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Ozone treatment of stored potato tubers

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Abstract. During storage, potato tubers are susceptible to different pathogen, which can attack the skin and flesh of the tubers. The most serious damage can be caused by rot inducing bacteria and fungi. A possible way to prevent microbial damage may be the use of ozone in the air ventilated through the stored tubers. However, the tubers can undergo qualitative changes, e.g. dehydration and loss of starch content. This article presents the results of a five-month experiment in which ozone concentration of 5 mg m^{-3} was periodically introduced in some of the stored potato tubers of the cultivar 'Dali'. All potato tubers were stored in closed storage boxes with a metal frame and wood panels in the floor and walls (ground area 1.6×1.2 m, height 0.95 m) which were continuously aerated using the ambient air in a potato warehouse. There was 900 kg of tubers stored in the box. At the end of the experiment, the ozonated variant was compared with the control (not treated). The ozone-treated tubers had 2.95 times lower incidence of infection by rot and the number of microorganisms on healthy tubers was lower than the control. The ozone-treated tubers were less frequently dehydrated. The water loss was higher in control by 0.86%. There was no significant difference in silver scurf manifestation or in the starch content between the two variants.

Key words: cold plasma, potato diseases, tuber quality, vegetable storage.

INTRODUCTION

At present, potatoes are mostly stored in large-capacity warehouses in bulk aerated through floor grates, with controlled environments mostly using outdoor air rather than active cooling. Another option is storage in boxes which are with air ventilation through the ambient air (Schuhmann & Gottschalk, 2012). Bacterial and fungal diseases can cause significant losses during storage. However, during growth, potato diseases should be minimised as well, especially potato late blight (*Phytophthora infestans*), because they may further manifest in storage (Runno-Paurson et al., 2016). Therefore, seed potatoes are treated before planting (Loit et al., 2018). For storage, it is important to prevent mechanical damage which is the entry point for infection. Furthermore, all mechanisms and surfaces in contact with tubers have to be maintained clean and regularly disinfected (Schuhmann & Gottschalk, 2012). Traditionally considered storage diseases are dry rot (caused by *Fusarium* and *Phoma* fungi), soft rot and potato blight on tubers. Other diseases common during potato storage are not as destructive and usually do not cause rot, but only attack the skin or thin layer of flesh beneath it (Hausvater & Doležal, 2011). In the Czech Republic, fungicides are not used and are not allowed during the potato storage period. Therefore, alternative methods are being investigated to prevent potato diseases to reduce storage losses. A possible option is the inclusion of ozone in the storage environment.

In general, ozone has germicidal effects similar to ultraviolet radiation (Gibson et al., 2019; Gündüz & Korkmaz, 2019). For this nature, it is used for air sterilization, e.g. in food industry, (Nguyen et al., 2019) or for drinking water (Wanqing et al., 2019). There is research studying the effects of ozone on the quality of agricultural crops during storage. Ozone is considered an alternative to chemical pesticides and its advantage is, among others, the absence of chemical residues in stored products (Isikber & Athanassiou, 2015), and thus can be used with organic food products.

Most relevant works focus on the application of ozone during storage of fruits and vegetables, especially since it leaves no residue on the treated product (Horvitz & Cantalejo, 2014). The need for further research, in particular into desirable O_3 concentration and exposure time, has been emphasized (Horvitz & Cantalejo, 2014). Ozone in concentration of 0.085 mg m^{-3} has been shown to significantly prolong the shelf life of broccoli and cucumbers stored at 3 °C. At the same time, ozone significantly reduces by oxidation reactions the amount of ethylene which is produced e.g. by metabolic activity in apples and pears in fruit stores (Skog & Chu, 2001). Liew & Prange (1994) have found fungistatic effects of ozone in concentrations ranging from 15.9 to 127 mg m^{-3} for carrot storage, while monitoring post harvest pathogen effects. The effect of the application of high ozone concentrations (0–5 g m^{-3}) in laboratory conditions did not affect the quality of the carrot and at the same time prevented a sharp increase in soluble solids, thereby increasing the shelf life (Souza et al., 2018).

When monitoring the effect of ozone on the properties of stored strawberries, an increased content of vitamin C was found, however, with a negative effect on strawberry flavour (Pérez et al., 1999). Similar results were obtained using infected strawberries stored in an atmosphere with ozone concentration of 3.2 mg m^{-3}. A positive effect on quality has been reported, while decay incidence, weight loss and fruit softening were reduced. (Nadas et al., 2003). When using ozone at concentration of 0.5 mg m^{-3} during orange storage, a positive effect on the reduction of rot on fruit surface was found, while aging and weight loss were also reduced (Di Renzo et al., 2005). More detailed tests with several varieties of mandarins and oranges were carried out in a storage with ozone doses of 1.6 to 60.0 mg kg^{-1}. The application of ozone did not reduce the quality of the fruit and prolonged its subsequent shelf life. Decay of fruits was delayed and weight losses were reduced (García-Martín et al., 2018).

Positive effects were also found when ozone was applied in cereals. When dosing ozone in wheat grain 0.22 mg g^{-1} min^{-1}, 96.9% of fungal spores were inactivated within 5 min. Increased temperature of the wheat grain also increased the effectiveness of the ozone treatment. These ozone concentrations did not reduce germination of the grains. (Wu et al., 2006). With application of 0.16 a 0.10 mg g^{-1} min^{-1} in barley, 96.0% of spores and a small amount of mycelium were inactivated. The effectiveness in barley also increased with temperature (Allen et al., 2003). When passing through a layer of grain, there is a phenomenon of ozone demand of the medium. Therefore, for large scale applications higher concentrations of ozone have to be used to counteract these losses (Isikber & Athanassiou, 2015).

Spencer (2003) used ozone dose 20.0 mg kg^{-1} h^{-1} for 1.7 and 21 days immediately after potato harvest, which did not show a significant effect on the incidence of diseases. A high dose of ozone was also applied once during storage. The results show that ozone reduced potato tuber diseases, but its effect was limited. Hamm (2004) monitored the effect of ozone during potato storage on silver scurf disease. In a two-year trial, a positive effect on this disease prevention could not be verified. Waterer et al. (2003) conducted tests to verify ozone application before and during storage of potatoes for disease control. They used high ozone concentration 1,000 mg m^3 for 16 s and low concentration 5 mg m^{-3} for 6 months of storage. High concentration significantly reduced the infection by bacterial soft rot (BSR), however, it did not affect Fusarium dry rot (FDR), Rhizoctonia black scurf (RBS) and silver scurf (SS). Application of low concentration during storage resulted in an increase in FDR infection. Other types of infections were not affected. Both potato samples were not stored in the same environment which could have resulted in skewed results. Reported works indicate only a limited possible utilization of ozone in potato stores. More recent studies have not been found.

Since the published results on the potato topic are ambiguous the present research aimed to verify the utility of ozone in pilot conditions. Therefore, the aim of this trial was to investigate the effect of ozone treatment, together with microclimatic conditions, on quality of potato tuber cultivar 'Dali' during 133 days in air at temperature of 4.5 °C.

MATERIALS AND METHODS

The cultivar 'Dali' of potato was used to investigate the effect of ozone during the storage period. Trials were conducted on field run potatoes obtained from commercial growers in the Vysočina Region, Czech Republic.

An amount of 900 kg of potato was stored in a closed wooden pallet box with a steel frame, whose ground plan dimensions were 1.6×1.2 m. The height of the potato layer was 0.88 m. The box was sealed using plastic film to assure a better control over the aeration of the box. Another box of the same type was stacked on top, holding bagged potatoes samples. At the top, there was an outlet hole sized 20×20 cm (Fig. 4). The stored potatoes were permanently aerated with ambient air by an air conditioning duct fan TUBE 100WK (supplier Kanlux, s.r.o., Czech Rep.) so that the air speed above the layer of potatoes was 0.012 m s^{-1} (thermal anemometer AIRFLOW TA4, Airflow, United Kingdom), which corresponded to 85 m^3 h^{-1}.

For ozone generation, the PROFIZON-X generator (Guangzhou Chuanghuan Ozone Electric Appliance Co., Ltd, China) was used (Fig. 1).

The ozone concentration was measured by a WASP-XM-E (Guangzhou Chuanghuan Ozone Electric Appliance Co., Ltd, China) (Fig. 2), under the bottom of the box, near the bottom of the potato layer. The ozone generator supplied 0.4 g h^{-1} of ozone, creating a concentration of ozone in the inlet air to the pallet of 5 mg m^{-3} pallets with a deviation of 0.5 mg m^{-3}. The ozone generator was turned on once every 48 h during 8 h.

The complete experimental setup is shown in Fig. 3. The assembly was placed within one section of a potato warehouse with computer-controlled ventilation.

An identical experimental setup was used also for the treatment in which no ozone was applied during the storage period. It was located in a different section of the warehouse to avoid cross-contamination between the treatments. The size of each section was 6 m×26 m with positive pressure aeration through underfloor channels. The sections were partially loaded each with 150 t potatoes of the same cultivar 'Dali'. For each section, a fan APR 800 (Janka Radotín, s.r.o., Czech Rep.) with a 5.5 kW motor was used.

Figure 1. Ozone generator PROFIZON-X.

Figure 2. Ozone meter WASP-XM-E.

During the storage period the parameters of the air passing through the boxes and the ambient air were monitored continuously, i.e. its temperature and the relative humidity (RH). Data loggers R 3120 (COMET SYSTEM, s.r.o., Czech Rep.) were used for monitoring the temperature and the RH. The accuracy of the temperature measurement with the data logger was ± 0.4 °C. They were placed at two locations in each storage condition: In the top box above the potatoes and outside the boxes at 4.0 m height above the floor.

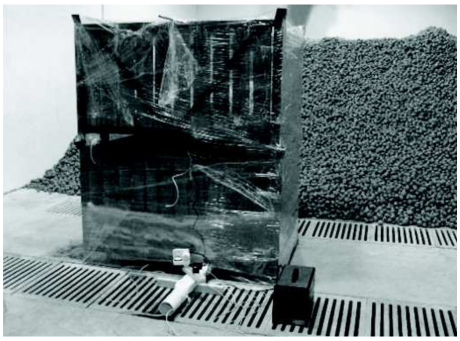

Figure 3. Storage boxes with ventilator and ozone generator during the storage period of 'Dali' potato tuber.

At the end of the experiment, the health (quality) of the potatoes was evaluated. From both boxes, 12 samples were taken into 20 L container (sample weight 10–15 kg). In each sample, the number of tubers infected by mixed infection of dry rot (*Fusarium* spp.), potato gangrene (*Phoma foveata*), and soft rot (*Pectobacterium* spp.), the number of partially dehydrated tubers as well as their weight were determined.

The occurrence of skin scurf (*Helminthosporium solani*) was also evaluated. The scurf rating was performed both prior to the experiment and at the end of the experiment. Each time, the determination was done using 100 randomly selected tubers free of rot and dehydration, where the degree of infection was evaluated on a scale from 1 (non-infected) to 9 (over 90% of the skin affected). The share of infected tubers was evaluated as well as the intensity of the disease manifestation on the tubers calculated as a weighted average of the infection degree from the sample.

A sprouting test was carried out to test for a negative effect of ozone. Samples of 100 tubers for each treatment were divided into boxes containing 25 tubers and stored in the dark at 20–25 °C and 70% relative humidity for 10–12 days (Tuček et al., 1988). Tubers with 2 or more sprouts were considered to be able to germination.

Figure 4. Datalogger placement in a storage box.

The potato samples were further examined for differences in their microbiological contamination. For this purpose, tubers weighing 95–100 g were selected. The total number of microorganisms and the amount of yeast and mould were determined for 3 ozone treated and 3 control tubers. Physiological saline solution was used to rinse the tubers and subsequently dilute the samples and inoculate growth media by smear technique (ISO 6887-1, 2017).

For determination of the total number of microorganisms, an agar medium with enzymatically hydrolysed casein, yeast extract and glucose were used (standard methods agar). To determine the total number of microorganisms, 0.1 mL of the fourth and fifth ten-fold dilutions of the sample were inoculated on a medium in Petri dishes and incubated for 72 h at 30 °C.

The amount of yeast and mould was determined by horizontal method, aerobic cultivation at 25 °C on a selective agar medium with Bengal red and chloramphenicol (ISO 21527-1, 2008). For the determination of yeast and fungi, 0.1 mL of the second and third ten-fold dilutions were inoculated, followed by incubation at 25 °C for 120 h. The number of microorganisms on the tubers was derived from the number of colony-forming units (CFU).

For the quality assessment of the tubers, the dry matter content and the starch content were determined. Dry matter content was measured gravimetrically by drying at 105 °C. The content of starch was found using a Hošpes-Pecold balance. It was calculated from the weight of tubers in air and in water.

RESULTS AND DISCUSSION

The experiment took place from 1.11.2018 to 14.3.2019. Microclimatic conditions, i.e. temperature and relative air humidity, were monitored in the storage boxes and in the ambient air in the warehouse sections. These data are shown in Tables 1 and 2 during the testing period.

The differences between average monthly temperatures inside both storage boxes were 0.2 °C at most, the minimum as well as the maximum temperatures. The ambient temperatures inside the warehouse sections were close in terms of average temperatures, the difference being 0.3 °C. At the same time, the minimum and maximum temperatures differ at most 1.0 °C during some months in minimum temperature and maximum temperature. Temperature fluctuations inside the boxes were influenced primarily by the temperature and humidity of the ambient air ventilated into the box, as can be seen in Fig. 5.

Table 1. Temperatures in ozone treated and control treatments

Month	Temperatures in ozone treated box						Temperatures in non ozonated box					
	Storage box			Ambient air			Storage box			Ambient air		
	Min (ºC)	Mean (ºC)	Max (ºC)	Min (ºC)	Mean (ºC)	Max (ºC)	Min (ºC)	Mean (ºC)	Max (ºC)	Min (ºC)	Mean (ºC)	Max (ºC)
11.2018	3.4	6.5	9.4	2.3	5.9	10.3	3.4	6.4	9.4	2.8	6.2	11.3
12.2018	3.5	4.2	5.0	2.4	3.8	4.9	3.4	4.1	5.0	2.8	4.0	5.0
01.2019	2.8	3.7	4.4	1.4	3.2	4.1	2.7	3.6	4.3	2.3	3.4	4.2
02.2019	3.0	3.8	4.6	1.4	3.4	4.6	3.0	3.7	4.5	2.3	3.6	4.7
03.2019	4.4	5.3	6.1	3.6	5.2	6.1	4.2	5.1	5.9	3.5	5.2	6.1
Mean	4.6			4.2			4.5			4.3		
Standard deviation	1.4			1.5			1.4			1.5		

In Table 2, humidity in the test and control portions of the experiment are given as monthly average, minimum and maximum values for each measurement. Differences in humidity in the sections for both variants are very small - the average humidity differs by a maximum of 2.1%, the minimum humidity differed by 2.3% at most, even at the maximum humidity the differences were 5.3% at most.

Table 2. Air humidity in ozone-treated and control treatments.

Month	Air humidity in ozone treated box						Air humidity in non ozonated box					
	Storage box			Ambient air			Storage box			Ambient		
	Min (%)	Mean (%)	Max (%)	Min (%)	Mean (%)	Max (%)	Min (%)	Mean (%)	Max (%)	Min (%)	Mean (%)	Max (%)
11.2018	72.4	87.6	96.5	60.3	87.4	99.1	67.4	81.6	88.3	58.0	85.5	93.8
12.2018	75.2	88.9	95.1	67.2	85.9	95.4	68.6	80.4	85.4	67.3	84.3	92.6
01.2019	80.4	91.1	97.3	66.7	84.0	93.7	69.8	79.1	84.8	67.5	81.9	91.7
02.2019	86.0	95.5	100.0	62.8	83.5	95.1	71.5	79.3	83.4	63.5	82.0	90.6
03.2019	83.1	97.9	100.0	60.6	81.7	91.6	66.3	79.7	84.0	62.4	80.9	89.0
Mean	91.4			84.9			80.1			83.2		
Standard deviation	5.1			5.0			3.3			4.8		

The humidity in the non-ozonated pallet started at lower values than the humidity in the box, but this difference decreased during storage. The humidity in the boxes showed a considerable difference in values. This difference increased over time, from 6.0% at the start of the experiment to 18.2% at the end of storage time. High humidity in the ozonated storage box was confirmed by visual observation by formation of condensation on the inner walls of the storage box during February and March. The trends of temperature can also be observed in Fig. 5 (T_{ie} – air temperature in ozone-treatment box, T_{ic} – air temperature in non-ozonated box) and Fig. 6 (T_{ee} – air temperature in ozone-treatment section, T_{ec} – air temperature in non-ozonated section). Humidity can be watched in Fig. 7 (H_{ie} – humidity in ozone-treatment box, H_{ic} – humidity in non-ozonated box), which also confirms condensation in the period.

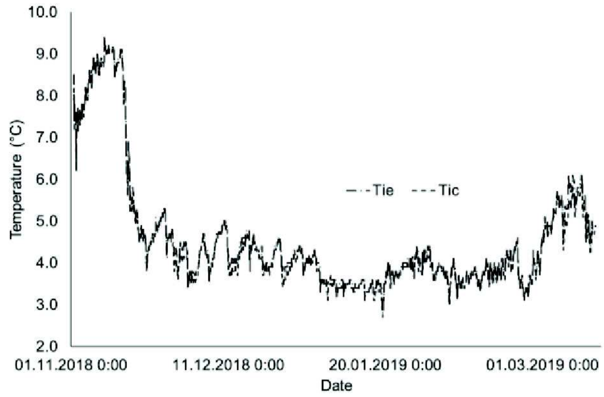

Figure 5. Air temperature in of ozone treated and non ozonated boxes.

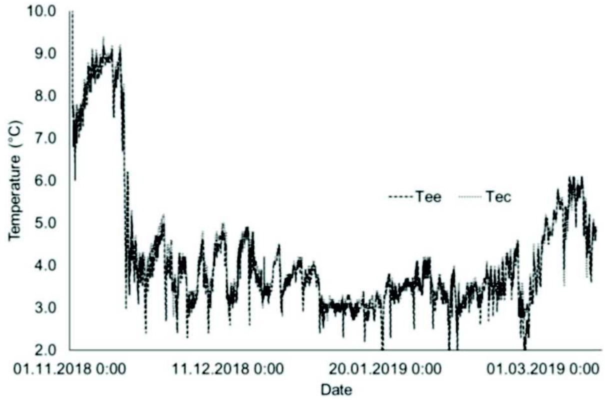

Figure 6. Air temperature in ozone-treated and non ozonated boxes.

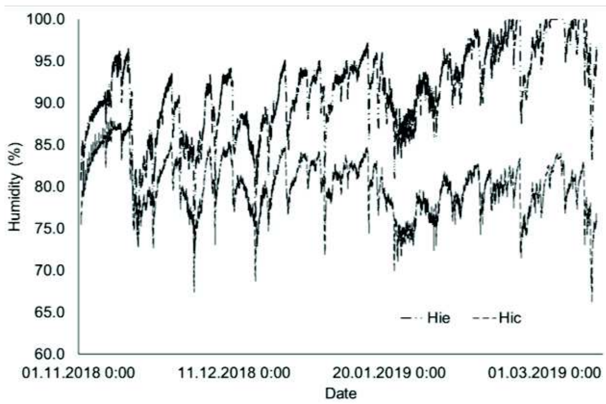

Figure 7. Humidity in ozone treated and non ozonated boxes.

Health state (quality) of the tubers was evaluated at the end of the experiment. All values are shown in Table 3 and 4, where they are also converted to a percent values.

Table 3. Quality of ozone treated potato tuber sample

Sample no.	Infected tubers				Dehydrated tubers				Healthy tubers		Sum	
	Amount		Mass		Amount		Mass		Amount	Mass	Amount	Mass
	pcs	%	kg	%	pcs	%	kg	%	pcs	kg	pcs	kg
1	4	2.60	0.208	1.58	20	12.99	1.256	9.55	130	11.694	154	13.158
2	1	0.65	0.016	0.13	14	9.15	0.794	6.47	138	11.470	153	12.280
3	2	1.72	0.178	1.51	17	14.66	1.330	11.28	97	10.280	116	11.788
4	3	2.22	0.156	1.29	16	11.85	1.010	8.35	116	10.930	135	12.096
5	2	1.54	0.076	0.59	12	9.23	0.792	6.19	116	11.924	130	12.792
6	2	1.63	0.094	0.75	9	7.32	0.658	5.27	112	11.742	123	12.494
7	2	1.37	0.084	0.63	26	17.81	1.596	12.02	118	11.600	146	13.280
8	2	1.47	0.146	1.12	16	11.76	1.192	9.11	118	11.742	136	13.080
9	0	0.00	0.000	0.00	16	13.33	1.404	10.86	104	11.524	120	12.928
10	2	1.48	0.042	0.32	23	17.04	1.636	12.49	110	11.424	135	13.102
11	1	0.60	0.056	0.42	26	15.66	1.532	11.39	139	11.864	166	13.452
12	2	1.42	0.159	1.11	16	11.35	0.994	6.96	123	13.135	141	14.228

Table 4. Quality of untreated potato tuber samples

Sample no.	Infected tubers				Dehydrated tubers				Healthy tubers		Sum	
	Amount		Mass		Amount		Mass		Amount	Mass	Amount	Mass
	pcs	%	kg	%	pcs	%	kg	%	pcs	kg	pcs	kg
1	14	9.40	1.402	12.76	6	4.03	0.304	2.77	129	9.278	149	10.984
2	8	4.94	0.490	3.93	17	10.49	1.172	9.40	137	10.812	162	12.474
3	13	7.65	1.272	10.12	26	15.29	1.334	10.62	131	9.960	170	12.566
4	3	1.85	0.394	3.46	7	4.32	0.308	2.71	152	10.678	162	11.380
5	5	2.53	0.420	3.19	21	10.61	1.208	9.19	172	11.520	198	13.148
6	12	8.05	0.524	4.41	25	16.78	1.572	13.22	112	9.794	149	11.890
7	3	2.07	0.104	0.85	21	14.48	1.272	10.37	121	10.890	145	12.266
8	7	3.68	0.322	2.55	21	11.05	1.024	8.12	162	11.264	190	12.610
9	2	1.10	0.066	0.56	26	14.29	1.124	9.56	154	10.562	182	11.752
10	6	3.26	0.314	2.46	21	11.41	0.784	6.13	157	11.692	184	12.790
11	6	2.96	0.366	3.06	16	7.88	0.866	7.23	181	10.746	203	11.978
12	3	1.70	0.108	0.91	17	9.66	0.936	7.85	156	10.878	176	11.922

Differences between ozone treated and non ozonated samples were statistically evaluated by testing the null hypothesis of equal mean values. The results are shown in Tables 5 and 6.

Table 5. Statistical comparison of infected tuber shares between variants

	Ozone treated Amount, %	Non ozonated Amount, %	Ozone treated Mass, %	Non ozonated Mass, %
Mean	1.39	4.10	0.79	4.02
Standard deviation	0.705	2.789	0.530	3.717
F-test	0.0000704		$1.97 \cdot 10^{-7}$	
t-test	0.0066		0.012	
Difference of means	2.71		3.23	

Table 6. Statistical comparison of dehydrated tuber shares between variants

	Ozone treated Amount, %	Non ozonated Amount, %	Ozone treated Mass, %	Non ozonated Mass, %
Mean	12.68	10.86	9.16	8.10
Standard deviation	3.23	4.04	2.49	3.09
F-test	0.4708		0.4908	
t-test	0.2358		0.3632	
Difference of means	1.82		1.06	

The differences between the means of the number and weight of the infected tubers in the ozone treated samples and in the non ozonated (control) samples were found to be statistically higher. The differences between the mean frequency and weight of dehydrated tubers in the ozone treated samples and in the control samples were found to be statistically nonsignificant.

The sprouting values are listed in Table 7. The results of statistical evaluation are shown in Table 8. The difference between variants being statistically significant.

Table 9 shows the numbers of microorganisms in non ozonated and ozonated tuber samples.

The results showed a significant reduction of the total number of microorganisms by about 1 order of magnitude. The fungicidal activity of ozonation was manifested by a reduction in the number of yeast and mould by 2 to 4 orders.

Table 7. Comparison of sprouting between variants

	Sample no. (25 pcs)	Sprouted tubers (at least 2 sprouts) pcs	Share of sprouted tubers, %
Ozone treated	1	25	100
	2	24	96
	3	25	100
	4	24	96
Non ozonated	1	22	88
	2	24	96
	3	22	88
	4	22	88

Table 8. Statistical comparison of sprouting

	Ozone treated, %	Non ozonated, %
Mean	98	90
Standard deviation	2.31	4.00
F-test	0.39	
t-test	0.0134	
Difference of means	8	

The effect of ozone treatment on the degree of silver scurf infestation is shown in Table 10.

From Table 10, it is clear that the ozone treatment did not affect the degree of silver scurf in tubers.

In addition, the dry matter and starch content of potato samples were determined. For this purpose, 8 ozone treated samples and 8 control samples were used. The values obtained are shown in Table 11. The measured values were evaluated statistically and the results are shown in Table 12.

Table 9. Microbiological contamination on tubers

Sample	Total number of microorganisms (CFU on 1 tuber)	Yeast and mould (CFU on 1 tuber)
Non ozonated - 1	4.5×10^5	2.7×10^4
Non ozonated - 2	7.3×10^5	9.1×10^3
Non ozonated - 3	3.6×10^5	9.1×10^3
Ozone treated - 1	1.0×10^5	4.8×10^2
Ozone treated - 2	9.1×10^4	< 10
Ozone treated - 3	9.3×10^4	< 10

Table 10. Infection of tubers by silver scurf

Sample	Weighted average of the infection degree		Difference
	Before storage	After storage	
Non ozonated - 1	1.62	2.18	0.56
Non ozonated - 2	1.62	2.42	0.8
Ozone treated - 1	1.58	2.30	0.72
Ozone treated - 2	1.52	2.56	1.04

Table 11. Content of dry matter and starch in tuber samples

	Sample no.	Dry matter content % wt.	Starch content % wt.
Ozone treated variant	1	19.98	14.7
	2	20.73	14.7
	3	19.87	14.9
	4	19.95	14.5
	5	20.77	14.5
	6	20.30	14.7
	7	18.80	14.7
	8	20.32	14.7
Non ozonated variant	1	21.63	14.7
	2	20.92	14.7
	3	20.18	14.5
	4	21.90	14.9
	5	21.27	14.9
	6	20.74	14.7
	7	20.22	14.7
	8	20.71	14.7

Table 12. Statistical comparison of dry matter and starch contents in tubers

	Dry matter content, % wt.		Starch content, % wt.	
	Ozone treated	Non ozonated	Ozone treated	Non ozonated
Mean	20.09	20.95	14.68	14.73
Standard deviation	0.62	0.62	0.128	0.128
F-test	0.9934		1.0	
t-test	0.0155		0.4483	
Difference of means	0.86		0.05	

The differences between the mean values of dry matter content were statistically significant, while the differences between the mean values of starch content were nonsignificant. The higher dry matter content in the control tubers is probably due to the loss of water during the experiment. The loss of water in control tubers was 0.86% higher. This is also in agreement with the measured values of air humidity, which were significantly higher in the ozone treated variant than in the control variant.

The results showed a significant impact of ozone treatment on the quality of potato tubers during storage, i.e. reducing the infestation of potato tubers by mixed infection from fungal and bacterial diseases (*Fusarium* spp., *Phoma foveata*, *Pectobacterium* spp.). This was also evidenced by the reduction of possible bacterial and rot sources of infection. This was not in complete agreement with results by Waterer et al. (2003). On the other hand, the ineffectiveness of ozone on the silver scurf on potatoes (*Helminthosporium solani*) was confirmed. This is in agreement with Waterer et al. (2003) and Hamm (2005).

At the same time, the possibility of a negative influence of ozone on the utility properties of potatoes, especially on their sprouting, was ruled out. This issue would be very sensitive when storing seed potato tubers.

An important finding was the effect of ozone on reducing the weight losses in tubers. That corresponds to findings in other types of produce, e.g. oranges (Di Renzo et al., 2005), strawberries (Nadas et al., 2003) and mandarins (Garcia-Martin et al., 2018).

CONCLUSIONS

The results showed the positive effect of ozone application on the reduction of the spread of potato diseases during storage and verified the option of using air ozonation technology in potato warehouses. This technology can significantly reduce losses due to bacterial and fungal diseases. In the case of large-scale warehouses, where bulk potatoes are aerated through floor grates, the generated ozone can be supplied to the inlet air behind the fan. However, the fan speed must be adjustable so that the air velocity exiting from the stored layer of potatoes can be set between 0.01 and 0.015 m s^{-1}. In the practice, the fans were designed for an air speed exiting the layer 0.1 m s^{-1}. Therefore, their speed had to be reduced to about 10 to 15%. This way, the passage time through a typical 4 m layer of stored tubers is several minutes. This time is sufficiently short to assure a sufficient ozone concentration.

Ozone application is possible at predetermined intervals when the fan is not used for its main purpose, i.e. climate control. This could be e.g. for 8 h once every 48 h which was tested in the present study.

In practical applications, attention should be paid to operator safety, as ozone is toxic in higher concentrations. The permissible permanent concentration at workplaces is under 100 µg m^{-3} or 200 µg m^{-3} in the short term. When these values are reached in the warehouse service rooms, the ozone source, including the main fan, must be switched off. To do this, it is necessary to install safety sensors connected to the control systems.

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