Biochar coating potential to suppress storage diseases in carrots and potatoes (CHARCOAT)

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TITLE

Biochar coating potential to suppress storage diseases in carrots and potatoes (CHARCOAT)

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SAMMENDRAG:

Kan påføring av biokull hemme utvikling av lagersjukdommer på potet og gulrot? Biokull er et karbonrikt materiale som kan brukes til å forbedre kvaliteten på dyrka jord. Forskning har også vist at biokull kan motvirke plantesjukdommer som skyldes jordboende sopp, eller soppsmitte via bladene. I dette prosjektet har vi undersøkt om påføring av knust biokull på overflaten av poteter og gulrot hadde noen effekt på forekomst av lagersjukdommer. Både gulrot og poteter er utsatt for smitte av mikroorganismer som kan gi store tap under lagring, i form av ulike sjukdommer som råte og skurv. Det er ikke uvanlig at 40% av totalavlinga sorteres vekk under lagring. For å undersøke om biokull kunne motvirke dette, ble det gjennomført forsøk i ulik skala fra laboratorium til storskala. I laboratoriet testet vi hvordan biokull kunne behandles for å kunne feste seg til overflaten på poteter og gulrot. I et middels skala-forsøk lagret vi gulrot med og uten biokull på overflaten under dårlige lagringsbetingelser, og undersøkte om det ble mindre sjukdom på røtter som var dekket med biokull. Forsøkene i stor skala ble gjennomført i lageret til Sunndalspotet AS, med kasser på 500 kg poteter med og uten påføring av biokull som forsøksenhet. Prosjektet omfattet også en vurdering av utfordringer med bruk av biokull til å dekke overflaten på poteter og gulrot.

Innledende forsøk i laboratoriet viste at biokull må knuses ned til en partikkelstørrelse på < 0,7 mm (< 700 µm) for å feste seg til overflaten på poteter. Slik biokullet forelå fra StandardBio AS, med furu som råstoff, var det kun 4% av materialet som var så finkornet. Finkornet biokull som festet seg til overflaten av poteter løsnet ikke igjen av seg selv, men var likevel enkelt å fjerne ved vasking. Et enkelt lagringsforsøk (22 °C) med to plastbokser med poteter, dekket eller ikke dekket av biokull, viste noe større vekttap for poteter uten biokull. Det kan tyde på at påføring av biokull gir en form for isolasjon som hemmer respirasjon.

Lagringsforsøk med gulrot foregikk i mellomstor skala, der sekker med 15 kg gulrot ble lagret ved ca. 8 °C, dvs. godt over optimal lagringstemperatur. Gulrøttene var uvaska eller vaska, og deretter påført eller ikke påført biokull. Vaska gulrot påført biokull holdt seg betydelig bedre enn vaska gulrot uten biokull, men ikke like godt som uvaska gulrot. For uvaska gulrot ga ikke påføring av biokull noen ekstra holdbarhet eller redusert vekttap etter 3 måneders lagring.

I storskala på lageret til Sunndalspotet AS ble poteter med eller uten påføring av biokull lagret i vedsekker lagt inn i vanlige 500 kg kasser fylt opp med poteter. Påføring av biokull ga en betydelig nedgang i forekomsten av lagersjukdommer som sølvskurv. Andelen av poteter i klasse 1 økte med 10%. I et potteforsøk med poteter der settepotetene var eller ikke var påført biokull og dyrket i jord smittet med svartskurv og tørråte, var det imidlertid ingen positiv effekt av biokull på veksten av potetplantene.

Hvis biokull skal tas i bruk til å dekke poteter eller andre grønnsaker, vil det kreve at materialet er finmalt. Dette er en annen form for anvendelse enn det biokull tidligere har vært brukt til, f.eks. til jordforbedring. Slik bruk vil gi utfordringer med støv, som kan gi eksplosjonsrisiko og utfordringer for helsa både til dem som arbeider med materialet og for folk i omgivelsene. Også i vaskevann vil finkornet biokull representere en utfordring som må vurderes. Biokullet i vår undersøkelse inneholdt 1,2 mg total polysykliske aromatiske hydrokarboner (PAH) per kilo tørt biokull. Dette er 1/3 av maksimal konsentrasjon for europeiske kvalitetskrav til biokull. PAH-innholdet vil påvirkes av substratet som forkulles, og av forholdene i pyrolyseprosessen. Anvendelse av biokull i finkornet form i stor skala vil kreve grundige undersøkelser og tilpasninger.

Prosjektet var et samarbeid mellom NORSØK, NIBIO, Landbruk Nordvest, Sunndalspotet As og StandardBio AS, med finansiering fra Regionalt forskningsfond Møre og Romsdal.

SUMMARY:

Can biochar coating decrease diseases severity during potato and carrot storage? Biochar is a carbon rich material used to improve soils' quality. Recently, biochar has also been found to suppress plant diseases caused by foliar and soil borne pathogens. Here, we tested if biochar coating could reduce storage diseases of carrots and potatoes. During storage, potatoes and carrots are vulnerable to different microorganisms that can cause a variety of post-harvest diseases. The losses due to storage diseases could reach up to 40% of volume of the harvested carrot and potato. To test the potential of biochar as a disease suppressor, we performed laboratory, middle- and large-scales trials. In the laboratory, we studied the best way to apply biochar as a coating for carrots and potatoes. Further, in a middle scale facility, we tested the effectiveness of biochar coating to diminish disease incidence under stressed environmental conditions. After gathering knowledge about biochar use and its potential to control storage diseases, we ran a trial in commercial potato store. Finally, we performed a germination test with coated potatoes in soils infected with potato soilborne diseases. Furthermore, we discussed the bottlenecks and environmental-social impacts on of using biochar coating in the potato industry.

Initial studies in laboratory demonstrated that biochar needs to be crushed to a particle size <700 µm to stick to the surface of potatoes. Without mechanical treatment, only 4% of the biochar particles passed this mesh size in a sieving test. The adhering biochar was not lost during storage and was easily removed by washing. Somewhat higher weight loss of non-coated potatoes during storage (at 22 °C) may indicate that the coating had a kind of insulation effect.

A pilot study of carrots stored at about 8°C demonstrated the well-known fact that industrial washing of carrots makes them susceptible to fouling. Coating washed carrots with biochar was quite efficient to avoid fouling, but not as efficient as not washing them. Coating of unwashed carrots did not decrease the weight loss of carrots during storage or increase the number of edible carrots after about 3 months of storage.

In the industrial scale trial, we observed that after 6 months of storage, potatoes coated with biochar had a significant lower proliferation of potato diseases, increasing in 10% the total amount of the Quality 1 potatoes when compared to the un-coated potatoes. However, in our germination experiment we did not see a clear effect of biochar coating in the germination of potatoes in soils with potentially infected with diseases.

For practical application of biochar in vegetable industry, many challenges need to be addressed. The use of biochar as fine particles increases the amount of dust which may imply a risk of explosion, and which has consequences for both environment and human health and may also affect water quality. StandardBio biochar contains a low concentration of polycyclic aromatic hydrocarbon (PAH), 1.2 mg of total PAH /kg of dry biochar. This value is at least three times lower than the limit values stipulated for sustainable production of biochar of the European biochar certificate. However, the concentration of PAH can change according to the applied substrate to make the biochar, and production conditions during pyrolysis. Thus, package plants planning to apply biochar for storage purpose need to have a careful plan for the use of biochar.

The project was a collaboration between NORSØK, NIBIO, Landbruk Nordvest, Sunndalspotet AS and StandardBio AS, with funding from the Møre og Romsdal Regional Research Fund.

COUNTRY:	Norge/Norway
COUNTY:	Møre og Romsdal
MUNICIPALITY:	Tingvoll

APPROVED	**PROJECT LEADER**
Turid Strøm	Tatiana Rittl
NAME	**NAME**

Preface

The CHARCOAT project was a regional cooperation between agricultural research institutes NORSØK and NIBIO, the agricultural extension service in Nordmøre region - Landbruk Nordvest, a local potato distribution company Sunndalspotet AS, a local carrot production and distribution company Smøla produksjonslag AS and a company in Telemark (S. Norway) producing biochar from untreated Norwegian wood, StandardBio AS. The project was a spin-off from former cooperation activities in the projects POTETGIV and MERMOLD, both (partly) funded by the Møre og Romsdal Regional Research Fund and with NORSØK as the responsible partner. Application of biochar could possibly be an environmentally friendly method to reduce yield loss and increase profit for vegetable and potato farmers, and the method could also be applied for storing organically grown potatoes and carrots. Cooperation with local conventional growers may also increase the interest to produce organically grown vegetables and potatoes. The project was conducted during 2020-2021.

On behalf of NORSØK, we want to thank all partners involved in the CHARCOAT project, who were always supportive and creative in developing practical solutions to the many detailed research questions which turned up under way.

Tingvoll, 23.06.21

Anne-Kristin Løes and Tatiana Rittl

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1 Introduction

Potatoes and carrots are important staple food crops worldwide. In Norway in 2018, 326 thousand tons of potatoes and 43 thousand tons of carrots were produced (Statistics Norway, 2019). Mature potato tubers and carrot roots are usually harvested during autumn and placed in storage rooms until washing, sorting, packaging, and distribution over the following year. During storage, potatoes and carrots are vulnerable to different microorganisms that can cause a variety of postharvest diseases.

In Norway, the most important post-harvest diseases in potatoes are silver scurf (*Helminthosporium solani;* Sølvskurv in Norwegian), skin spot (*Polyscytalum pustulans;* blæreskurv *in Norwegian*), black scurf (*Rhizoctonia solani;* svartskurv in Norwegian), Fusarium dry rot (*Fusarium* sp., Fusarium råte in Norwegian) and Gangrene (*Boeremia sp.;* causing Phoma disease, foma råte in Norwegian) (Nærstad et al. 2012, Heltoft et al. 2016). In carrots, main storage diseases are licorice rot (*Mycocentrospora acerina*, klosopp in Norwegian) and crater rot (*Fibularhizoctonia carotae,* gulrot hvitflekk in Norwegian) (Bond, 2016). These diseases reduce potato and carrot quality and may lead to significant financial loss. Financially, losses during storage are economically more important than those in fields, because they include fixed and variable costs for harvesting, transport, storage and sorting. Franke et al. (2013) reported that losses during carrot storage could reach up to 40% of volume. Locally, at Sunndalspotet AS, calculations have shown an economic loss of at least 7 million NOK annually due to storage disease, mainly silver scurf towards the end of the storage season. Convenient methods to suppress storage diseases will significantly increase the profits for the vegetable industry and contribute to reduced food waste. Reducing food waste and loss is one of the main components of the Zero Hunger Challenge announced at the United Nations Conference on Sustainable Development (known as Rio + 20). Thus, preserving potato and carrot quality during storage is pivotal.

Biochar, a carbon rich material which has been used to increase soil carbon sequestration and improve soil quality in arable soils, has also recently been found to suppress plant diseases, caused by both foliar and soilborne pathogens. A review study that summarized the data of the effect of biochar on soil borne diseases, reported that in 85% of the studies, biochar was found to reduce plant disease severity (Bonanomi et al., 2015). Several different mechanisms have been proposed to explain biochar disease suppression in soil, among them a direct fungitoxic effect of biochar, and the sorption of allelopathic, phytotoxic compounds in soil that could, when not being sorbed to biochar, harm plant parts and thus increase pathogen attacks (Jaiswal et al., 2018). Under storage conditions, a fungitoxic effect of biochar could reduce the proliferation of storage diseases. Furthermore, due to its high porosity, biochar used as a vegetable coating could regulate moisture around potatoes and carrots, thus decreasing the chances of disease proliferation. Biochar coating can work as insulation layer and protect vegetables from drying out. But also, due its hydrophobicity, dry biochar coating could prevent vegetables' surface from getting wet. Moreover, biochar has a high pH and many aromatic molecules which may have a negative effect on pathogens. However, the use of biochar as a coating for vegetables in industrial scale may also imply challenges. To stick to the surfaces of vegetables, biochar must be milled to a fine dust, which will attach not only to the vegetable but also to conveyor belts and equipment, leading to potential inconveniences, such as extra dirt. There may also be a health issue for people working in these facilities, or with the water quality of the recipient. Such disadvantages have not yet been discussed in the literature and require attention.

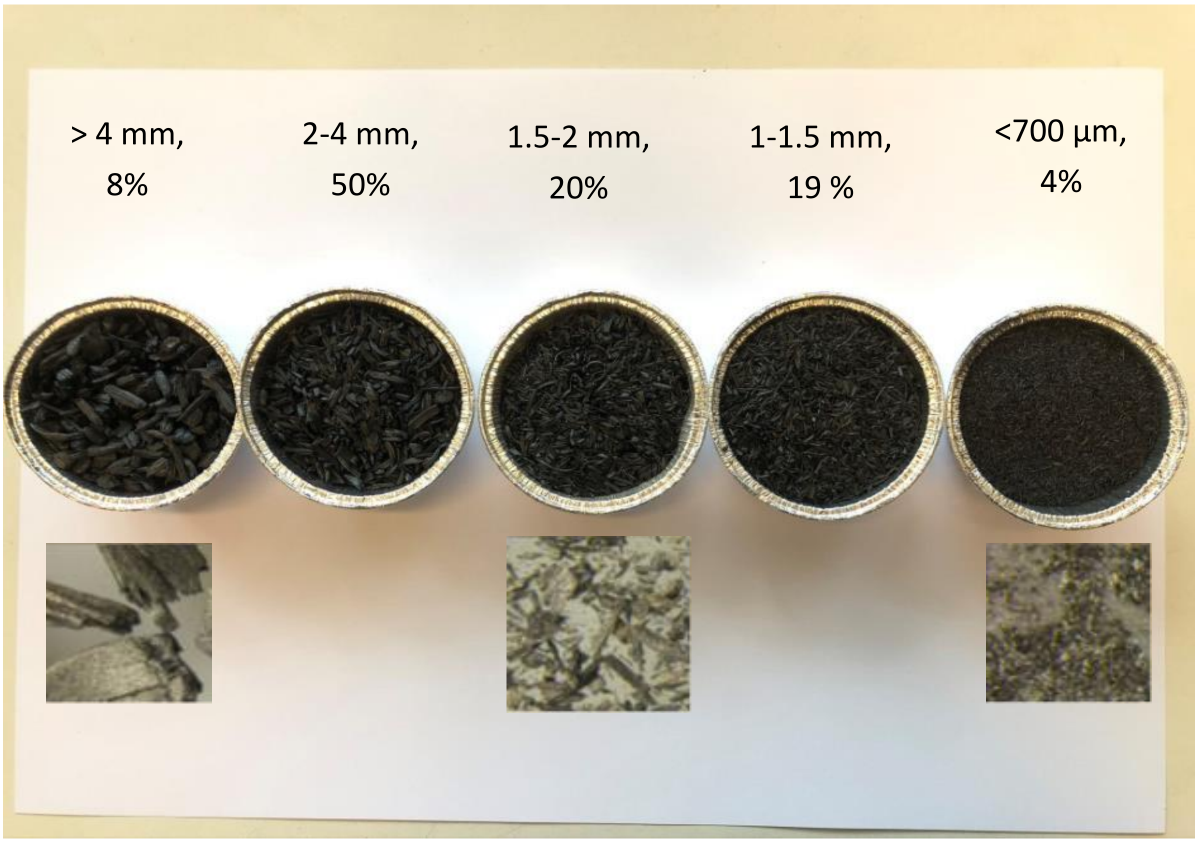
The objective of the present study was to evaluate the potential of biochar to control diseases during potato and carrot storage. Furthermore, we wanted to assess the practicality and possible risks of using biochar for coating of vegetables and potatoes in industrial scale.

2 Initial testing of biochar adherence to potato

To prepare for the full-scale testing of biochar in a commercial storage, the use of biochar as coating was first studied under laboratory conditions. The biochar used in our experiments was produced by StandardBio AS, at their location in Bø, Telemark, southern Norway.

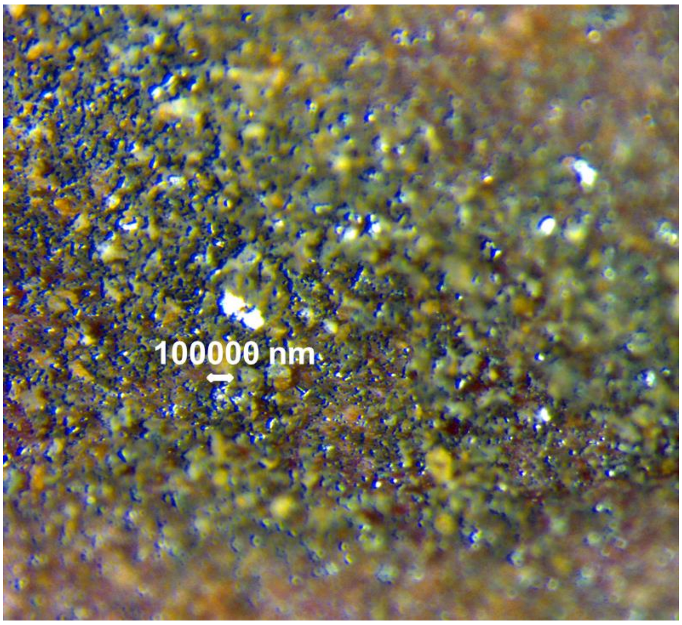
2.1 Biochar coating adherence

The biochar was produced from wood chips from Norwegian pine (*Pinus sylvestris* L.) pyrolyzed at 400°C for 5 minutes (fast pyrolysis). After production, wood biochar was wetted/quenched (approx. 45% moisture content) to avoid its combustion. To test which particle size adhered to the surface of the potato and carrot, we dried a small amount of biochar at 105 °C for 24 hours and fractioned it by sieving it through sieves with different mesh sizes. We used 5 different mesh sizes: > 4 mm, 2-4 mm, 1.5- 2 mm, 1-1.5 mm and < 700 µm (0.7 mm) and weighed the fractions. The particle size distribution of the biochar varied from bigger than 4 mm to smaller than 700 µm (**Picture 1**). Fifty percent of the wood biochar had a particle size between 2 and 4 mm, while only 4% was smaller than 700 µm.



Picture 1. Wood biochar particle size distribution after sieving. Sizes (in mm) refer to sieve meshes used during the sorting. Percentages show the proportion of biochar with a particular size. Inserted below three size classes are microscopy pictures to see the physical structure in detail. Photo: biochar particles Tatiana Rittl, NORSØK; inserted microscopy pictures Anne De Boer, NIBIO.

We sieved approximately two kilos of biochar and distributed each fraction in a tray, and then rolled dry potatoes in each tray. To our surprise, the biochar smaller than < 700 µm was the only biochar fraction that adhered to the surface of the potato. Indeed, smaller particles than 100 µm (100 000 nm; 0.1 mm) adhered in the potato surface (**Picture 2**).



Picture 2. Microscopy picture of a biochar coated potato. Photo: Berit Blomstrand, NORSØK.

We tried to improve the adherence of the coarser biochar fractions by using potatoes with moist surface, however, the wetness of the surface did not improve the ability to adhere to particles > 700 µm. Also, neither washing nor potato type had any effect on the adherence, and only biochar <700 µm could adhere to washed or unwashed, wet, or dry surfaces of Folva or Asterix potatoes (**Picture 3**).

Picture 3. Upper row: untreated potatoes; bottom row: biochar coated potatoes. From left to right: unwashed Folva, washed Asterix, unwashed Asterix. Photo: Tatiana Rittl, NORSØK.

Biochar coated potatoes (<700 µm) were submitted to air flow to test how strongly biochar adhered to their surface. There was no loss of biochar by air flow. We also observed if the biochar coating would come off with time, e.g. due to the loss of moisture. We did not observe any biochar loss which could indicate that the coating would loosen during storage. However, with washing, the biochar coating was easily removed.

2.2 Biochar coating effect on potato storage characteristics

To test the effect of biochar coating on characteristics of potato which are commonly measured during storage, we assessed weight loss, volatile organic carbon (VOC), respiration rate (CO_2), air temperature, air humidity, and potato quality by visual assessment. To do so, approximately five kilograms of biochar-coated potatoes (<700 µm biochar) and five kilograms of untreated potatoes were placed in two transparent plastic boxes and stored at 22 °C for one month. For this assessment, we incubated one box of each treatment. The weight loss was evaluated by weighing each box weekly. Changes in concentration of VOC, CO_2, air temperature and humidity inside of the boxes were monitored daily using an AmbiMate MS4 Sensor Module sensor accoupled to a minicomputer (Raspberry Pi), developed by Consult Hammer, exclusively for this work.

The air temperature inside of the box with untreated potatoes was somewhat higher than in the box with biochar treated potatoes, with higher values in the beginning of the incubation, about 1 °C. However, this difference decreased over time (**Figure 1**). It may be that the coating slightly hampered the production of heat from the potatoes, like a layer of insulation. The relative air humidity in the boxes sharply increased within two days for both untreated and biochar-tread potatoes, from 30 to 85%. The relative air humidity stayed high (up to 90%) until the end of the experiment, with the box of untreated potatoes showing slightly lower humidity in the beginning (**Figure 2**).

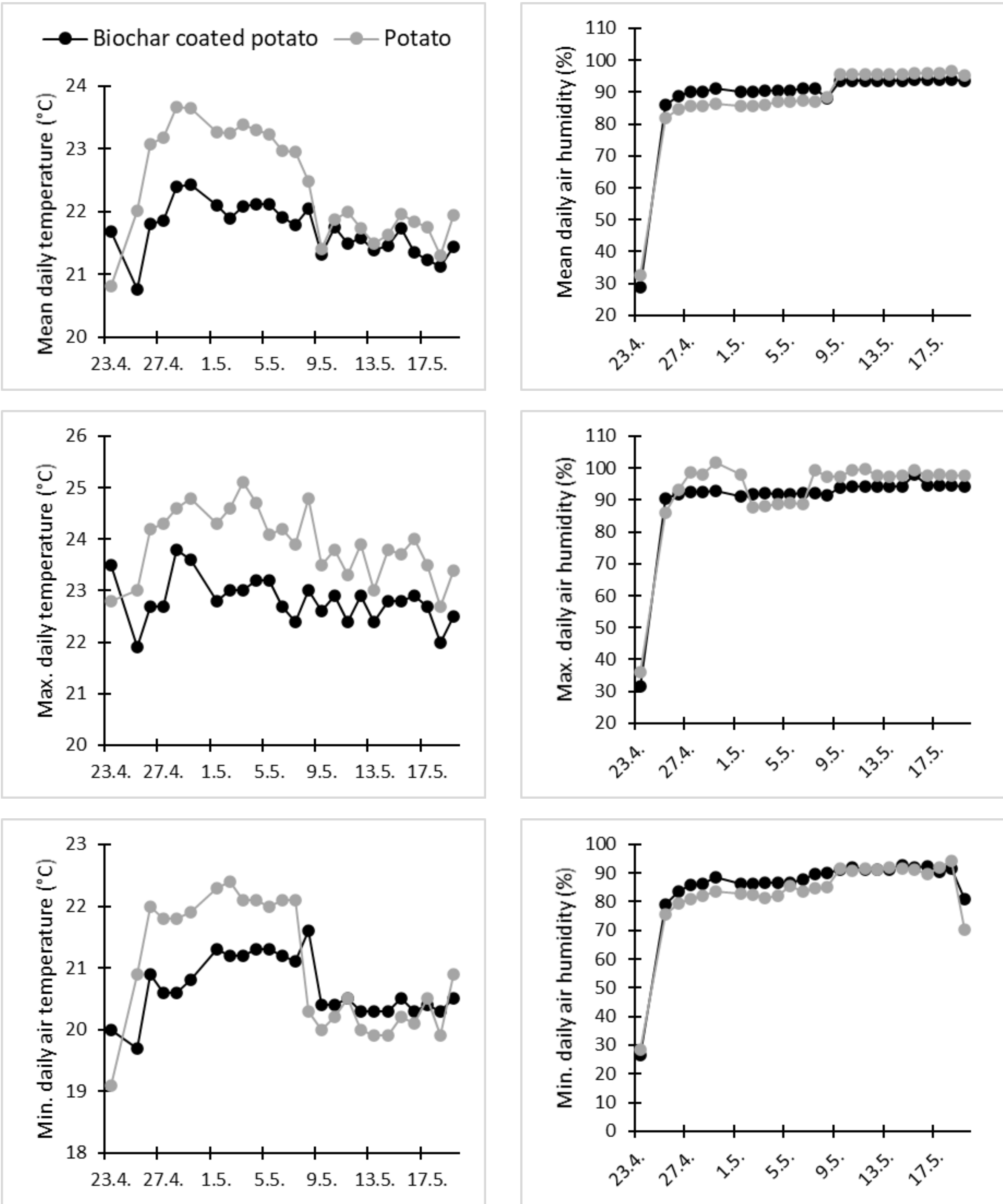


Figure 1. Mean, maximum and minimum daily air temperature (left) and air humidity (right) measured inside of transparent boxes filled with untreated potatoes and biochar -coated potatoes.

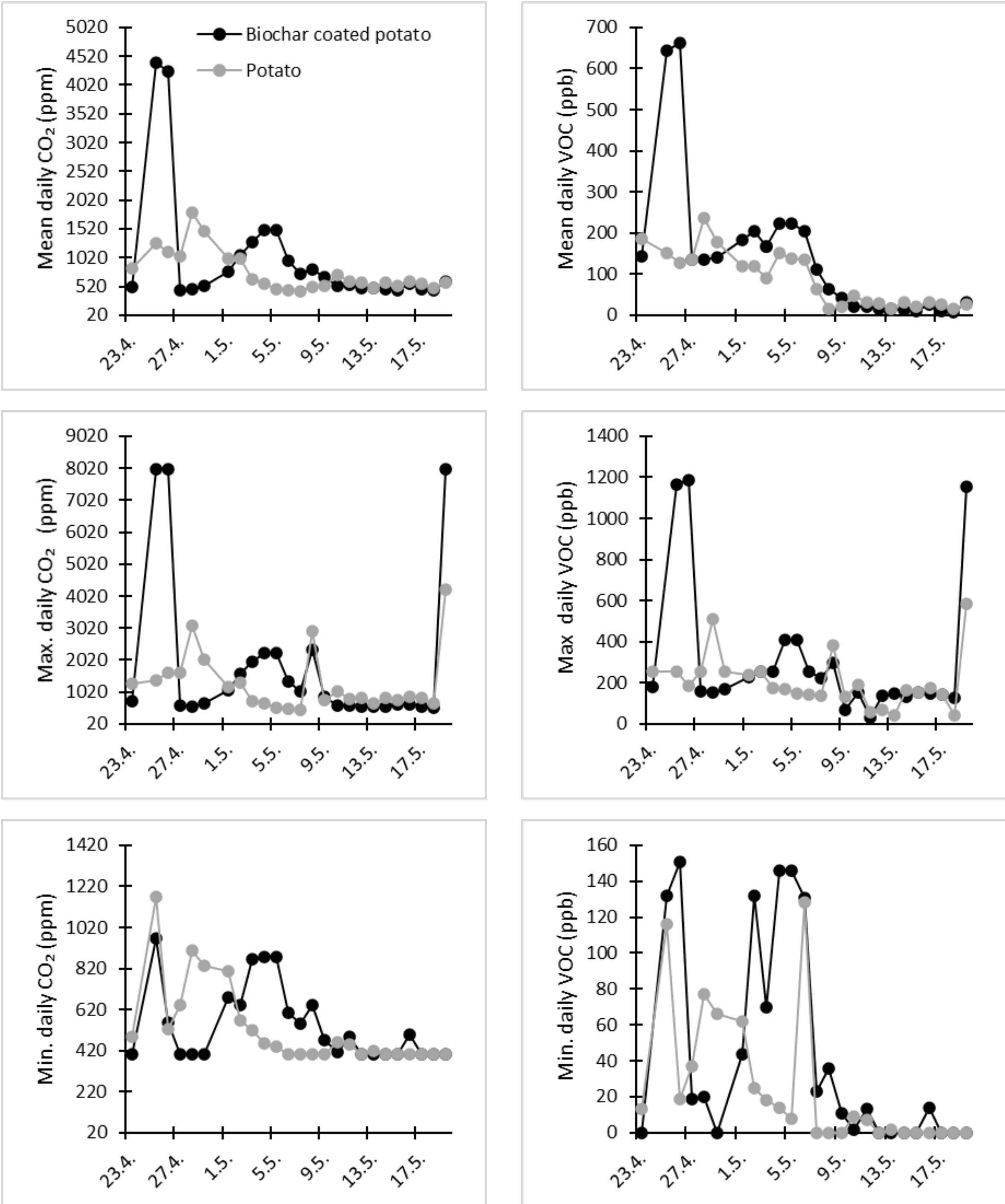


Figure 2. Mean, maximum and minimum daily values of CO_2 (left) and volatile organic carbon (VOC) (right)measured inside of transparent boxes filled with untreated potatoes and biochar-coated potatoes.

The increase in the CO_2 concentration inside of the boxes was measured as a proxy of potato respiration. The sensor utilized the concentration of VOC to infer the CO_2 concentration of the air inside of the box. Therefore, the changes of VOC and CO_2 followed the same pattern over time (**Figure 2**). The highest peaks for CO_2 and VOC at the start of the experiment in the box with biochar-treated potatoes were more likely caused by biochar dust rather than higher potato respiration. When handling the biochar-coated potatoes, very fine biochar particles may have been suspended in the air. Although they were not visible to us, these particles filled the air inside of the box, settling after 5 days. After these initial high peaks, it seems that uncoated potatoes had a period of higher respiration and VOC than coated potatoes for about 4 days, followed by a higher respiration for coated potatoes for about six days. Thereafter, the patterns of the CO_2 and VOC emissions were very similar.

As shown by a steeper line of the decreasing average potato box weights, the weight loss of potatoes stored at 22 °C was significantly larger (*p=0.001*) for untreated potatoes (**Figure 3**). On average, untreated potatoes lost 1.9 g per day, while coated potatoes lost 1.6 g per day. Such high losses of weight will never occur in a commercial potato storage where the temperature is much lower (4-5 °C). Reduced weight loss by coating with biochar points in the same direction as the initially lower temperature in the box with coated potatoes (**Figure 1**) and may possibly be explained by the insulating effect of the coating layer.

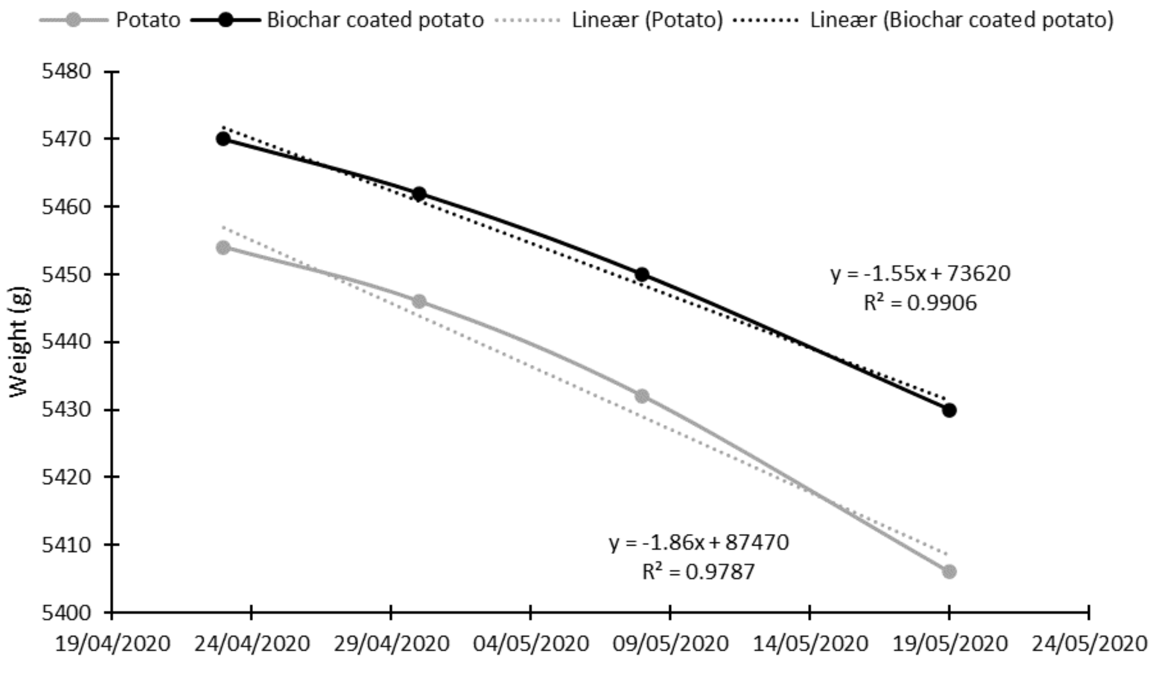


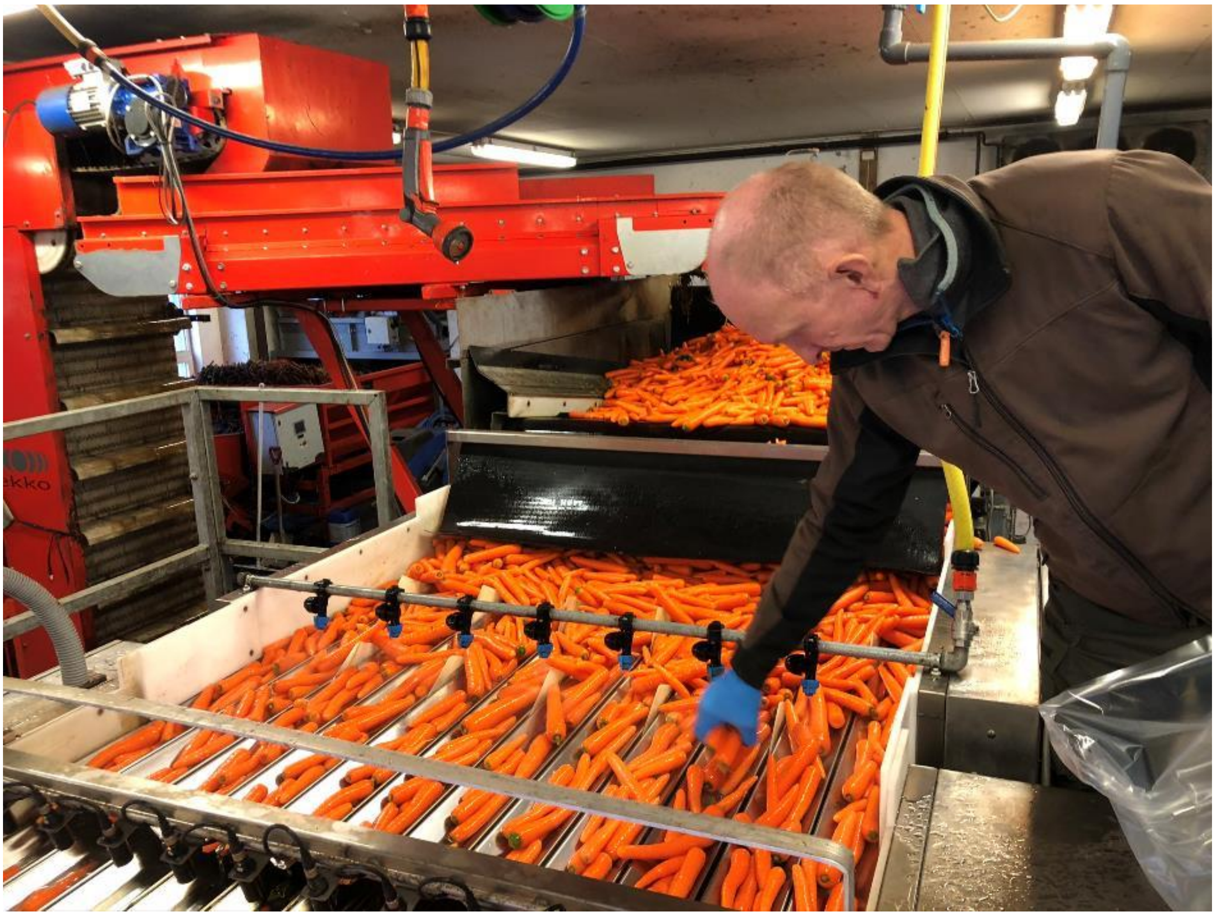
Figure 3. Weight loss (g) of potatoes incubated at 22 °C with and without biochar coating; weight of boxes of ca. 5 kg potatoes recorded weekly.

2.3 Partial conclusions

- Biochar must be processed to a particle size < 700 µm to adhere to the surface of potatoes. The wetness of the surface, or whether potatoes are washed, do not affect this result.
- Biochar particles < 700 µm adhere strongly to the potato surface and will not fall off during storage but is easily removed by water.
- Biochar coating may decrease potato weight loss during storage, possibly due to an insulation effect of the coating.

3 Intermediate scale assessment of carrots stored under stress

To test the potential of biochar to suppress carrot storage diseases under stressful environmental conditions, we applied carrots from Smøla Produksjonslag SA which were sampled on 24th of September 2020 by Anne-Kristin Løes and Tatiana Rittl during a visit at the plant. One sample was taken from recently washed carrots in the packaging plant (**Picture 4**), and the other from unwashed carrots (**Picture 5**). The carrots at Smøla are grown in peat soil which adheres to the roots in much the same way as biochar. Hence, a treatment with unwashed carrots was included in the intermediate scale storage test, as a coating of soil may have a similar effect to the biochar coating to protect the carrots during storage (**Picture 5**).



Picture 4. Carrots being washed and sorted at Smøla Produksjonslag SA on September 24, 2020, here demonstrated by Odd Harald Solheim. Photo: Tatiana Rittl, NORSØK.

Picture 5. Fresh carrots grown in peat soil at Smøla, washed carrots (left) and unwashed (right). Photo: Tatiana Rittl, NORSØK.

We used one cultivar of carrots from Smølagrønt AS, harvested at the end of the growing season. The experiment comprised four treatments: (i) washed carrots (ii) washed carrots coated with biochar; (iii) un-washed carrots; (iv) unwashed carrots coated with biochar. There were five replicates of each treatment, each comprising ca. 15 kg of carrot stored in a perforated plastic bag. Carrots were coated with biochar using a specially designed box mimicking a conveyor belt, developed by Sunndalspotet AS (**Picture 6**). We developed the following procedure to coat the carrots: (1) Approximately 1 L of the <700 µm biochar was spread on the surface of the manual "conveyor belt"; (2) approximately two kilos of carrots were placed on one side of the "conveyor belt", then this side was lifted and the carrots rolled over the surface covered with biochar; (3) then the other side was lifted and the carrots rolled back; (4) this procedure was repeated five times until the surface of the carrots was completely covered with biochar. To avoid that some treatments had more physical stress than others, all treatments were rolled over the manual "conveyor belt". The carrots not treated with biochar were rolled over a clean surface.

Picture 6. Tatiana Rittl coating the carrots using the manual "conveyor belt" developed by Ivar Bakken from Sunndalspotet AS. Photo: Anne-Kristin Løes, NORSØK.

To stimulate disease incidence in the trial, we stored carrots at higher temperature and humidity than recommended and normally found in industrial scale storage facilities. The carrots were stored in a basement without controlled temperature for 86 days (Figure 4), until significant disease symptoms developed. The bags with carrots were placed next to each other, but not on top of each other, on a large table. The air temperature around the carrots decreased over time from about 12 to about 5 °C (**Figure 4**), with one drop to -1 °C mainly due to sensor fail. The average temperature was 8 °C, recorded with a sensor EC-TM Temp. In an industrial scale plant, storage temperature would be around 1 °C (± 0.5 °C). During the study, weight loss and disease development were evaluated regularly by recording the weight and by visual assessment. At the end of the experiment, we assessed the percentage of edible carrots by visual assessment. Before the visual assessment, carrots were washed and five randomly picked carrots from each replicate bag were displayed side by side. The evaluator was asked to answer a yes or no question: would I eat this carrot? Yes-answers received +1 value, and No-answers received 0 values. In the end, a percentage of edible carrots were calculated for each treatment. Carrots with a low cover percentage (<10%) of brown rot, tip rot or foulness were considered edible.

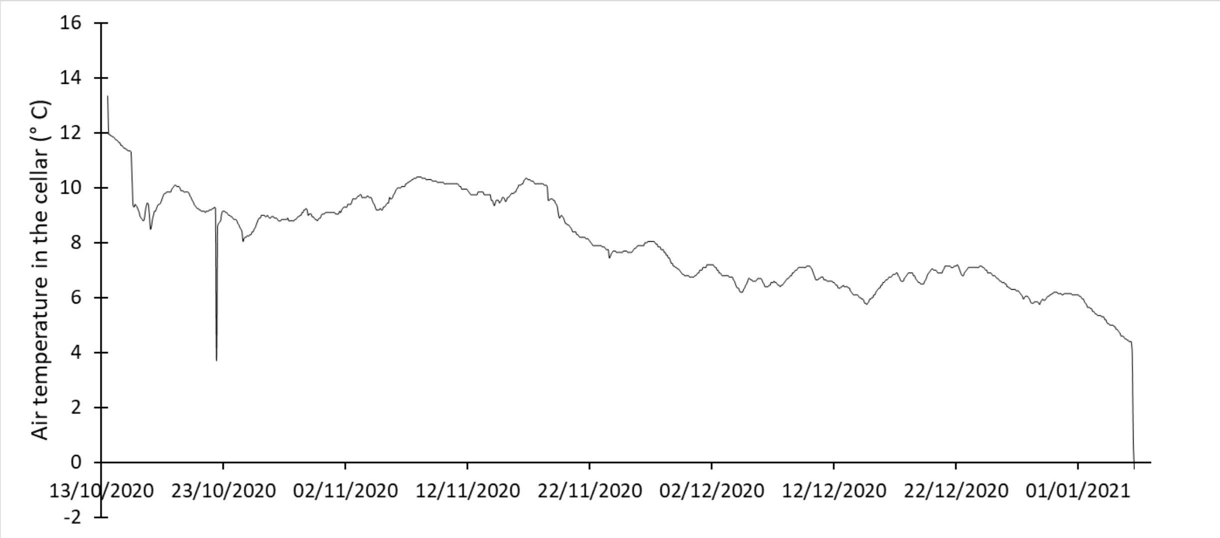


Figure 4. Basement air temperature during storage of the carrots.

All the treatments showed visual appearance of fouling. The weight loss varied among the treatments (**Table 1 and Figure 5**). Lowest loss was found for unwashed carrots coated with biochar, which lost on average 67 g per day, whereas washed, uncoated carrots lost the most, on average 113 g per day. The accumulated weight loss after storage showed that washing gave the highest weight loss, more than 60%, whereas no washing and washing + coating with biochar gave comparable weight losses.

Table 1. Relative weight loss (%) after 86 days storage

Treatment (washed/ unwashed)	Treatment (biochar)	Total weight loss (kg)	Weight loss (%)	Edible carrots (%)
Unwashed carrots	With	6	39	84
	Without	7	43	92
Washed carrots	With	8	46	86
	Without	10	62	20

Biochar affected weight loss only if the carrots were washed ($p<0.001$). Unwashed carrots had a similar weight loss as washed and coated carrots and coating of unwashed carrots did not reduce weight loss significantly ($p=0.604$). The experiment was terminated when we started to observe some development of a white mould, possibly *Sclerotinia or* grey mold in the washed carrots without biochar (**Picture 7**). There were no disease symptoms in the other treatments. Overall, the washed carrots without biochar treatment had the smallest proportion of edible carrots, only 20% (**Picture 7**) whereas the unwashed carrots without biochar still had 92% edible roots after almost 3 months of storage in non-favourable conditions. The proportion of edible carrots was very similar (no significant difference) in washed and unwashed treatments with biochar coating, about 85%.

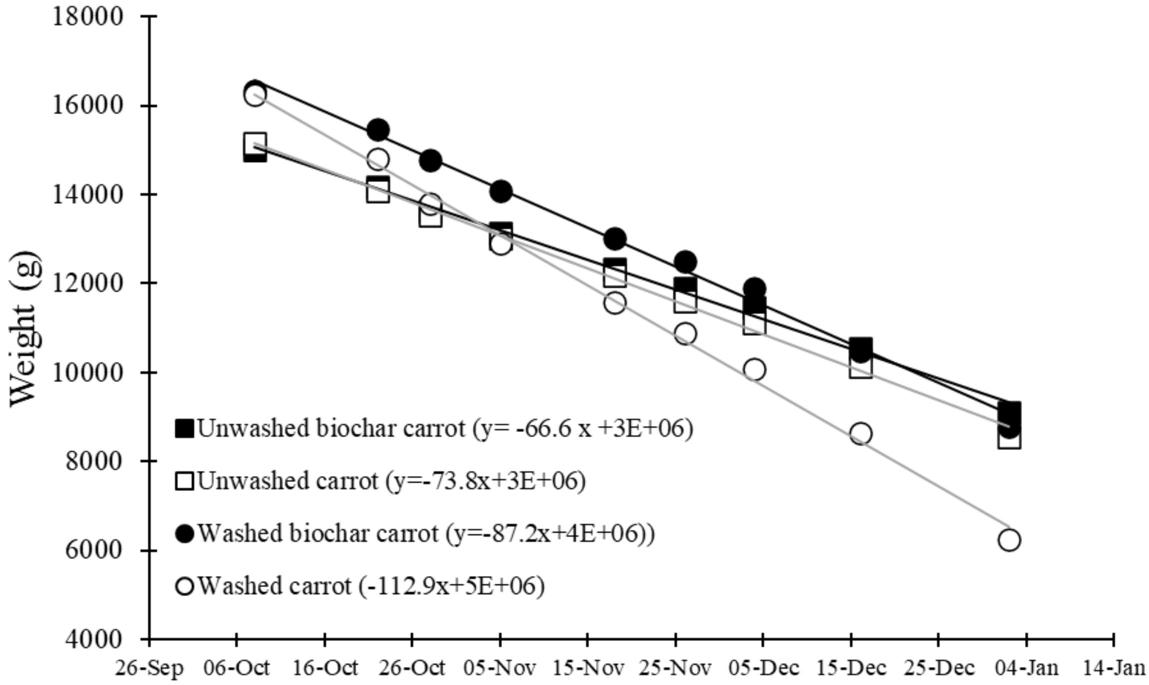
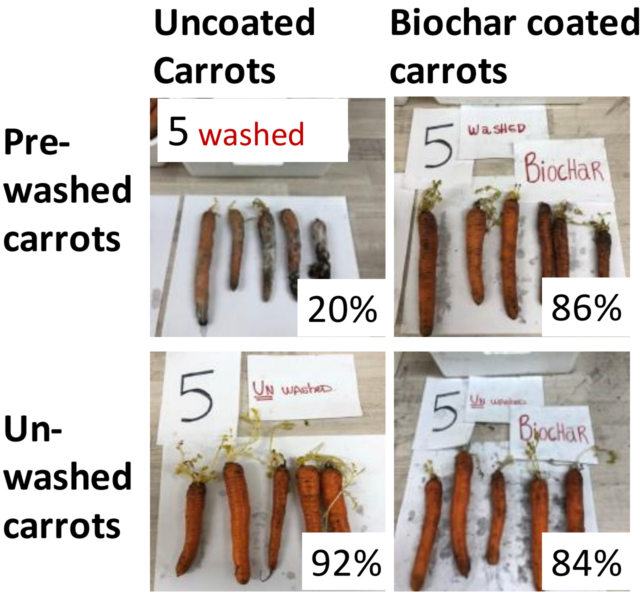


Figure 5. Average weights of bags containing about 15000 g of carrots during storage for 86 days, recorded weekly. Each value is an average of 5 replicate bags per treatment (washed or unwashed carrots, with or without biochar coating).



Picture 7. The percentage represents the proportion of edible carrots in each treatment at the end of the 86 day-experiment. Photo: Tatiana Rittl, NORSØK.

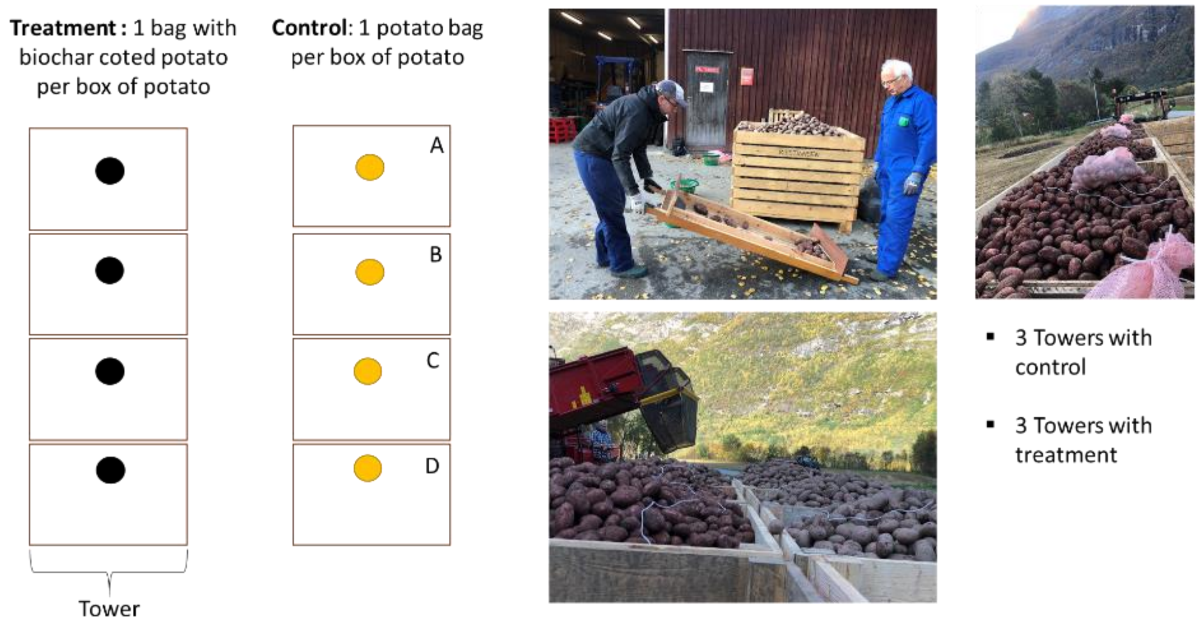
Since we did not inoculate the carrots with some disease agent, the fungi and/or bacteria causing storage disease entered the experiment via the carrots, likely by organisms located at some part of the carrot such as the root tip, or in leaf residues at the top of the roots or among the carrots and spreading from there to the surface of the roots. It is well known that washing reduces the storage quality of carrots significantly, as was clearly demonstrated in this testing. It was interesting to see that a biochar coating could have a similar effect as a non-washing. However, since the effect of not washing the carrots were at least as good as washing the carrot and coating with biochar and coating unwashed carrots with biochar did not increase the quality significantly as compared with unwashed, uncoated carrots, we cannot recommend a coating with biochar in practice, unless possibly for carrots grown in a soil where very little material sticks to the surface after harvest.

3.1 Partial conclusions

- Biochar coating decreases carrot weight loss, but only if carrots are initially washed.
- For washed carrots, a biochar coating decreases or delays the appearance of storage disease.
- Biochar coating increases the amount of edible washed carrots after storage in stressing conditions.
- Biochar coating has similar effect as storing the carrots without washing (= soil coating) in preventing both storage diseases and weight loss.

4 Industrial-scale trial

Based on our experiences obtained by the lab and intermediate scale studies, we tested the potential of biochar to suppress potato storage diseases at industrial scale in the winter of 2020-2021. We coated potatoes with biochar < 700 µm. Potatoes were coated in the same way as the carrots described in chapter 3. Briefly, we rolled the potatoes over a manual convey belt covered with biochar (1 l of biochar). The control treatment was potato of the same cultivar (Nansen) from the same grower, without biochar. Each experimental unit comprised about 5 kg of potatoes which were weighed and placed in a net bag usually applied for storage of firewood. Each potato bag was placed in the middle of a normal storage box of 900 kg potatoes during potato harvest (**Picture 8**). In total, we placed 24 bags, 12 with biochar-coated potatoes, 12 without biochar coating, in 24 boxes. Treatment boxes were piled in "towers" comprising 4 boxes ahead of each other, resulting in 3 replicate "towers" of each treatment, where A was on top and D on the floor of the storage room (Picture 7). Treatment and control potato towers were stored in the same row in the storage room with every second "tower" with and without biochar. Potatoes with and without biochar were stored with the farmer, Lars Gunnar Kristiansen for 5 months (ca September 15, 2020 to February 16, 2021). and at Sunndalspotet for 2 months (February 16 to April 15, 2021). In the Kristiansen storage, the temperature decreased slowly until a stable storage temperature (3.8 to 5°C) was reached on 1st December 2021 (temperature was logged, data not shown).



Picture 8. Illustration of treatment and control towers, black and yellow dots represent bags with biochar-coated and un-coated potatoes placed inside of potato boxes during potato harvest in September 2020. Photo: Tatiana Rittl, NORSØK.

After storage until April 2021, potatoes were assessed for diseases via the optical system applied at Sunndalspotet AS (Celox) and manually. The Celox optic sorting system has a camera that searches for defects like difference in colour, bends, breakage, or blemishing. This system could not be used for a scientific assessment of the degrees of diseases in the surface of the potatoes with and without biochar coating. Even after washing, there was a slight difference in the colour between biochar-coated and uncoated potatoes that resulted in a systematic error in the optical system sorting. A calibration of Celox for previously biochar-coated potatoes could overcome this problem for practical use, however this was beyond the scope of this project. Therefore, we assessed potato quality manually for both biochar-coated and uncoated potatoes (**Table 2**).

Manual assessment was performed by Ivar Bakken (Sunndalspotet), Frode Grønmyr (Landbruk Nordvest) and Tatiana Rittl (NORSØK). Both Celox and the manual assessment classified the potatoes in seven different categories, where six were sorted out due to various diseases or other defects, and one was Quality class 1 potatoes applicable for sale. If skin disease covers > 10% of the potato surface, the potato will be sorted out and classified as sorted out due to silver scurf (sølvskurv), black scurf (skurv), black dot (svak med skade), growth cracks (vekst-sprekk), green skin (grønnfarging), and blemishing (skallmisfarging). The statical difference between means of the treatment with biochar and control was checked using analysis of variance (ANOVA) for each quality characteristic (e.g. silver scurf), and was considered different when $p < 0.05$.

There was no effect in the potato quality of location of potato bags in top, bottom, or medium position of storage tower. Biochar-coated potatoes showed a significant decrease in the proportion of potatoes being sorted out due to silver scurf and blemishing, where 7% and 5% less potatoes were sorted out for these reasons in coated potatoes compared with the control. As a combined effect, this would increase the number of potatoes that can be sold as Quality class 1 potatoes with 12% (**Table 2**), which could represent a significant gain in income for the farmers. In April, farmers receive 6 NOK per kg of potato in Quality class 1. An increase of 12% of potato sale at this point of the storage season will result in a gain of 72,000 NOK for 100 tonnes of delivered potatoes, which would imply an increased payment of 25%. Furthermore, biochar-coated potatoes could possibly increase the duration of the period of storage when potatoes can be sold for consumption without packaging. This could increase the gains even further.

Table 2. Mean weight loss, percentage of potatoes with skin diseases or other reasons for being sorted out from saleable potatoes (Quality class 1), and percentage of Quality class 1 (saleable) potatoes after seven months of storage. For each characteristic, different letters (a, b) indicate a significant difference between coated and non-coated potatoes (*n=12*) assessed manually for potato diseases, ANOVA, p=0.05, Tukey t-test. Optically sorted potatoes (Celox system) are shown for comparison.

	Manual		Celox
	Biochar coating	Control	Control
Weight Loss (g)	0.29a	0.26a	-
Silver scurf (%)	29b	36a	12
Black scurf (%)	8a	8a	0
Black dot (%)	0	0	18
Growth cracks (%)	0	0	6
Green skin (%)	0	0	1
Blemishing (%)	2b	7a	0
Quality class 1 potatoes (%)	61a	49b	64

Biochar is expected to have an effect not only when coating a potato or vegetable, but also when placed in the same environment. For instance, small amounts of biochar can be placed in a refrigerator to reduce odour and improve the quality of air. To see if the bags with coated biochar potatoes had some effect on reducing the incidence of potato diseases in the boxes where they had been located, we assessed potato quality in potatoes which had been stored nearby the treatment bags in the **boxes A**. For that, circa of 5 kg of potatoes in close contact to the treatment bags (with and without biochar) were manually picked and manually assessed. The potatoes in the control boxes had less percentage of potatoes with disease, but the differences between coated and uncoated neighbour-potatoes were not statistically significant (ANOVA, p>0.05) (**Table 3**).

Table 3. Average proportions (n=3) of potatoes sorted out due to skin diseases and other criteria, and proportions of Quality class 1(saleable) potatoes, after storage near to bags of potato coated by biochar or not (control). Std = standard deviation.

	Biochar box	Std	Control box	Std
Silver scurf (%)	46	6	34	8
Black scurf (%)	0	1	2	1
Black dot (%)	0	0	0	0
Growth cracks (%)	0	0	0	0
Green skin (%)	0	0	0	0
Blemishing (%)	0	0	1	1
Quality class 1 potatoes (%)	54	6	63	9

4.1 Partial conclusions

- Box position in the tower had no significant effect on the quality of the potato.
- Biochar-coating of potatoes reduced the out-sorting of potatoes by 12% compared with uncoated potatoes. This may affect very positively on farmers' income.
- Biochar-coating of potatoes significantly decreased the incidence of silver scurf and blemishing
- Potatoes located close to coated potatoes were not positively affected by biochar coated potatoes (no reduction in out-sorted potatoes).

5 Environment and health

5.1 Health risks from dust and PAH

Polycyclic aromatic hydrocarbons (PAHs) are chemical compounds which only contain carbon and hydrogen, which are organized in multiple aromatic rings. PAHs are a category of persistent organic pollutants with carcinogenic (causing cancer), teratogenic (affecting development of organisms, i.e. foster(self-evident after birth it is no foster anymore), and mutagenic (causing permanent changes in genes) toxicities. The formation of PAHs during biochar production is inevitable, and the type and amount depend on the feedstock and production conditions. Therefore, before use biochar in a large scale, we must assess its risk. Further risks linked to large-scale application of this material are explosion and fire, and dust which may harm the working environment and possibly pollute waterbodies. In brief, all these risks are discussed in this section.

StandardBio biochar was sent to analyses to a specialized laboratory in Europe, Eurofins Umwelt Ost GmbH. PAH concentration in the biochar was low, 1.2 mg of total PAH /kg of dry biochar. This value is lower than the limit values stipulated for sustainable production of biochar of the European biochar certificate (European Biochar Certificate (EBC), 2012), which is 12 mg of total PAH /kg of dry biochar for basic quality grade and 4 mg of total PAH /kg of dry biochar for the premium quality grade. The concentration of PAH in each biochar type is unique and it can vary significantly due to differences in the feedstock and production conditions. Therefore, it is important that the concentration of PAH in the biochar is regularly analysed when changes in feedstock or production conditions occur.

As a part of project activities, Kari Fløystad and Annbjørn Husby at Landbruk Nordvest have conducted a preliminary risk assessment with proposals for measures that can limit the harmful effects of biochar dust in the working environment in the potato packaging plant. This risk assessment is of a general nature based on information acquired from The Norwegian Institute of Public Health, the Norwegian Labour Inspection Authority, the Norwegian Food Safety Authority and STAMI (Norwegian Institute for the Working Environment). If biochar should be applied in large scale, e.g. to coat potatoes during storage, it will be important to take precautions to ensure that employees who work with biochar are not exposed for concentrations of this material which may lead to serious illness. Training of the staff would also be important, by providing information and implementing good routines that everyone should follow. If further use of biochar is planned for storage of potatoes and vegetables, the occupational health service should be hired, with safety engineers who can make a more in-depth risk assessment and subsequent recommendations with a view to reducing harmful effects on the health of employees. Employees should also join in regular occupational health checks. It will also be important with analyses of the biochar to be used to see that the content of (PAH) compounds is within acceptable levels.

When it comes to PAH intake, Norwegian inhabitants get this primarily from grilled food, smoked meat and fish as well as contaminated seafood. Calculating PAH intake for those with high consumption of such food items in this country is considered of little concern. It is emphasized, however, that in principle it is desirable that exposure to genetically toxic and carcinogenic substances (e.g., PAH compounds) in foods be as low as practically possible. If potatoes or other vegetable food should be stored with contact to biochar, it will be interesting to see if the food absorbs PAH compounds during the storage process. Threshold values for PAH in food are laid down in Regulation 1881/2006 from the EU Commission. Exposure to biochar dust can have major health consequences, especially based on respiratory impact. Dust is a serious risk for people working in polluted areas, such as farmers, farm workers, and possibly workers in vegetable storage and packaging facilities. Fine particles may enter the lungs and trigger a development of allergies and inflammations, causing health problems like allergy and asthma. By inhaling air with biochar dust, PAH compounds can enter the lungs and into the blood. It can lead to many different diseases and ultimately death as a result.

The heart is also affected, both the electrical activity, and the direct impact of the heart muscle (see appendix A, chart). In addition to respiratory exposure, PAHs can also be absorbed through the skin and stomach / intestines. It is largely a lack of knowledge about the effects of PAH compounds on human health. From what we have learned, the threshold value of PAH in air has been set to approximately 0.04 mg / m^3, (Arbeidstilsynet, 2010).

5.2 Danger of explosion and fire

A danger of fire and in worst case, explosion may arise when large volumes of dry biochar is present or accumulates. Risk of fire occurs in dry biochar of all particle sizes, whereas risk of explosion occurs with high concentration of fine particles in the air. For a large-scale application if finely ground biochar, care must be taken during production, storage, and application to avoid these risks. Further, care must be taken to avoid accumulation of dust in areas which are difficult to assess for cleaning . Such dust will pose a danger of explosion / fire in the long run and affect negatively on workers' health. It's strongly recommended to get pyrotechnical expertise to assess the biochar potential risk of explosion and fire hazard.

5.3 Remediation / cleaning

In addition to regular cleaning and means to avoid risks described above, vegetable/potato package plants planning to apply biochar for storage purpose need to have a careful plan for the decontamination of the biochar after use. Biochar is already used in granular form as a soil amendment, with positive effects e.g. on soil structure and water holding capacity. Hence, could the biochar dust be compiled and applied to soil? If biochar dust is collected by washing, the water could be compiled and the sludge or slurry could be mixed into soil during tillage, to avoid that fine particle of biochar enters waterbodies. In perspective to the risk of fine particles entering waterbodies, any large-scale application of biochar to soil, especially with fine fractions, should assess if this may affect the quality of groundwater. In a context of climatic change and more heavy rainfalls , any secondary use of residual dust / sludge for arable land should indeed be investigated for such consequences. Since the biochar will imply a significant cost for the vegetable/potato packaging plants, not only to produce it and apply it but also to collect it after use in a safe way, the amount of biochar which has to be applied should be minimised. Is there also secondary risk of harming marine life nearby river outlets? This is an important issue, as the consequences are completely unknown. Increased precipitation with climate change may increase soil erosion, transferring larger amounts of soil to waterbodies.

The cost of protection equipment for employees could become significant, especially if disposable equipment for daily use is applied. (**Appendix B: Risk analysis, working environment**).

Final important note

From a Chemical Risk Analysis point of view, Annbjørn Husby and Kari Fløystad points out the Chemical Risk Analysis mandate, and an underlying rule of thumb: When searching for new chemicals for improving the food production chain, one should always have the concept of substitution in mind. Substitution: Is there another way, or just no way. Is it actually worth it, or should one leave things as is?

6 Soil borne diseases

As a part of the project, we performed an experiment to study the potential of biochar coating to reduce soilborne disease infection during potato germination and initial growth. We collected three different types of soil in three different places. Soil contaminated with black scurf (*Rhizoctonia solani)* was collected in Sunndal in an area with a historical problem with black scurf. Soil contaminated with late blight (*Phytophtora infestans*) was collected in Tingvoll farm where an experiment with late blight was conducted on year before (Wibe et al., 2021). A control soil was collected at Tingvoll farm from a field without a history of potato diseases. The study was a randomized experiment with four replicates for each of totally 18 treatments (3 methods of coating the potatoes x 3 soil types x 2 potato varieties), in total 72 pots. The four replicates of each treatment were put together in a plastic tray as one experimental unit. The treatments consisted of 3 potato coating treatments (biochar, chemical (Maxim® 100 FS, 30 l /t) and no coating) (**Picture 9**) x 2 potato varieties (Nansen and Folva) x 3 soil types (infested by black scurf, infested by late blight, non-infested soil). We chose these cultivars because they have different susceptibility to soilborne disease; Nansen is more resistant to late blight than Folva. Pots of 1.5 L were used. Each pot received ca. 2 kg of soil and moisture was adjusted to 70% of the maximum water holding capacity after full saturation and free drainage (WHC). One coated or uncoated seed potato was planted per pot. During the growth period, soil water content was adjusted to 70% of WHC by weekly weighing of each pot. Black scurf treatments were placed in a colder room, average temperature 8°C for two weeks to accelerate the development of Black scurf, which develops faster at cold and wet conditions. The others were kept in a room used for raising of vegetable transplants, with appropriate conditions for plant growth. All treatments were kept for five weeks.

By harvest of the pots after five weeks, we measured the following characteristics: height of the highest sprout in each pot; weight of the highest sprout in each pot; diameter of highest sprout in each pot; number of sprouts per pot, total sprout fresh weight per pot; fresh weight per sprout, dry weight per sprout. For that, we cut the sprouts of each pot about to 2 mm above the soil surface. The height of the highest sprout was measured using a graph paper and ruler and its diameter using a pachymeter. Fresh weight was measured shortly after cutting the sprouts. Sprouts were put in a paper bag and dried at 105 °C until constant weight was achieved. The average values per treatment of each measurement is given on **Appendix C**. To estimate the overall effect of the treatments, we calculated the relative difference of all parameters analysed. For that we normalized our data for each measured characteristic, dividing the measurements by the maximum measured value within the dataset. Thus, values presented here vary from 0 to 1. The summary of the measurements can be seen on **Figure 6.**

Picture 9. Coated potatoes. From left to right, no coating, biochar, and chemical coating. Photo: Tatiana Rittl, NORSØK.

After five weeks, there was a visible difference in the size and number of sprouts between treatments according to soil type independently of the coating used (**Picture 10**). Potatoes settled in the soil infested by black scurf did not germinate or germinated poorly, and coating could not overcome this. In soil infected by late blight, and in non-infected soil, both potato varieties germinated well, and coating had no substantial effect.

Overall, Folva sprouts from seed potatoes coated with biochar had a better growth than sprouts from chemically coated or uncoated seed potatoes (**Figure 6**). For the Nansen variety, sprouts from chemically coated and uncoated treatments performed better than sprouts from biochar-coated seed potatoes, especially in the late blight-infested soil (**Figure 6**). The chemical coating had no suppression effect on black scurf for the Folva variety, however it showed a positive effect on suppressing the disease in the Nansen variety.

Picture 10. Pictures of the germination of the two potato varieties with different coatings, control (no coating); chemical and biochar in three different soils infested by potato diseases or non-infested. Numbers represent the identification of each pot. Photo: Tatiana Rittl, NORSØK.

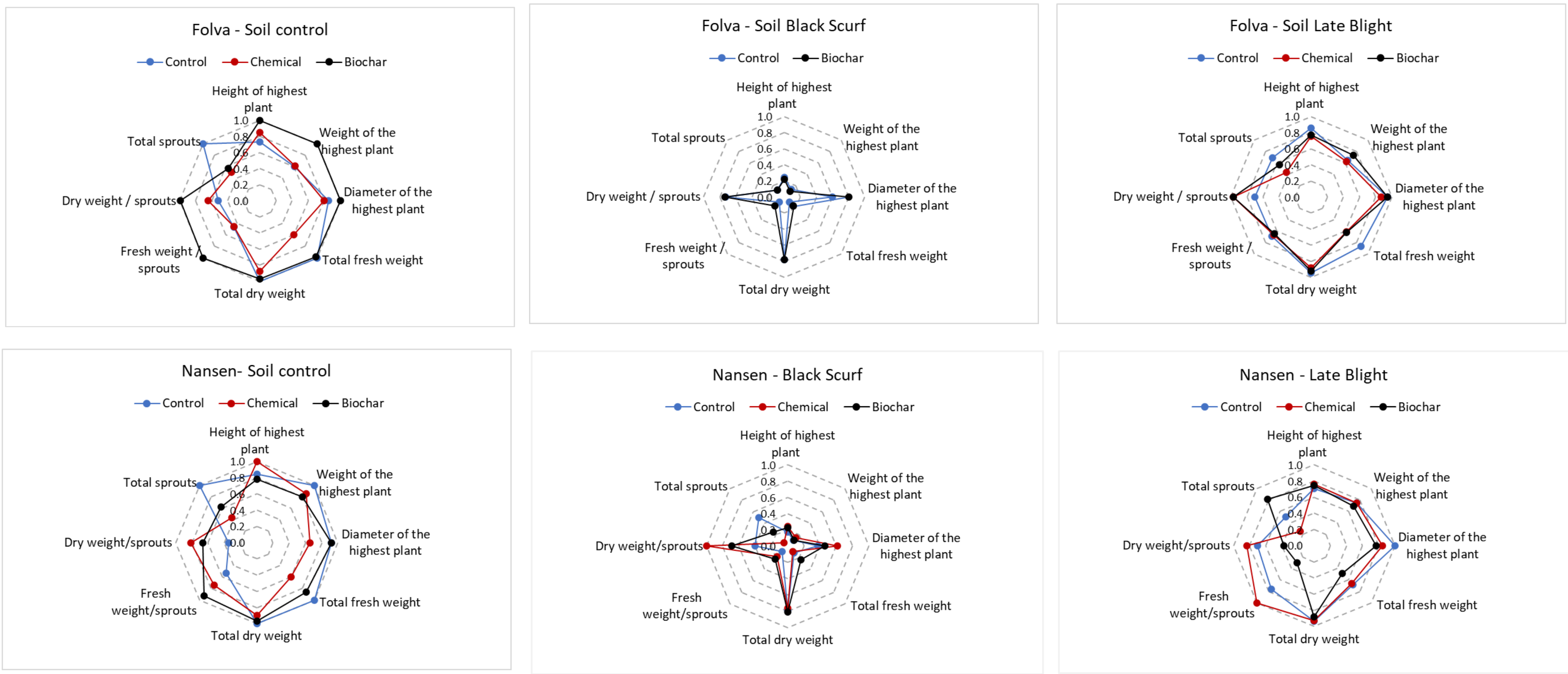


Figure 6. Characteristics of sprouts from Folva and Nansen seed potatoes recorded after five weeks of germination and growth in three different soil types: non-infected soil \(Control), soil infected by black scurf (Black Scurf) and soil infected by late blight (Late Blight).

For both potato varieties, there was a clear and negative effect of chemical coating on the **total sprout fresh and dry weight** in non-infested soil. The potatoes grown in soil infested with black scurf were in the beginning (2 weeks) located at a much lower temperature that the other treatments, and hence had much lower values of all recorded characteristics. This soil-borne disease could be especially relevant to mediate by coating, e.g., with biochar. For both varieties, the **total sprout fresh weight** in black scurf- infected soil was somewhat higher with biochar coating than with no coating or chemical coating. The height of the highest sprout was also recorded. However, since the light and temperature conditions were not optimal for potato growth, the sprouts were longer than desired from a grower's perspective (**Picture 10**). Too high temperature favoured sprout elongation.

6.1 Partial Conclusions

- There were no significant differences between potatoes settled in the non-infested and late blight-infested soils.
- Sprouts from the Folva potatoes coated with biochar showed a better development than those chemically coated or uncoated.

7 General discussion

Through this one-year project we learned a lot about the potential to use wood biochar as a coating for potatoes and carrots and its potential for suppressing diseases during potato and carrot storage. Our first challenge was to find a biochar particle size that easily adheres to the surface of the potatoes and carrots, which is also easily removed. For that we fractionated biochar in different particle sizes, and we found that only biochar particle sizes smaller than 700 µm were suitable for coating (**WP1**).

Biochar surface area increases tremendously when the particle size is reduced. It was estimated that when 1 cm^3 biochar particle size with a total surface area of 6 cm^2 is crushed to the size of 625 µm, it results in 4 096 small particle sizes with a total surface are of 96 cm^2 (http://biochar.info/?p=en.biochar_preparation). StandardBio biochar, made from pine wood, is a mix with different particle sizes (**Figure 1**). It has an average specific surface area of 400 cm^2 /g . By using the fraction smaller than 700 µm, we estimate that the total surface area increased from 400 cm^2/g to about 6 400 cm^2 /g. Smaller particles are better distributed over the surfaces of potatoes and carrots, where they may work as a habitat for bacteria and fungi. Here, we observed that biochar coating could reduce water loss from potatoes stored in a plastic box over 1 month. We did not have resources to test this in large scale. Biochar coating also reduced water loss form washed carrots, but not from unwashed roots. If the reduced water loss of about 15% less respiration (**WP1**) is relevant for practical storage conditions of potatoes, economic gains could be significant. This needs further testing.

For the carrots (**WP2**), we observed that biochar coating had effects similar to soil when it came to suppressing carrot diseases during storage. After storing carrots under stressed conditions, the number of edible carrots coated with biochar (85%) was comparable to the un-washed carrots (92%), and significantly superior to the washed carrots (20%).

For potatoes (**WP3**), we observed that biochar coating significantly reduced storage diseases, especially Silver Scurf (7%) and blemishing (5%). The overall effect of biochar coating on suppressing potato storage diseases was a 12% increase in Quality class 1 (saleable) potatoes at the end of the storage season, which represents a significant gain in income for potato growers.

Several different mechanisms have been proposed to explain biochar disease suppression in soil, among them the direct fungitoxic effect of biochar and the sorption of allelopathic, phytotoxic compounds that can harm plant parts and thus increase pathogen attacks (Jaiswal et al., 2018). These two mechanisms of disease suppression may also have played a role during storage time of carrots and potatoes. Furthermore, due to its high porosity, biochar used as a vegetable coating could also regulate moisture around potatoes and carrots, thus decreasing the chances of disease proliferation. Biochar has a high pH, which may also affect the biology of emerging pathogens. Silver scurf in the potatoes develops if there is high humidity in the air especially in the beginning of the storage period and if the potatoes are not ventilated well enough. While in the carrots, we did not observe an additive effect when biochar was applied on un-washed carrots, the soil around the carrots may had prevented biochar to interact with the carrots' surface, masking its potential coating effect.

We also performed a small trial to test the effect of biochar in reducing soilborne disease (black scurf and late blight) severity in potatoes. However, the results here are not conclusive. The infection with black scurf was severe and only few potatoes germinated independently of the variety. For Folva variety, the potato sprouts in the biochar coating treatment showed a better development than those chemically coated or uncoated. For the Nansen variety the potato sprouts in the treatment with chemical coat showed an overall better development. Several studies have pointed out a positive effect of biochar soil amendment on soilborne diseases (Bonanomi et al., 2015). The fact that we did not see a clear pattern with biochar coating suggests that interaction between biochar and time may be important and it may play a role in the soilborne disease suppression.

Although we observed positive effects of biochar coating on the weight loss and disease suppression during storage, the use of biochar as a coating during storage at an industrial scale implies many challenges. Small particles must be applied, which will increase dust levels, impacting environmental quality and human health. Furthermore, biochar is an inflammable material, and the chance of combustion increases with decreasing particle size. During this project we discussed alternatives to reduce such problems. One alternative is to use biochar bags instead of coating. This alternative would significantly decrease the amount of dust. However, it would have consequences for the air flow inside of the potato boxes during storage as the air would be trapped in the biochar bags, reducing its speed with direct consequences to the temperature and moisture in the storage room.

8 Conclusions

In conclusion, we demonstrated that the use of very fine biochar coating could reduce weight loss of potatoes and carrots during storage and suppress or delay the disease development in storage. Biochar coating did not have a significant effect to suppress the development of potato soilborne diseases. Our study was quite preliminary, so this result is not conclusive.

The use of biochar coating for storage of vegetable in industrial scale implies many challenges which need to be addressed to ensure safety for employees and the environment surrounding the plants.

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Appendix A

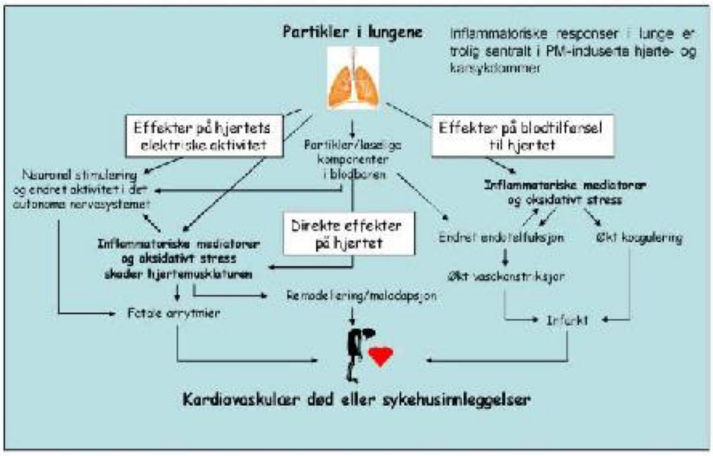
Levande kunnskap - Levande landbruk

Landbruk Nordvest SA

Polysykliske Aromatiske Hydrokarboner (PAH)

Det finnes flere hundre Pah forbindelser. Ta utgangspunkt i de kreftfremkallende, ofte Benzo a pyren (Bap). Mest i korn og sjømat. Grilla og røkt mat.

Grenseverdi i matvarer 20pha mikrogram per kilo.



Appendix B

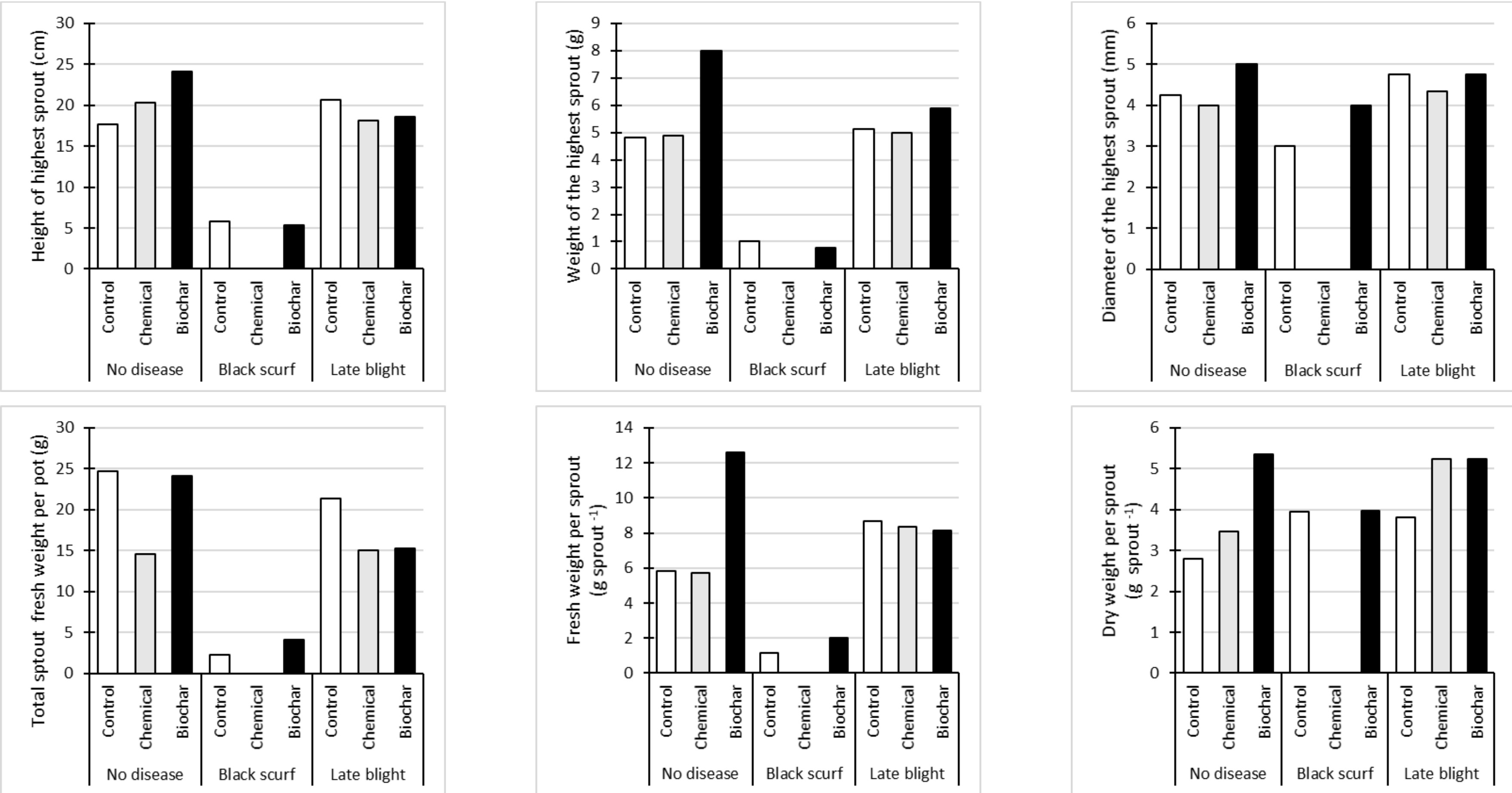
Risikoanalyse arbeidsoppgaver/arbeidsmiljø

Landbruk Nordvest SA

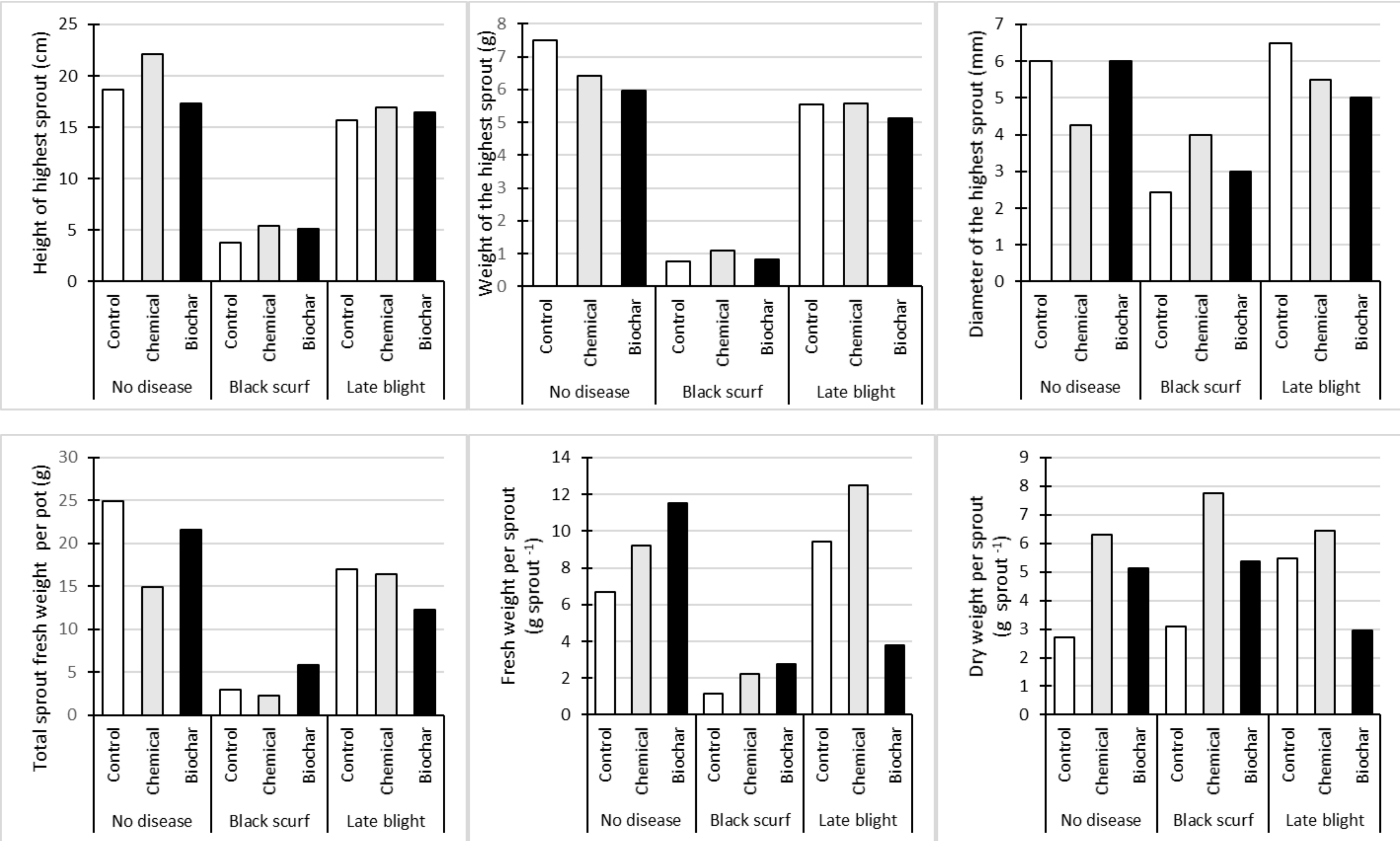
Arbeidsoppgave: Påføring av biokol før lagring av potet og gulrot. Fjerning av biokol etter lagring, før pakking og distribuering til markedet.
Vurdert av: Annbjørn Husby og Kari Fløystad, HMS-rådgivere.

KSL-standard 2, dok 2.2					
(A) Forekilder/identifisert risiko	(B) Sannsynlighet for skade (1-5)	(C) Konsekvens av skade, Hva kan skje? (1-5)	Viktighet/prioritet (B x C)	Hva kan gjøres for å redusere konsekvensene? Forebyggende tiltak	Redusert risiko (1-5)
Polysykliske Aromatiske Hydrokarboner PAH-støv i arbeidsmiljøet - Hud - Øyne - Luftveier (kreft-risiko) - Indre organer (hjerte) - Genetisk (luftveier → DNA) - Eksplosjonsfare!!! Det finnes over 100 PAH-forbindelser. BAP mest kreftfremkallende. (Benzo a pyren)	Hud: 5 Øyne: 5 Luftveier: 5 Hjerte: 4 Genetisk: 5 Eksplosjon: 4	Hud: 2 Øyne: 2 Luftveier: 4 Hjerte: 4 Genetisk: 3 Eksplosjon: 4	Hud: 10 Øyne: 10 Luftveier: 20 Hjerte: 16 Genetisk: 15 Eksplosjon: 16	Helmaske åndedrettsvern Helmaske åndedrettsvern Tett halvmaske, minimum P3-filtrering Tett halvmaske, minimum P3-filtrering Tett halvmaske, minimum P3-filtrering Sanering. Brannsikker dress, maske, hanske NB! Støvmåling i lokalet bør utføres. Størrelse på partikler spiller mye inn mtp hvor langt forbi bronkiene og ut i alveolene støvet kommer. Alveolene → Overgang til blodet	2 = Ok 2 = Ok 4 = Ok 4 = Ok 3 = Ok 8 = Uheldig
Risiko luftveier: -Potensiell utvikling av kreft i eksponerte celler. Risiko hjerte: (via lungene) - arytmi, infarkt, forstyrret blodtilførsel, koagulering				-Anbefaling skotrekk og heldekkende dress -Skifte av antrekk før overgang til ren sone -Opplæring, info og instrukser til personale -Ofte skifte av P3-filter -Personbårne støvmålere -Ventilasjon/avtrekk → Evt påvirkning ytre miljø: Nærliggende menneskelig aktivitet v/avtrekkspunktet -Rengjøring av lokale og maskiner -NB! Skjegg påvirker maskefunksjon Risikovurdering gjort av fagfolk type verne-ingeniør anbefales. Ansatte fulgt opp med jevnlig helsekontroller.	

Appendix C



Growth characteristics of sprouts from Folva potato germination parameters evaluated after five weeks of incubation in three different soil types: non contaminated soils (no disease), Black scurf contaminated soil (Black Scurf); Late blight contaminated soil (Late Blight).



Growth characteristics of sprouts from Nansen potato evaluated five weeks after planting in three different soil types: non-infested soil (no disease), Black scurf infested soil (Black Scurf); Late blight infested soil (Late Blight).

Norsk senter for økologisk landbruk, NORSØK er ei privat, sjølvstendig stifting.
Stiftinga er eit nasjonalt senter for tverrfagleg forsking og kunnskapsformidling for å utvikle økologisk landbruk. NORSØK skal bidra med kunnskap for eit meir berekraftig landbruk og samfunn. Fagområda er økologisk landbruk og matproduksjon, miljø og fornybar energi.

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