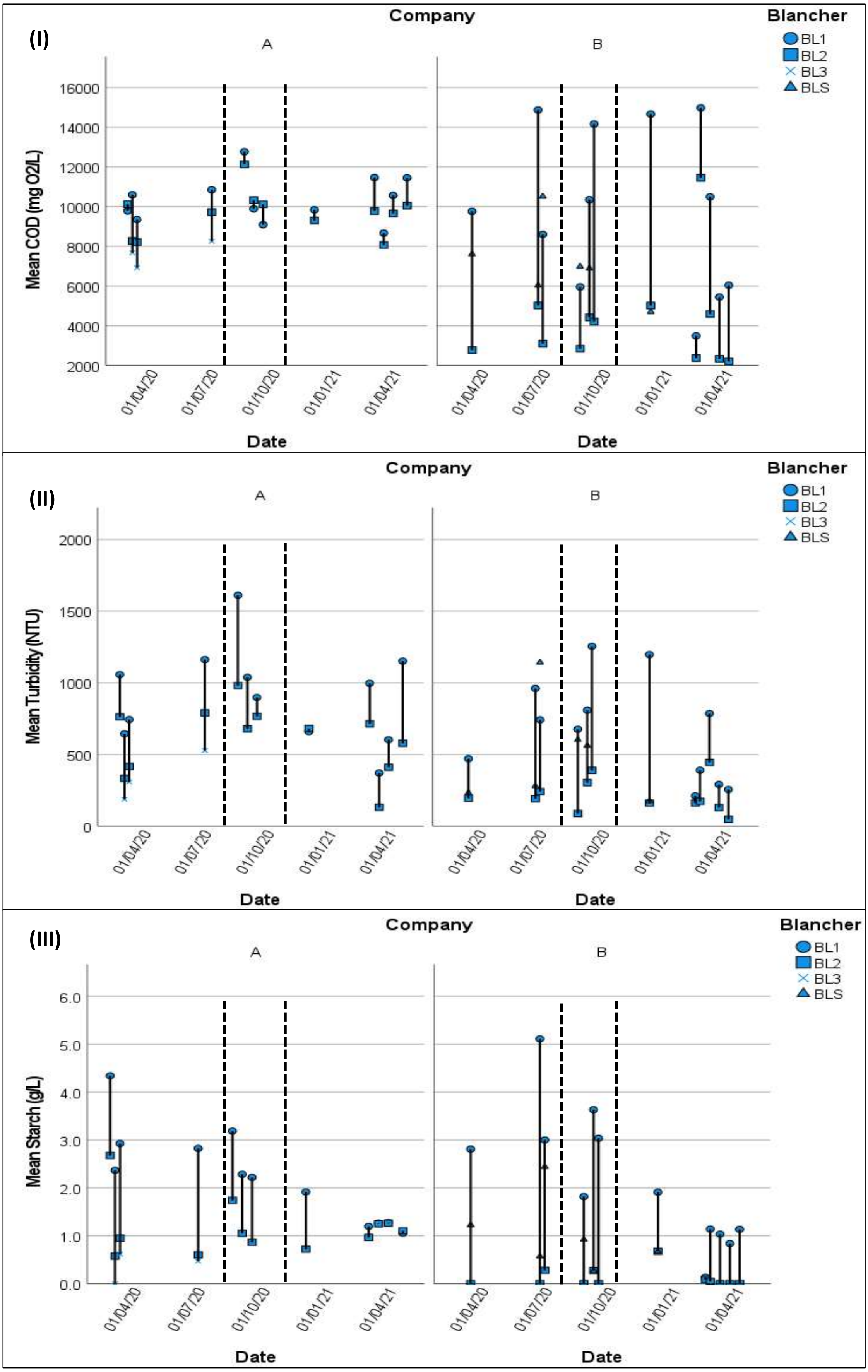

Figure 2: Chemical Oxygen Demand (COD) (I), glucose (II) and starch (III) concentrations from the different blancher types (BL1, BL2, BL3 & BLS) sampled in companies A (n = 27) and B (n = 30). The dotted line represents the start and end of freshly harvested potatoes being processed (non-stored).

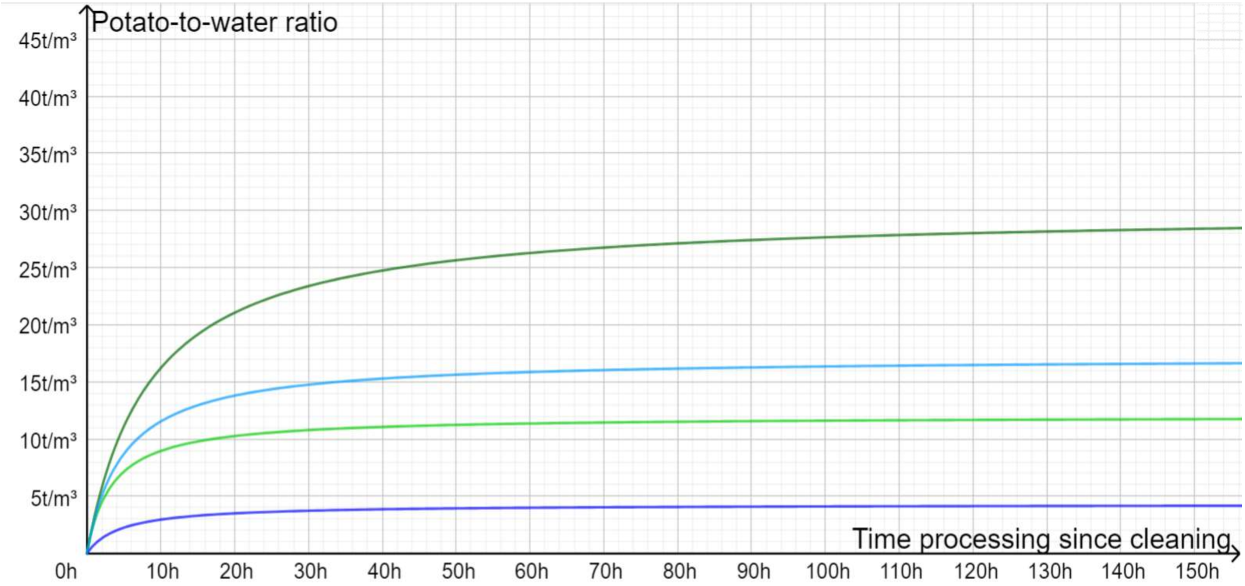

Figure 3: Simulation of the potato-to-water ratio through time in the blanchers of potato processing companies based on recorded data. A and C = the highest recorded potato processing capacity (t/h) with the lowest recorded total blancher volume (m^3) and water refreshment flow (m^3/h) for respectively BL1 and BL2, B & D = the lowest recorded potato processing capacity (t/h) with the highest recorded total blancher volume (m^3) and water refreshment flow (m^3/h) for respectively BL1 and BL2.

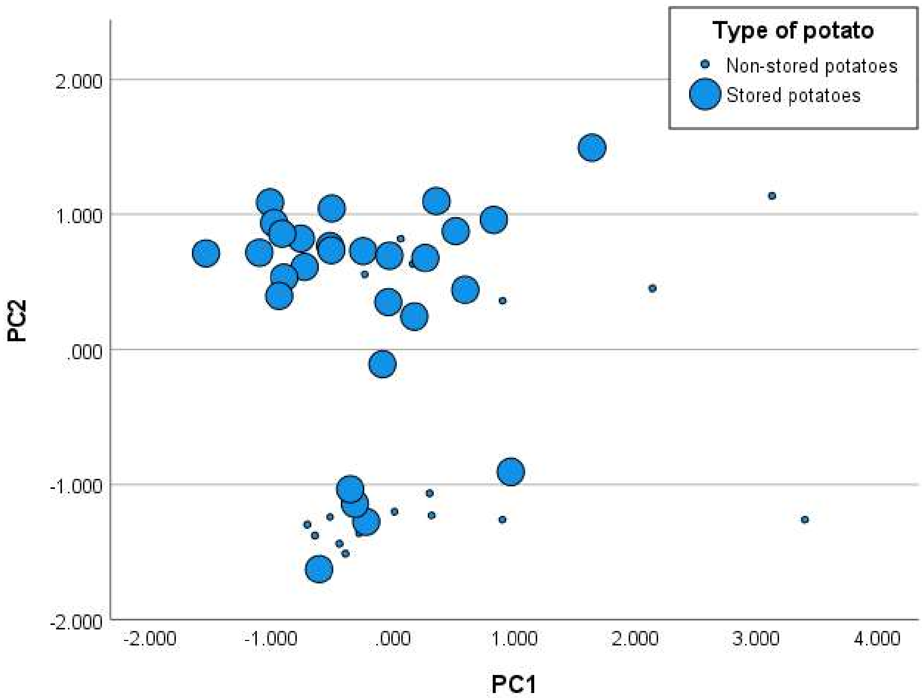

Figure 4: Results of the principal component analysis, with components 1 and 2 plotted. The distinction of the type of potato (i.e. stored or non-stored/freshly harvested) is visualized by dot size.

Tables

Table 1:
Ranges of used processing conditions during blanching at the moment of sampling for every type of blancher at seven different companies with the respective number of samples taken per blancher type between brackets; with BL 1 to 3 in the same line for the production of fries and BLS as blancher for producing (mashed) potato specialities.

	BL1 (n=27)	BL2 (n=26)	BL3 (n=3)	BLS (n=12)
Blanching temperature (°C)	80 – 92	60.5 – 75	70.5	70 – 85
Blanching time (min)	0.75 – 2.5	6 – 20	6 – 14	7 – 26
Processing rate (t/h)	6 – 50	6 – 50	36 – 44	2 – 9
Blancher volume (m^3)	3 – 8.5	20 – 35	31.8	4 –15
Water refreshment rate (m^3/h)	1 – 2.5	1.8 – 10	7.2 – 8.2	0.4 – 4.3 *
Mass potatoes processed per volume of water used (t/m^3)	5.52 – 34.35	0.38 – 6.17	4.39 – 5.85	0.63 – 8.02

* In companies B and C steam was used to maintain a constant water level instead of a constant fresh water refreshment.

Table 2

Physicochemical composition and microbiological screening of potato blanching water from 68 different samples obtained at the seven sampled companies (A-G) and four different hot water screw blanchers (BL1, BL2, BL3 & BLS).

	n	Minimum	Median	Maximum	Mean	Standard deviation
pH	68	5.07	6.40	7.87	6.34	0.72
Viscosity (Pa.s)	68	1	1	1	1	0
Conductivity (mS/cm)	68	1.99	4.78	7.92	4.56	1.39
Turbidity (NTU)	68	48.2	624	3086	744	641
BOD (mg O_2/L)	42	525	4432	14331	5117	3070
COD (mg O_2/L)	68	2212	9331	28840	9032	4349
Nitrates (mg NO_3^--N/L)	66	0.360	3.33	26.8	5.28	5.35
Orthophosphate (mg PO_4^{3-}-P/L)	68	14.5	42.6	98.8	46.6	20.8
Total phosphorus (mg P/L)	23	40.1	109	196	117	48.5
Chlorides (mg Cl^-/L)	66	120	345	786	348	142
Dry matter (m%)	68	0.29	1.10	3.12	1.06	0.51
Ash (m%)	60	0.05	0.31	0.65	0.30	0.12
Hardness (mmol $CaCO_3$/l)	50	1.3	3.9	7.5	4.1	1.4
Kjeldahl nitrogen (m/V%)	66	0.005	0.052	0.126	0.052	0.022
Glucose (g/L)	68	< 0.050 *	0.145	1.69	0.264	0.323
Starch (g/L)	68	< 0.120 *	1.08	5.11	1.40	1.22
K (mg/L)	65	296	1307	2400	1279	510
Ca (mg/L)	63	18.8	45.0	239	58.1	38.5
Na (mg/L)	65	< 0.006 *	27.9	174	40.9	41.5
Mg (mg/L)	64	33.8	116	416	126	65.2
Fe (mg/L)	65	< 0.009 *	0.604	4.54	0.843	0.715
Mn (mg/L)	65	0.088	0.391	86.3	1.72	10.7
Ni (mg/L)	65	0.010	0.063	4.645	0.773	1.32
Cd (mg/L)	65	< 0.004 *	0.052	4.36	0.694	1.23
Cr (mg/L)	54	< 0.002 *	0.095	0.644	0.186	0.193
B (mg/L)	54	< 0.004 *	0.623	19.88	2.70	3.85
Cu (mg/L)	34	0.029	0.092	0.467	0.166	0.134
Pb (mg/L)	34	0.033	0.962	4.21	1.13	1.19
Zn (mg/L)	45	< 0.007 *	1.24	2.45	0.998	0.838
Absorbance at 220 nm	50	11.4	33.8	80.2	35.1	14.9
Absorbance at 254 nm	50	5.95	16.8	41.9	18.0	8.34
Absorbance at 310 nm	50	3.15	8.93	23.3	9.82	4.63
Absorbance at 436 nm	50	0.550	5.09	12.6	5.71	2.53
Minimal particle diameter (µm)	66	0.058 *	4.94	104	38.9	41.1
Median particle diameter (µm)	66	11.2	142	879	211	274
Maximal particle diameter (µm)	66	41.4	477	879	399	220
D4.2 (µm)	66	28.4	241	517	217	114
D3.2 (µm)	66	24.9	222	512	195	103
Total colony count at 22°C (logCFU/ml)	12	1.8	3.3	4.3	3.3	0.8
E. coli or coliforms (logCFU/ml)	12	< 1.0 *	< 1.0 *	< 1.0 *	< 1.0 *	-
Lactic acid bacteria (logCFU/ml)	10	1.2	2.7	3.4	2.6	0.8
Thermophilic aerobic spores (logCFU/ml)	11	1.2	2.6	4.8	2.7	1.1

* Indicates the LOD.

Table 3

Average concentrations with their standard deviation of the physicochemical composition and microbiological screening of blanching water between companies A & B comparing BL1 and BL2.

	n	Company A BL1	Company B BL1	Company A BL2	Company B BL2
pH	12	6.66 ± 0.30	7.09 ± 0.44	5.53 ± 0.34 *	6.64 ± 0.45 *
Viscosity (Pa.s)	12	1 ± 0	1 ± 0	1 ± 0	1 ± 0
Conductivity (mS/cm)	12	4.81 ± 0.36	4.17 ± 1.28	5.60 ± 0.68 *	2.83 ± 0.72 *
Turbidity (NTU)	12	912 ± 331	671 ± 355	604 ± 238 *	211 ± 117 *
BOD (mg O_2/L)	6	5304 ± 2037	5739 ± 2731	4498 ± 1567	1956 ± 1693
COD (mg O_2/L)	12	10364 ± 1161	9904 ± 4100	9648 ± 1120 *	4197 ± 2523 *
Nitrates (mg NO_3^--N/L)	11	8.94 ± 2.75	6.13 ± 4.07	3.48 ± 2.86 *	0.832 ± 0.456 *
Orthophosphate (mg PO_4^{3-}-P/L)	12	46.1 ± 5.5	40.9 ± 17.1	72.6 ± 11.3 *	28.0 ± 14.3 *
Total phosphorus (mg P/L)	2	152 ± 61	153 ± 48	134 ± 15	91.5 ± 35.8
Chlorides (mg Cl^-/L)	11	390 ± 56	321 ± 121	388 ± 51 *	175 ± 46 *
Dry matter (m%)	12	1.23 ± 0.12	1.03 ± 0.48	1.24 ± 0.14 *	0.47 ± 0.15 *
Ash (m%)	11	0.32 ± 0.03	0.30 ± 0.12	0.38 ± 0.07 *	0.16 ± 0.07 *
Hardness (mmol $CaCO_3$/l)	8	3.8 ± 0.3	3.9 ± 1.0	4.2 ± 0.5 *	2.0 ± 0.6 *
Kjeldahl nitrogen (m/V%)	12	0.057 ± 0.007	0.049 ± 0.021	0.064 ± 0.008 *	0.026 ± 0.010 *
Glucose (g/L)	12	0.455 ± 0.312	0.419 ± 0.272	0.158 ± 0.157	< 0.05 (LOD)
Starch (g/L)	12	2.24 ± 0.98	2.13 ± 1.42	1.15 ± 0.58 *	0.113 ± 0.205 *
K (mg/L)	12	1410 ± 272	1115 ± 467	1596 ± 331 *	625 ± 296 *
Ca (mg/L)	12	39.4 ± 11.5 *	70.6 ± 18.0 *	40.9 ± 11.8 *	29.2 ± 9.2 *
Na (mg/L)	12	33.8 ± 45.1	59.2 ± 16.0	37.6 ± 50.4	64.2 ± 34.3
Mg (mg/L)	12	121 ± 105	141 ± 59	105 ± 56	119 ± 42
Fe (mg/L)	12	1.14 ± 1.19	1.01 ± 0.84	0.726 ± 0.390	0.679 ± 0.587
Mn (mg/L)	12	0.462 ± 0.110	8.16 ± 25.90	0.466 ± 0.161 *	0.269 ± 0.125 *
Ni (mg/L)	12	0.802 ± 1.279	1.37 ± 1.73	0.639 ± 1.052	1.54 ± 1.77
Cd (mg/L)	12	0.667 ± 1.040	1.16 ± 1.55	1.11 ± 1.72	0.923 ± 1.249
Cr (mg/L)	9	0.251 ± 1.040	0.228 ± 0.202	0.297 ± 0.298	0.147 ± 0.098
B (mg/L)	9	3.16 ± 3.25	3.99 ± 3.97	2.70 ± 2.83	4.91 ± 6.06
Cu (mg/L)	7	0.158 ± 0.129	0.147 ± 0.124	0.227 ± 0.168	0.085 ± 0.060
Pb (mg/L)	7	1.27 ± 1.23	1.42 ± 1.43	0.845 ± 0.775	1.47 ± 1.36
Zn (mg/L)	10	1.02 ± 0.89	0.763 ± 0.850	1.14 ± 1.01	0.687 ± 0.791
Absorbance at 220 nm	8	41.4 ± 3.9	33.2 ± 11.3	32.5 ± 7.8 *	20.1 ± 9.2 *
Absorbance at 254 nm	8	21.4 ± 2.9	15.1 ± 4.7	17.3 ± 4.9 *	10.3 ± 4.6 *
Absorbance at 310 nm	8	11.4 ± 2.4	8.30 ± 2.60	9.15 ± 2.40 *	5.96 ± 1.91 *
Absorbance at 436 nm	8	6.52 ± 1.52	4.91 ± 1.20	5.35 ± 1.42	3.78 ± 0.96
Minimal particle diameter (µm)	11	45.6 ± 42.9	33.6 ± 37.1	37.9 ± 46.6	53.8 ± 39.0
Median particle diameter (µm)	11	241 ± 322	295 ± 356	252 ± 316	249 ± 299
Maximal particle diameter (µm)	11	494 ± 199	412 ± 241	365 ± 210	384 ± 166
D4.2 (µm)	11	233 ± 87	224 ± 137	207 ± 100	229 ± 119
D3.2 (µm)	11	205 ± 74	196 ± 117	188 ± 91	216 ± 120
Total colony count at 22°C (log CFU/ml)	3	3.9 ± 0.5	3.4 ± 0.3	3.0 ± 1.1	2.9 ± 1.1
E. coli or coliforms (log CFU/ml)	3	< 1 (LOD)	< 1 (LOD)	< 1 (LOD)	< 1 (LOD)
Lactic acid bacteria (log CFU/ml)	3	2.4 ± 0.5	3.4 ± 0.1	3.1 ± 0.5	1.8 ± 0.8
Thermophilic aerobic spores (log CFU/ml)	3	2.5 ± 0.4	2.2 ± 0.7	3.4 ± 2.0	3.0 ± 1.6

* indicates the parameters being statistical different between company A and B

Table S1

Overview of the seven sampled potato processing companies, with the sampling moment and frequency for each blancher type throughout the complete campaign.

	Company:	**A**			**B**			**C**			**D**		**E**	**F**	**G**	
	Blancher type:	**BL 1**	**BL 2**	**BL 3**	**BL 1**	**BL 2**	**BL S**	**BL 1**	**BL 2**	**BL S**	**BL 1**	**BL 2**	**BL S**	**BL S**	**BL 1**	**BL S**
2020	**February**	2x	2x	1x												
	March	1x	1x	1x	1x	1x	1x									
	April															
	May															
	June	1x	1x	1x	2x	2x	2x									
	July *															
	August *	2x	2x		1x	1x	1x									
	September *	1x	1x		2x	2x	1x	1x	1x	1x	1x	1x	1x	2x		
	October														1x	2x
	November	1x	1x													
	December				1x	1x	1x									
2021	**January**															
	February	1x	1x		2x	2x										
	March	2x	2x		3x	3x										
	April	1x	1x													

* Period in which freshly harvested potatoes are (partially) processed instead of stored potatoes.

Table S2:
Average concentrations with their standard deviation of the physicochemical composition of blanching water coming from BL3- and BLS-type blanchers.

	BL3 (n=3)	**BLS (n=12)**
pH	5.28 ± 0.12	6.01 ± .44
Viscosity (Pa.s)	1 ± 0	1 ± 0
Conductivity (mS/cm)	4.97 ± 0.20	4.85 ± 1.68
Turbidity (NTU)	342 ± 172	968 ± 892
BOD (mg O_2/L)	3968 ± 576	6213 ± 4174
COD (mg O_2/L)	7622 ± 669	10258 ± 6986
Nitrates (mg NO_3^--N/L)	1.13 ± 0.13	6.82 ± 7.65
Orthophosphate (mg PO_4^{3-}-P/L)	56.2 ± 20.1	45.2 ± 24.4
Total phosphorus (mg P/L)	nd. *	111 ± 63
Chlorides (mg Cl^-/L)	307 ± 130	414 ± 172
Dry matter (m%)	0.97 ± 0.09	1.23 ± 0.83
Ash (m%)	0.31 ± 0.01	0.31 ± 0.15
Hardness (mmol $CaCO_3$/l)	3.4 ± 0.2	4.9 ± 1.5
Kjeldahl nitrogen (m/V%)	0.056 ± 0.011	0.056 ± 0.033
Glucose (g/L)	0.121 ± 0.107	0.379 ± 0.508
Starch (g/L)	0.36 ± 0.32	1.48 ± 1.10
K (mg/L)	1560 ± 87	14132 ± 594
Ca (mg/L)	32.8 ± 4.0	96.8 ± 32.6
Na (mg/L)	5.1 ± 4.6	37.5 ± 49.2
Mg (mg/L)	104 ± 30	142 ± 58
Fe (mg/L)	0.475 ± 0.066	0.723 ± 0.491
Mn (mg/L)	0.527 ± 0.089	0.384 ± 0.167
Ni (mg/L)	0.053 ± 0.002	0.049 ± 0.021
Cd (mg/L)	0.027 ± 0.023	0.058 ± 0.043
Cr (mg/L)	0.024 **	0.080 ± 0.037
B (mg/L)	0.628 **	0.346 ± 0.423
Cu (mg/L)	0.354 **	0.248 ± 0.075
Pb (mg/L)	0.120 **	0.099 ± 0.006
Zn (mg/L)	1.490 ± 0.372	1.432 ± 0.371
Absorbance at 220 nm	26.7 ± 10.2	38.3 ± 19.2
Absorbance at 254 nm	13.0 ± 5.3	20.1 ± 10.5
Absorbance at 310 nm	6.1 ± 2.9	10.8 ± 5.6
Absorbance at 436 nm	3.00 ± 2.21	6.39 ± 2.9
Minimal particle diameter (µm)	37.5 ± 57.3	38.9 ± 44.1
Median particle diameter (µm)	134 ± 23	102 ± 70
Maximal particle diameter (µm)	503 ± 45	373 ± 274
D4.2 (µm)	284 ± 50	194 ± 124
D3.2 (µm)	251 ± 42	172 ± 109

* nd. = not determined

** no standard deviation was calculated due to a lack of valid outcomes

Table S3:

Rotated principal component matrix as results of the PCA with all the physicochemical parameters except viscosity, BOD, total phosphorus, hardness and results of the micro-element analysis (potassium, sodium…).

	Component				
	1	2	3	4	5
pH	0.153	-0.164	-0.712	-0.132	0.421
Conductivity (mS/cm)	0.504	0.045	0.729	0.390	0.041
Turbidity (NTU)	0.871	0.020	0.138	0.212	0.234
COD (mg O_2/L)	0.605	0.101	0.292	0.669	0.204
Nitrates (mg NO_3^--N/L)	0.284	0.067	-0.073	0.822	0.200
Orthophosphate (mg PO_4^{3-}–P/L)	0.077	0.000	0.923	-0.101	0.134
Chlorides (mg Cl^-/L)	0.673	-0.134	0.511	0.182	0.287
Dry matter (m%)	0.660	0.117	0.478	0.382	0.366
Ash (m%)	0.504	-0.058	0.735	-0.011	0.307
Kjeldahl nitrogen (m/V%)	0.508	0.067	0.530	0.592	0.045
Glucose (g/L)	0.254	0.148	0.175	0.227	0.779
Starch (g/L)	0.490	-0.055	0.025	0.210	0.655
Absorbance at 220 nm	0.905	0.062	0.137	0.301	0.128
Absorbance at 254 nm	0.936	0.025	0.135	0.220	0.073
Absorbance at 310 nm	0.973	0.000	0.066	0.114	0.095
Absorbance at 436 nm	0.952	-0.032	0.034	0.032	0.104
Minimal particle diameter (µm)	-0.178	0.643	-0.201	-0.102	0.390
Median particle diameter (µm)	-0.020	0.932	-0.044	-0.042	0.022
Maximal particle diameter (µm)	0.064	0.965	0.036	0.121	0.090
D4.2 (µm)	0.058	0.925	0.121	0.089	-0.083
D3.2 (µm)	0.053	0.937	0.113	0.066	-0.079