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Biological Effects of Corona Discharge on Onions in a Commercial Storage Facility

Jun Song,[1] Lihua Fan,[2] Paul D. Hildebrand,[3] and Charles F. Forney[4]

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SUMMARY. The biological effect of corona discharge on onions (*Allium cepa* L.) in a commercial storage was investigated. Surface discoloration and mold were modestly but significantly reduced by the corona discharge when onions were stored for 2 or 4 weeks with or without an additional 2 weeks of shelf life under high humidity. Corona discharge treatment also reduced airborne mold spores in the storage room. No significant changes in internal decay, firmness, sprouting, or rooting, in treated onions were found.

Agriculture and Agri-Food Canada, Atlantic Food and Horticulture Research Centre, 32 Main Street, Kentville, N.S., B4N 1J5, Canada

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[1]Postharvest physiologist, Fletcher Enterprises, P.O. Box 355, Hudson, Quebec J0P 1H0, Canada, c/o AAFC, Atlantic Food and Horticulture Research Centre, 32 Main Street, Kentville, N.S., B4N 1J5, Canada.

[2]Food microbiologist.

[3]Plant pathologist.

[4]Postharvest physiologist.

Onions can be stored for 6 months or longer at recommended storage conditions of 32 °F (0° C) and 65% to 70% relatively humidity (RH) (Hardenburg et al., 1986). Proper curing and low humidity in storage is necessary to minimize postharvest diseases. However, under low humidity storage, onions can suffer substantial moisture loss resulting in reduced yield of salable produce and softening and shriveling of the onions. In addition, maintaining low RH in conventional refrigerated storage rooms is difficult if not impossible. Under high humidity, onions may develop blue and black mold as well as soft rot caused by *Penicillium* (Link: Fr.), *Aspergillus niger* (van Tieghem), and *Erwinia carotovora* pv. *carotovora* [(Jones) Bergey], respectively (Maude, 1983). Controlled atmosphere (CA) storage has been used with limited success to reduce onion decay and maintain freshness and eating quality (Adamicki and Kepka, 1974), but it has not been economical or practical for storage of pungent type onions. An effective method to inhibit decay and surface mold and maintain onion quality is needed by the industry as an alternative to CA or synthetic chemicals.

In corona discharge (nonthermal plasmas), electrical energy is used to create large quantities of highly reactive species, including atomic oxygen, ozone, hydroxyls, and other charged molecules (Lowke and Morrow, 1994). Negative air ions (NAI), which have been reported to have biological effects, may also be produced (Krueger and Reed, 1976). Corona discharge has been reported to reduce the decay and extend the storage life of harvested fresh fruits and vegetables (Tanimura et al., 1997, 1998). Potential mechanisms by which the corona could affect produce quality include the destruction of ethylene and other volatiles, removal of airborne fungal spores, and the production of ozone and other reactive species that could inhibit pathogenic microorganisms.

To determine the effects of a commercially available corona discharge system on the decay and quality of fresh onions, a commercial trial was conducted in onion storage rooms at Nova Agri Associates (Port Williams, Nova Scotia). Nova Agri is one of the leading onion suppliers in Atlantic Canada, storing, packing, and marketing onions throughout most of the year. Most of their onion storage uses outside air for temperature and humidity control. However, as onions are stored longer into the spring, refrigerated storage is used and humidity control becomes a problem. This study explored the effects of corona discharge on controlling decay and quality of onions stored under high humidity during this time.

Materials and methods

EXPERIMENTAL SETUP. A corona discharge system (model FE 40; Fletcher Enterprises, Hudson, Quebec), was installed in a 35,000-ft^3 (991-m^3) storage room (treatment room) at Nova Agri which has high humidity and serious mold problems. The unit was installed in the middle of the room, 20 ft (6.1 m) above the floor in the airstream of the existing circulation fans. The treatment room was cooled by refrigeration at all times throughout the study. A second storage room was used as the control room without a corona discharge system. This room was cooled with outside air briefly at the beginning of the study, but later was also cooled with refrigeration.

The corona in the FE 40 produced ozone and NAI. Ozone concentration was monitored every 20 s using an UV-ozone detector (model I-2000; IN USA, Inc., Needham,

Mass.). The ozone concentration was used to control the FE 40 via the system's control software. When preset ozone levels were detected, the FE 40 began either a startup or shutdown sequence. The system was operated at 350 Hz and 2.5 kV and the ozone concentration was controlled about a maximum set point of 50 ppb ($nL \cdot L^{-1}$) during the day (0600 to 1800 HR) and 250 ppb during the night (1800 to 0600 HR). During the first week of the experiment only, the ozone set point was 125 ppb during the night.

Negative air ion concentrations were measured with an ion meter (Alpha Lab, Salt Lake City, Utah) and the ozone and NAI concentrations in the treatment room were recorded continuously (every 5 s with 1-min averages) on a multichannel data logger (Campbell Scientific, Logan, Utah). Temperature and RH were also measured with a probe (HMP 45C; Campbell Scientific) and recorded continuously in both rooms in close proximity to the test onions.

AIRBORNE MOLD SAMPLING. Airborne mold spores were collected using a centrifugal air sampler (RCS; Biotest Diagnostics Corp., Denville, N.J.) with a sampling time of 1 min allowing 1.40 ft^3 (39.6 L) of air to be sampled. Sterile, rose-bengal-agar strips that only permit the growth of mold were used. Two samples were taken in each of the control and treatment rooms at weekly intervals. After 4 d of incubation at 75.2 °F (24 °C), microbial colonies on the strips were counted with the aid of a stereomicroscope. Data from the two strips were transformed to the logarithmic scale and analyzed according to the Student's paired *t* test. The number of mold colony forming units per volume of air were then back-transformed and expressed as cfu / m^3.

ETHYLENE AND VOLATILE ANALYSIS. Air samples for ethylene analysis were collected in the middle of each room using a 5.0-mL syringe and analyzed using a gas chromatograph (Carle AGE; series 400, Loveland, Colo.) equipped with a flame ionization detector. Other volatiles were collected using an air sampling pump (Supelco, Bellefonte, Pa.). One liter of air from each room was trapped onto 120 mg Tenax GR 20 / 35 (Alltech Associates, Inc., Deerfield, Ill.). Samples were analyzed on a gas chromatograph–mass spectrometer (GC–MS) system (Magnum; Finnigan MAT, San Jose, Calif.) equipped with an purge-and-trap concentrator (LSC 2000; Tekmar, Cincinnati, Ohio). Quantization was done using single ions of external standards. All peaks were normalized using the peak area of a 4 ng dodecane standard run on the day of analysis.

EVALUATION OF ONIONS. Each room contained varying amounts of onions throughout the study, ranging from 30% to 60% of the room's capacity. Twelve 5.0-lb (2.27-kg) bags of onions (about 20 onions / bag), taken directly from the packing line were individually weighed and placed on pallets in each storage room. Assessments of quality were determined for three bags from each room after 2 and 4 weeks of storage. After each storage period, an additional three bags of onions from each room were kept for another 2 weeks of shelf life at 68 °F (20 °C) and 100% RH to observe the residual effect of the corona treatment. Quality assessments included surface discoloration and internal decay ratings, weight loss, firmness, and formation of roots and sprouts. A rating scale of 0 to 5 was used to evaluate surface discoloration or internal decay where 0 = 0%, 1 = 1% to 5%, 2 = 6% to 10%, 3 = 11% to 30%, 4 = 31% to 50% and 5 = 51% to 100% of the surface area affected. Surface discoloration included physiological staining and mold on the onion surface. Weight loss was expressed as percent. Firmness was measured as force of penetration using a digital force gauge (DFIS 50; GEO-Met Instruments Inc., Kentville, Nova Scotia) equipped with a 6-mm (0.24-inch) diameter wedge-shaped probe. Number of roots formed per onion were counted and the length of the longest root was measured. Shoot formation was noted and length of shoots measured. The experiment was replicated three times from 15 Apr. through 27 May 1999.

The experimental data were analyzed with the ANOVA directive in Genstat 5 release 3 (Genstat 5 Committee, 1993) according to a randomized complete block design with three fac-

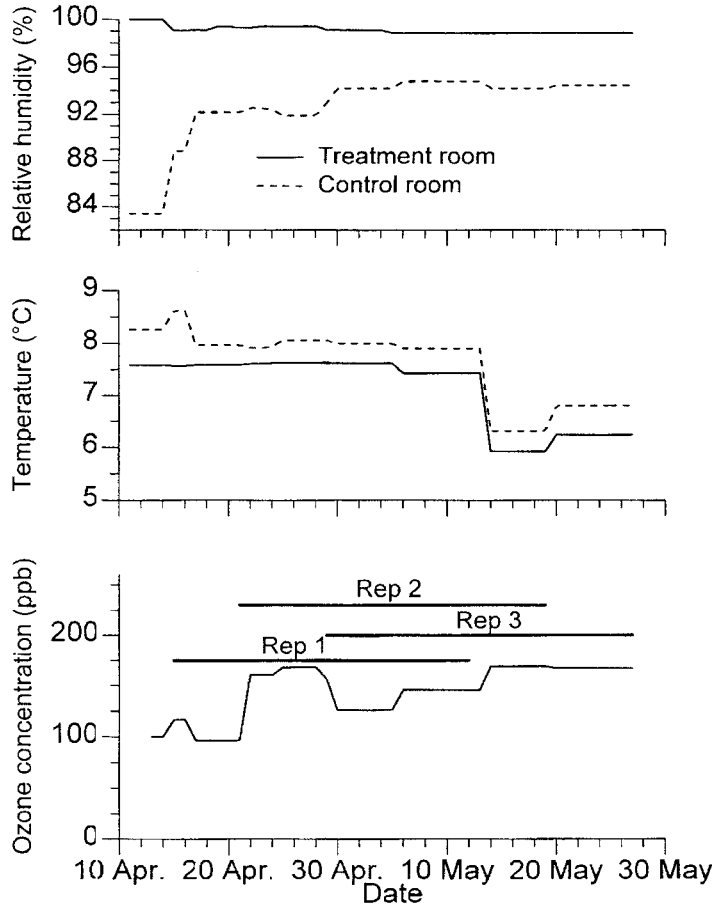

Fig. 1. Daily averages of relative humidity, temperature, and ozone concentration in the onion storage room treated with the corona discharge system and the control room during the three replications of the experiment [°F = 1.8(°C) + 32; ppb = $nL \cdot L^{-1}$].

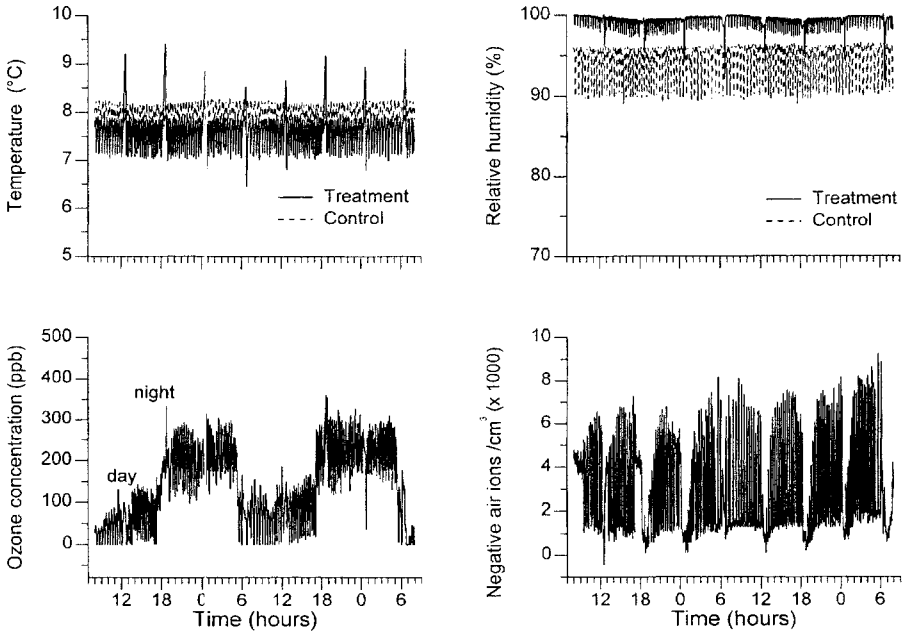

Fig. 2. Sample of temperature, relative humidity, ozone concentration, and negative air ion concentration in the onion storage rooms over a 48-h period. Ozone was absent in the control room and the ambient negative air ion concentration ranged from 300 to 1000 per cm³ [°F = 1.8(°C) + 32; ppb = nL·L⁻¹; 1000/cm³ = 16,387/inch³].

tors each with two levels: treatment (corona, no corona), treatment time (2 or 4 weeks), and shelf life (0 or 2 weeks). The percent discolored surface area of onions was also estimated from an equation obtained by regressing the midpoints of the severity categories of the rating scale against the rating scale values.

Results and discussion

STORAGE CONDITIONS. Daily averages of temperature, RH, and ozone in the onion storage rooms are presented in Fig. 1. The RH in the treatment room was at or near 100% throughout the experiment. During the first 3 d, the RH in the control room was less than 90%, but increased to 90% to 95% when the refrigerated cooling system was turned on. The temperature in the treatment room and control rooms averaged about 45.7 °F (7.6 °C) and 46.4 °F (8.0 °C), respectively, but then dropped to about 34.7 °F (1.5 °C) at the end of the experiment. The daily average ozone concentration was about 100 ppb during the first week of the experiment and then increased to about 170 ppb in response to an increase in the nighttime ozone concentration set point. From 30 Apr. to 15 May, the average ozone concentration was somewhat reduced which may have resulted from additional activity and loading of onions in the room.

A typical pattern of temperature, RH, ozone, and NAI values over a 48-h period in the storage rooms is shown in Fig. 2. The defrost cycles in the treatment room resulted in brief increases in temperature and decreases in RH. Defrost cycles in the control room were less obvious. Increased levels of NAI were detected whenever the FE 40 was on, but interestingly, they were quenched when the circulating fans turned on after a defrost cycle and gradually increased over a period of about 1 to 2 h. A possible explanation for this effect may be related to increased levels of airborne microdroplets of water being blown from the cooling coils following a defrost cycle. The NAI may be attracted to the water droplets resulting in lower free airborne ions. Ozone concentrations ranged from 0 to 150 ppb during the day and about 150 to 250 ppb during the night, but were not affected by defrost cycles.

AIRBORNE MOLD CONCENTRATION. The average weekly airborne spore concentration of both rooms is presented in Fig. 3. Before the FE 40 system was installed (15 Apr.), there were higher concentrations of airborne spores in the treatment room than in the control room. However, after the FE 40 was installed, airborne spore concentrations were reduced in the treatment room compared to the control room throughout most of the duration of this study.

SURFACE DISCOLORATION AND MOLD. The onion skins were colonized predominantly by *Penicillium* sp. and to a lesser extent by *Aspergillus* sp. A preliminary analysis indicated that the first week of lower nighttime ozone levels in replicate one did not affect the results and so all three replicates were included for subsequent analysis. The surface discoloration plus mold rating (SDM) of onions increased as storage increased from 2 to 4 weeks (Table 1), but there was no difference between the treated and control onions, even though the treated onions were exposed to higher humidity. The ANOVA indicated a significant interaction between the effects of treatment and shelf life. The averaged data for the 2- and 4-week storage periods plus shelf life showed that the treated onions had a SDM rating that was 27% (estimated affected surface

Fig. 3. Airborne spore concentrations sampled at weekly intervals in the room treated with the corona discharge system and in the control room. Differences between the treated and control rooms are noted above the bars. ^{NS,*,**}Nonsignificant or significant at $P < 0.1$ or 0.05 according to Student's paired t test (10^3 cfu/m³ = 28.3 cfu/ft³).

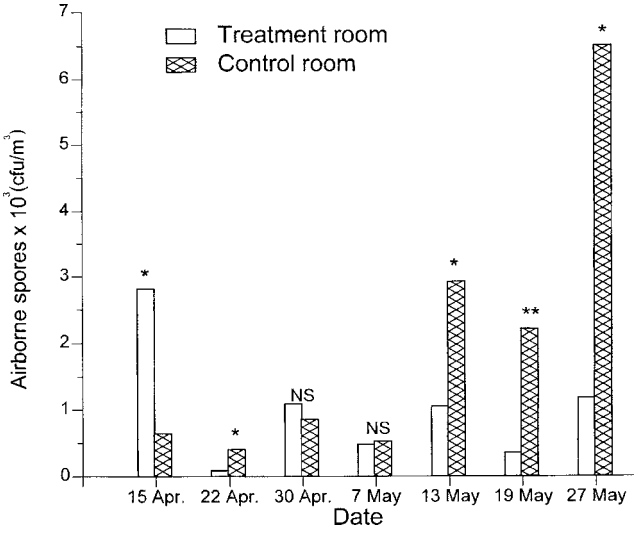

Table 1. Effect of corona discharge treatment on the surface discoloration plus mold (SDM) rating[z] and weight loss of onions. Onions were rated immediately following treatment times of 2 or 4 weeks or after an additional 2 weeks at 68 °F (20 °C) under high humidity (shelf life). Values in parentheses are estimated percentages of surface area affected.

	SDM[z]		Wt loss (%)	
Treatment	Control	Treatment	Control	Treatment
2 weeks	1.6 (5.6)	1.6 (5.6)	1.20	0.52
2 weeks + shelf life	4.4 (53.2)	3.5 (25.7)	1.65	1.30
4 weeks	2.0 (7.7)	1.9 (7.1)	1.55	1.03
4 weeks + shelf life	4.6 (62.6)	4.0 (38.6)	2.21	1.61
Factors				
Treatment (T)	**		**	
Treatment time (TT)	**		**	
Shelf life (S)	**		**	
T × TT	NS		NS	
T × S	**		NS	
TT × S	NS		NS	
T × TT × S	NS		NS	

[z]Rating scale: 0 = 0%, 1 = 1% to 5%, 2 = 6% to 10%, 3 = 11% to 30%, 4 = 31% to 50%, 5 = 51% to 100% of surface area affected.
[NS,**]Nonsignificant or significant at $P < 0.001$.

area) lower than the control onions. During the third replicate, it became evident that the discoloration of the onion skins that was being rated along with the surface mold did not change appreciably during storage. This discoloration apparently occurred in the field or during curing and was not related to mold development. Therefore, surface mold only and SDM were rated separately. This showed that treated onions had over two times less mold than the control onions upon removal from the storage rooms (Table 2). This observation, and the fact that the SDM rating of treated onions was reduced even after an additional period of harsh storage conditions on the shelf, suggests that the fungal population was substantially reduced during the corona treatment.

WEIGHT LOSS. The weight loss of onions in the treatment room was only 0.52% after 2 weeks and 1.03% after 4 weeks, which was significantly less than the weight loss that occurred in the control room (1.20% and 1.55%, respectively) (Table 1). Weight loss was again less in the treated onions than in the control onions even after two weeks of shelf life. These differences in weight loss were likely a result of the higher RH in the treatment room than in the control room.

Throughout the experiment, there were no significant treatment effects on internal decay or on numbers and lengths of roots and shoots. Although not significant, firmness was slightly higher in the treated onions [8.82 lb (4.00 kg)] than in the control onions [8.69 lb (3.94 kg)], which likely was due to the higher humidity in the treatment room. Similar results have been reported by Van den Berg and Lentz (1973) for the relationship between storage humidity and firmness. Also, there were no signs of phytotoxicity on onions as a result of the corona treatment.

One compound identified as dipropyl-disulfide was consistently lower (70.4%) in the treatment room compared to the control room. There were no substantial differences in other volatile concentrations between the two rooms. Disulfides, trisulfides, and alkyl thiosulfonates are considered to be the major onion volatiles (Schulz et al., 1998). The decrease of dipropyl-disulfide could explain the reduced pungent smell noted in the treatment room when the corona unit was turned off briefly. Corona discharge has been reported to be a promising energy efficient technology for the destruction of volatile gasses in pollution control (Ruan et al., 1997). Similarly, it would be of considerable interest to further investigate the destruction of volatiles, not only from onions but other commodities, in response to a corona discharge.

High humidity, often found in refrigerated storage, can reduce weight loss of produce, but may lead to increased levels of surface mold and decay. The corona discharge, as seen in this study, showed promise in overcoming this difficulty. Surface mold on the onions was reduced and airborne spores were also reduced thereby further limiting contamination of onions and pathogen development. The ozone presumably affected growth of fungal colonies on the onion surfaces and may have reduced airborne spores by reducing sporulation of mold colonies or by directly killing spores. The negative air ions may also have contributed to cleansing the air of airborne spores. Negative air ion generators have been shown to effectively reduce airborne microbes by precipitation (Gabbay et al., 1990; Mitchell, 1998). Li et al. (1989) reported that a combination of ozone with NAI was most beneficial to storage of mandarin oranges. Tanimura et al. (1997, 1998) also found that the combination of NAI and ozone produced by corona discharge inhibited microbial growth more strongly than ozone alone. However, the NAI concentration in the onion storage room treated by the FE 40 was lower than in Tanimura's reports and the degree to which negative air ions played a role in limiting mold growth is not known. The role of NAI with respect to inhibiting microbial growth during storage of horticultural products requires further investigation.

Table 2. Comparison between ratings[z] of mold alone and surface discoloration plus mold (SDM). Data represent means of three sample bags of onions from Rep III. Values in parentheses are estimated percentage of surface area affected.

	4 weeks		4 weeks + shelf life	
Parameter	Control	Treatment	Control	Treatment
Mold	1.3 ± 0.24[y] (4.3)	0.2 ± 0.13 (1.8)	4.5 ± 0.06 (58.7)	3.9 ± 0.38 (34.1)
SDM	2.3 ± 0.20 (9.9)	2.3 ± 0.22 (9.6)	4.8 ± 0.03 (71.2)	4.3 ± 0.24 (39.9)

[z]Rating scale: 0 = 0%, 1 = 1% to 5%, 2 = 6% to 10%, 3 = 11% to 30%, 4 = 31% to 50%, 5 = 51% to 100% of surface area affected.
[y]Standard deviation.

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