Norwegian University
of Life Sciences

Master's Thesis 2022 30 ECTS
Faculty of Biosciences

Prevalence of tip rot and carrot supply chain actors' awareness about the disease in Norway

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Acknowledgements

This thesis sums up my five years of studies in Plant Sciences at the University of Life Sciences (NMBU) here at Ås.

This thesis was part of the project RootCause – Understanding the causal agent(s) of tip rot to reduce carrot loss and waste within the supply chain. First and foremost, want to thank my supervisors Belachew Asalf, Anna Birgitte Milford and Arne Stensvand for the opportunity to become a part of this project and for guidance and discussions through the writing process.

I want to give special thanks to Vinh Hong Le and Rezan Amen for introduction and guidance on the techniques on isolation and identification of fungi. I also want to thank NLR Trøndelag and Tonje Aspeslåen for welcoming me and guiding me through the post-harvest assessments.

Finally, I want to thank friends and family for supporting me throughout my studies and who have made the past five years memorable.

Sammendrag

Gulrot er den viktigste frilandsgrønnsaken dyrket i Norge, og er lagret på kjølelager i opp til 8 måneder for å sikre jevn tilførsel til markedet gjennom vintermånedene og frem til neste sesong. Den lange lagringsperioden skaper derimot problemer knyttet il lagringssykdommer, som igjen reduserer produktkvaliteten og fører til lagersvinn. Gulrøtter påvirkes av flere ulike sykdommer i felt og på lager. Kunnskap om forekomst av lagersykdommer kan bidra til sikrere valg av passende tiltak for å redusere svinn knytet til sykdommer. I løpet av det siste tiåret har tuppråte blitt et økende problem i norsk gulrotproduksjon. Gulrotprodusenter har førstehånds erfaring med tuppråte, og kan koble sykdomsforekomst opp mot spesifikk landbrukspraksis, forhold i felt, klimatiske forhold eller opp mot andre faktorer. Produsenters kunnskap er verdifull i prosessen mot å identifisere forårsakende faktorer knyttet til tuppråte og hvilke faktorer som påvirker sykdommen. Denne oppgaven undersøker utbredelse av tuppråteproblemet i Norge, og kunnskap om produsenters bevissthet om sykdommen, mulige forårsakende faktorer, og faktorer knyttet til klimatiske og agronomiske forhold. Evaluering av sykdomsforekomst ble gjennomført i samarbeid med Norsk Landbruksrådgivning (NLR) på slutten av lagringssesongen i fylkene Innlandet, Rogaland, Trøndelag og Viken. Gulrotprøver ble samlet inn fra seks kommersielle lagre og ti faste lagre. Guløttene ble sortert og kategorisert i sykdomskategorier. Representative prøver ble send til verifisering og identifisering hos Norsk Institutt for Bioøkonomi (NIBIO). Produsenters kunnskap knyttet til tuppråte ble undersøkt ved gjennom kvalitative og kvantitative metoder som fokusgruppeintervju og spørreundersøkelse. Representative gulrotprodusenter ble valgt til å dele deres kunnskap og erfaringer knyttet til tuppråte gjennom diskusjoner i fokusgruppintervju. Verdifull informasjon om deres oppfatning av hovedårsaker til tuppråte og mulige tiltak mot sykdommen kom frem. Denne kunnskapen ble senere brukt til å utforme en spørreundersøkelse til innsamling av kvantitative data knyttet til vekstforhold og dyrkningspraksis blant gulrotprodusenter. Resultatene fra sykdomsevalueringene viste at gjennomsnittlig svinn på lager var 58%. Tuppråte ga størst svinn (29%) etterfulgt *Botrytis cinerea*, *Pythium* spp., og *Mycocentrospora acerina*. Variasjon i sykdomstilfelle mellom regioner viser til at faktorer som jordforhold, landbrukspraksis og lagringsforhold påvirker forekomst av tuppråte. Gulrotprodusenter delte verdifull kunnskap om tuppråte, inklusive mulige forårsakende faktorer samt mulige tiltak mot sykdommen. Denne kunnskapen kan bidra til å utvikle effektive strategier mot tuppråte.

Abstract

Carrot is one of the most important vegetable crops in Norway and is stored in cold storage for up to 8 months providing year-round supply to the market. The lengthy storage period is however causing problems linked to post-harvest diseases, reducing produce quality and causing storage losses. Carrots are affected by several diseases in the field and in storage. Knowledge about the incidence of post-harvest diseases may contribute to applying appropriate measures to reduce losses linked to diseases. During the past decade, tip rot has become an increasing problem in Norwegian carrot production. Carrot producers have first-hand experience with tip rot and may link the disease to certain agronomic practices, field condition, climactic events or to other factors. Their knowledge is valuable in the process of identifying the causal agent(s) of tip rot and which factors are influencing the disease. This thesis investigates the prevalence of the tip rot problem in Norway, and knowledge on producers' awareness about the disease, possible causal agents, and factors related to climatic and agronomic conditions. Post-harvest assessments were conducted in collaboration with the Norwegian Agricultural Extension Service (NLR) at the end of the carrot storage period in four major carrot producing regions. Carrots were sampled from six commercial storages and ten fixed storages and were sorted and categorized into disease categories and healthy carrots. Representative samples were sent to Norwegian Institute for Bioeconomic Research (NIBIO) for verification and identification of diseases. Information about the extent of the tip rot problem and the link to agronomic practices was investigated through qualitative and quantitative methods such as focus group interviews and questionnaires. Representative carrot farmers were selected to share their knowledge and experience on tip rot. Through open ended discussions, they shared their information on their perception on the main causes of tip rot and their knowledge about possible preventive measures against the disease. This information was later used to develop a questionnaire for a quantitative survey amongst all Norwegian carrot producers. Common agricultural practices were collected in a standard form. Post-harvest assessments revealed a mean storage waste of 58% loss. The major pathogens identified were tip rot, contributing to 29% storage loss, followed by *Botrytis cinerea*, *Pythium* spp., and *Mycocentrospora acerina*. Variation in incidence among regions suggest that factors such as soil conditions, implemented agronomic practices, and storage conditions influence the incidence of tip rot. Carrot chain actors have shared valuable knowledge on tip rot, including possible causal agents and measures against the disease. This knowledge may contribute to the development of effective management strategies against tip rot. Pre- and post-harvest causal factors of carrot disease should be considered in measured implemented against tip rot.

Table of contents

1. Introduction

1.1 The carrot plant

The domesticated carrot (*Daucus carota.* L. spp. *sativus*) is a biennial herbaceous species in the botanical family Apiaceae (Balvoll, 1999). The carrot plant produces a rosette of leaves and develops an enlarged taproot for nutrient storage in the first year of its life cycle and develops flowers and seeds in the following growing season (Davis & Raid, 2002). Cultivated carrots are harvested as a vegetative crop in the first year, before floral initiation (Simon, 2021). The plant organ of agricultural importance is the enlarged tap root (storage root) which consists of a core (xylem) surrounded by a thick layer of phloem (Fig. 1.1) (Rubatzky et al., 1999).

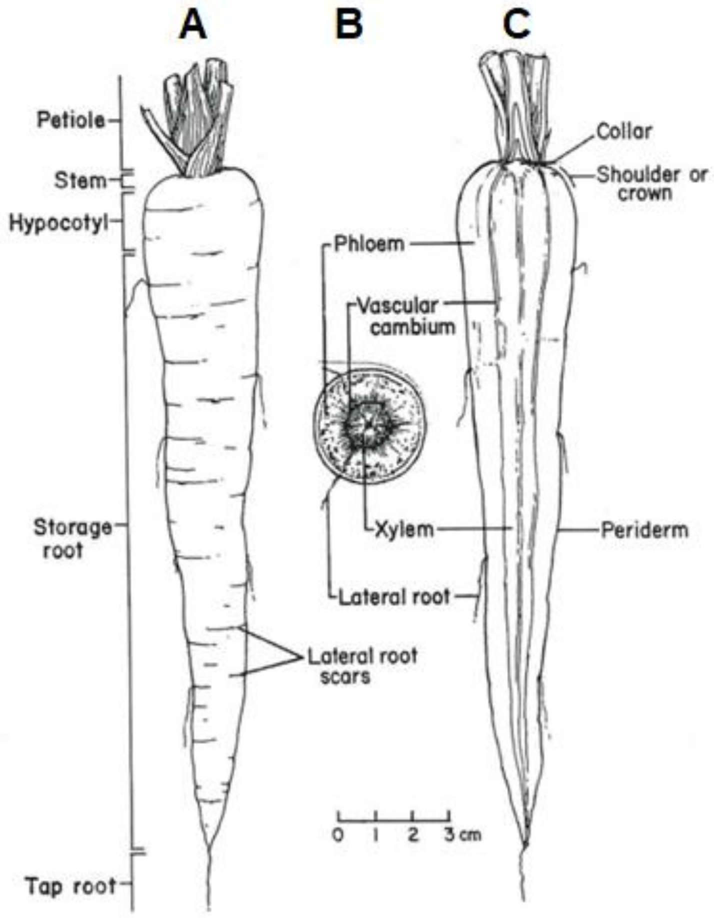

Fig. 1*: Carrot root anatomy: (A) external, (B) cross section, and (C) radial section. Illustration: Rubatzky et al. (1999).*

Beyond being of economic value for growers, carrots have significant impact on human health (Simon, 2021). The roots are nutritious with a high content of carotenoids, vitamins, phenolic compounds and polyacetylenes (Kartika et al., 2021; Rubatzky et al., 1999). Experimental evidence has reported several health benefits including anticarcinogenic, antioxidative and immunoenhancing effects (Silva Dias, 2014). These health benefits help make carrots a major vegetable crop cultivated around the world (Simon, 2021).

1.2 Carrot production in Norway

Carrots have been cultivated in the Nordic countries since the 1600s (Balvoll, 1999). Today, it is the main open field vegetables in Norway considering both production and diet, with a market value of approximately 465 million NOK (Hjukse, 2020) and an annual production of 53,017 tons (Statitics Norway, 2020). Norwegian production covers 85.9% of the national market demand (Opplysningskontoret for Frukt og Bær, 2020).

Carrots are grown over large parts of Norway, although the natural resources restrict large scale production in the least favourable areas (Franke et al., 2017). The main production regions are concentrated in the regions Innlandet, Rogaland, Trøndelag, and Viken (Balvoll, 1999), occurring within various rainfall regions (low to high precipitation) and over a range of soil types, (sand, loam, and silt) (Bond, 2016). Carrots are typically grown on fertile and friable soils, preferably consisting of a variation of silt, sand, and well drained peat soil (Balvoll, 1999; Simon, 2021). Root growth is promoted by a deep topsoil layer provided by deep tillage (20 - 25cm) and well-drained soil, improved by establishing ridges or raised beds in areas with heavy topsoil (Balvoll, 1999).

In Norway, carrots are grown from early spring until October and are then placed in long-term storage throughout the winter months, providing a continuous supply to the market. Harvesting is carried out when the storage root has reached a desired size (Simon, 2021). Mechanical harvesting is common, but may cause damage to the roots, reducing storability and promoting infections of disease-causing microorganisms (Balvoll, 1999; Wills & Golding, 2016). After harvest, the carrots are stored in wooden boxes lined with perforated plastic holding 400-800 kg (Heltoft & Thomsen, 2020). During the transition from field to cold storage, storage boxes are often placed in low light or in a cold room to reduce the temperature of the produce, thereby preventing deterioration and reduced storability due to high temperatures (Balvoll, 1999; Wills & Golding, 2016). The boxes are later stacked and placed in cold storages for long term storage. Carrots have good storability and can, when stored correctly, be stored for up to 8 months (Asalf et al., 2018).

Several types of industrial storages are used for carrots throughout Norway. The most common principles for air distribution used are (1) Findus, (2) Græe, (3) traditional air circulation with an evaporator placed in the middle of the ceiling, and (4) traditional air circulation storage with an evaporator placed on the rear end of the storage (Indergård et al., 2019). The air circulation storages are found to be most suited for carrots (Thomsen et al., 2020). Not all storages are however capable of mechanical air distribution. In cold-storages with air circulation, each storage box is supplied with a continuous stream of cold air, removing heat from the produce (Hoftun, 1980; Indergård et al., 2019). Correct stacking of the storage boxes is important to provide even air flow throughout the storage. Sufficient control of temperature, relative humidity (RH) and air flow is crucial to ensure good quality and storability of the produce (Thomsen et al., 2020; Wills & Golding, 2016). The carrots may be stored at 0 to 1˚C and RH close to 95% (Asalf et al., 2018; Balvoll, 1999). Throughout the storage period, carrots are collected from storage and are washed, polished, and packaged before being distributed to warehouses and stores.

1.3 Storage losses in Norwegian carrot production

Carrot production and quality are influenced by abiotic and biotic factors throughout the entire production chain, from sowing to consumption (Seljåsen et al., 2013). Quality at harvest is important for the storability as the carrot quality is determined by preharvest factors, while conditions during storage only contribute to maintaining the quality (Schmidt, 2018; Suojala, 2000). However, the Norwegian storage period is relatively long, raising problems linked to post-harvest diseases resulting in large amounts of storage losses (Asalf et al., 2018; Nærstad, 2015). During the past decade, tip rot has become a major problem in Norwegian carrot production, contributing to significant levels of rejections of carrots during sorting and packaging (Asalf et al., 2021; Nærstad, 2015). The disease is found throughout carrot producing regions of Norway.

In Norwegian production, carrot losses range from 10 to 40%, accounting for one of the largest losses of produce and lost income sources in Norwegian agriculture (Franke et al., 2013; Indergård et al., 2019). Producers can experience only 40 to 50% of their stored carrots maintaining marketability the year after harvest (Nærstad, 2015). Moreover, farmers have reported sowing up to 30 to 50% more carrot seeds than the contracted supply demand in order to compensate for possible produce losses linked to factors such as poor growing conditions in a season as well as high out-grading (Bond, 2016). There is a clear potential to increase the amount of marketable crop. In order to minimize storage losses of carrots and the economic losses in the carrot supply chain, knowledge about post-harvest epidemiology and prediction of the incidence of storage diseases based on field and storage conditions is important (Asalf et al., 2018).

1.4 Post-harvest diseases of carrots

The ability to infect the plant host varies between fungal pathogens. Fungal infection is accomplished by entering the host plant through natural openings or wounds, or by direct penetration of healthy tissue (Davis & Raid, 2002). Latent infections may occur when symptoms develop some time after infection. Fungi survive as spores and survival structures on plant residues or in soil, but may also survive on surfaces (i.e., on storage boxes or in packaging facilities). The main source of contamination comes from soil (Korsten & Wehner, 2003). Crop rotation is hence an important measure limiting the disease pressure of soil-borne pathogens. Rotations of 4 to 5 years is recommended for crops within the Apiaceae family, including carrots (Holz, n.d.). Carrots are affected by several fungal diseases in the field and in storage. The main storage pathogen in Norwegian carrot production is liquorice rot (*Mycocentrospora acerina*) (Hermansen et al., 2012). Other pathogens causing significant damage are grey mould (*Botrytis cinerea*), carter rot (*Fibularhizoctonia carotae*), and cottony rot (*Sclerotinia sclerotiorum*) (Hermansen, 2008). Knowledge about the biology of the causal agents of diseases and how to identify them is crucial for implementing measures against them (Schumann & D'Arcy, 2010). Some of the important carrot diseases found in stored carrots in Norway are presented below.

*1.4.1 Liquorice rot (*Mycocentrospora acerina*)*

Liquorice rot is the main post-harvest pathogen on carrots in Norway, causing losses of up to 30 to 50% during storage (Hermansen, 2008). The disease is caused by the necrotrophic pathogen *Mycocentrospora acerina* (Davis & Raid, 2002). The fungus has a range of host plants, including weeds (*Viola arvensis*) and vegetables (like carrots, lettuce, and celery) (Hermansen, 1992). It survives in soil as resting spores (chlamydospores) for up to 8 years (Hermansen, 2008). Sufficient weed control and crop rotation are important measures against the disease (Hermansen et al., 1997). Infections commonly occur on wounded or weak plant tissue and the fungus may develop in temperatures down to -3˚C (Hermansen, 2008). Symptoms are described as juicy and porous rot where newly infected tissue appears brown and becomes black when the fungus produces chlamydospores (Fig. 2) (Hermansen et al., 2012). Symptoms may appear anywhere on the root although typically on the root tip, and are commonly seen after 2 to 3 months of storage (Hermansen, 2008).

Fig. 2: *Symptoms of* Mycocentrospora acerina *in carrots. (**A**) Internal rot growing deep into the root core. (Photo: E. Fløystad, NIBIO) (**B**) Internal and external rot. (Photo: A. Hermansen, NIBIO). Available at: https://plantevernleksikonet.no/l/oppslag/1270/.*

*1.4.2 Cylindrocarpon root rot (*Cylindrocarpon *spp.)*

Soil-borne fungi within the genus *Cylindrocarpon* cause root rot in several plant species, including conifers, ginseng and carrot (Seifert et al., 2003). *Cylindrocarpon destructans* has previously been reported in carrots with root rot (Creelman, 1958). The fungus produces chlamydospores (resting spores), contributing to a long survival period of the pathogen in absence of its plant host (Booth, 1966; Taylor, 1964). Injured roots are infected by germinated chlamydospores present in soil, either in field or after harvest if soil is remaining on the roots during storage (Korsten & Wehner, 2003). Literature regarding symptoms on carrots is limited, but have been reported by Nærstad (2015) as firm rot with dark brown discoloration in the root tip. In a more recent study, Mohamad (2021) described symptoms identified in carrots inoculated with *Cylindrocarpon* spp. and stored at different temperatures. The symptoms appeared as brown to dark brown rot in the inoculation point. Dry and brown lesions initiating from the carrot tip grow deep into the core and surrounding tissue. Moreover, the rot had a darker discoloration at higher storage temperatures and after longer durations of storage. Cylindrocarpon root rot is an increasing problem in Norwegian carrot production (personal communication with B. Asalf, NIBIO).

*1.4.3 Crater rot (*Fibularhizoctonia carotae*)*

Crater rot is a typical post-harvest disease found in all carrot producing regions of Norway (Hermansen, 2008). The disease is caused by the fungal pathogen *Fibularhizoctonia carotae*, and occurs on carrots that have been in cold storage for several months (Davis & Raid, 2002; Hermansen, 2008). *F. carotae* has several vegetable hosts, including potato and carrots (Serikstad et al., 2014). The fungus survives as mycelium or as sclerotia (resting structures) in soil for many years, but may also survive on wooden storage boxes (Hermansen, 2008; Serikstad et al., 2014). Infections occur via soil or plant debris and may spread between carrots during storage. *F. carotae* can develop at temperatures as low as -3˚C (Hermansen, 2008). Common symptoms on carrots are seen throughput the root as dry, sunken lesions covered by a yellow-white mycelium and small white hyphal knots (Fig. 3) (Hermansen, 1993; Jensen, 1969). Favourable conditions for the fungus are high humidity and moist conditions during cold storage (Jensen, 1969). Under these conditions, *F. carotae* will develop and spread rapidly. Symptoms may develop from a firm rot to advanced decay seen as brown, soft rot and collapsed roots.

Fig. 3: *Symptoms of* Fibularhizoctonia carotae *in carrot. (Photo: L. Fagertun, NIBIO). Available at:* *https://www.plantevernleksikonet.no/l/oppslag/481/*.

*1.4.4 Grey mould (*Botrytis cinerea*)*

Grey mould is caused by the necrotrophic pathogen *Botrytis cinerea*, which attacks a large variety of crops (Williamson et al., 2007), including carrots. The fungus survives for several years as sclerotia (survival structures) in soil or on plant residues, or as mycelia on plant debris (Hermansen, 2008). Furthermore, it may survive on surfaces (i.e., in storage or at the packaging facilities) (Davis & Raid, 2002). Humid and warm conditions are optimal for fungal growth, and spores are spread through air in field and in storage. However, the fungus may also develop at temperatures down to 0˚C (Hermansen, 2008). *B. cinerea* is primarily problematic in stored carrots, commonly infecting weakened tissue and affecting any part of the carrot root (Hermansen, 1993). Initial symptoms of grey mould are water-soaked, light grey to brown lesions with uneven transitions to healthy tissue (Fig. 5). White mycelia with sclerotia are often present on the surface of the diseased tissue. Further sporulation covering the lesions in grey conidia does rarely occur during cold storage (Davis & Raid, 2002).

Fig. 4: *Symptoms of* Botrytis cinerea *on carrot. (Photo: E. Fløistad, NIBIO).*

*1.4.5 Black root rot (*Chalaropsis basicola *(Syn.* Chalara elegans*)*

Black root rot in carrot is caused by the pathogen *Chalaropsis basicola* (Davis & Raid, 2002). *C. basicola* is found in a range of plant hosts, including carrots, and was previously reported to cause severe losses in washed and packaged carrots when stored at elevated temperatures (Årsvoll, 1971). The pathogen survives as chlamydospores (survival structure) in soil and infections primarily occur after harvest on injured or weakened carrot tissue (Davis & Raid, 2002). Development of the fungi requires humid conditions and high temperatures (Hermansen, 1993). Measures against the disease include minimizing wounding during handling of the produce, regular cleaning and disinfection of the washing facility, and keeping the stored produce at cool temperatures (Davis & Raid, 2002; Hermansen, 1993). Symptoms are seen as grey to black discoloration in the surface tissue (Davis & Raid, 2002).

*1.4.6 Cavity spot (*Pythium *spp.)*

Cavity spot is an important disease of carrots grown in temperate zones (Hermansen et al., 2007). The disease is caused by several species within the Oomycete genus *Pythium* (Davis & Raid, 2002). In Norwegian production, the five species *P. intermedium*, *P. sulcatum*, *P. sylvatricum* and *P. vipa* have been isolated from symptomatic carrots (Hermansen et al., 2007). The species has several plant hosts and survive as oospores (resting spores) in soil, although some species survive on plant residues (Hermansen, 2008). Cavity spot rarely causes yield reductions but has significant economic impact that compromise the marketable value of the produce (Davis & Raid, 2002). Symptoms are evident at harvest but may develop further during storage. Although it is not considered a storage disease, secondary pathogens commonly infect the lesions during storage further deteriorating the produce (Davis & Raid, 2002; Hermansen et al., 2007). Typical symptoms are sunken cavities which initiate from small round spots (1 – 2 mm) that increase in size (up to 1cm) around the root (Fig. 5). Cavity spot is often seen as open wounds on the root surface as the uppermost part of the tissue cracks open exposing the cavity (Hermansen, 1993, 2008).

***Fig. 5:** Symptoms of* Pythium *spp. on carrots. (Photo: M. Halvorsrud).*

*1.4.7 Dry rot (*Fusarium *spp.)*

Dry rot in carrot is caused by various species within the genus *Fusarium*, including *F. acuminatum*, *F. avenaceum* and *F. solani* (Davis & Raid, 2002; Zhang et al., 2014). *Fusarium* spp. mainly affect injured carrots (Kora et al., 2005) or occur as secondary infections to other pathogens (Davis & Raid, 2002). Symptoms are dry and darkened lesions developing anywhere on the carrot root (Fig. 6) in field and in storage, although the disease is mainly a problem in stored carrots. Measures against the diseases include careful handling and avoiding humid conditions and elevated temperatures during storage (Davis & Raid, 2002).

Fig. 6: *Symptoms of* Fusarium *spp. in carrots: (A) Symptoms on the carrot base. (Photo: B. Asalf, NIBIO). (B) Cross section of carrot base with* Fusarium *spp. symptoms. (Photo: B. Asalf, NIBIO). Available at: https://plantevernleksikonet.no/l/oppslag/1880/.*

*1.4.8 Cottony rot (*Sclerotinia sclerotiorum*)*

Cottony rot is caused by the soil-borne fungus *Sclerotinia sclerotiorum* (Davis & Raid, 2002) and is found in all carrot producing regions in Norway (Årsvoll, 1971). *S. sclerotiorum* has a wide host range including potatoes, legumes, celery, and carrots (Alford, 2008; Hermansen, 2008). The fungus persists in soil or on plant debris as resting structures (sclerotia) for several years (Alford, 2008). Carrots are commonly infected by mycelia sprouted from the sclerotia, but air-borne ascospores may also infect carrot tissue in field (Hermansen, 2008). Infections often initiate from the leaves, later infecting the carrot root and developing characteristic white mycelia with light to dark sclerotia (Fig. 7) (Hermansen, 1993). Problems linked to cottony rot are often related to injured carrots, insufficient cooling of produce after harvest, and poor storage conditions (Hermansen, 2008).

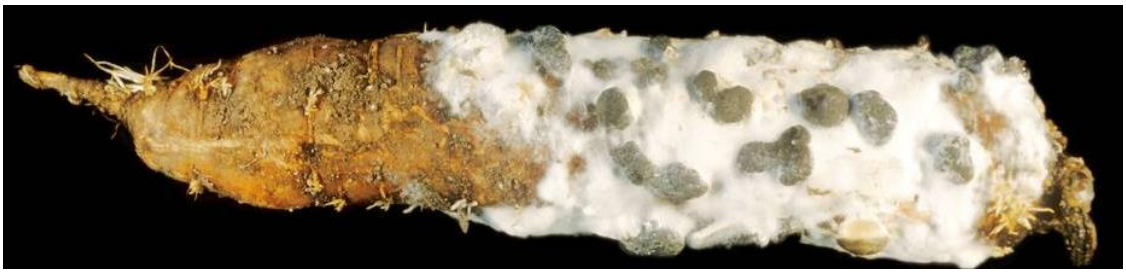

Fig. 7: *Symptoms of* Sclerotinia sclerotiorum *on carrot. (Photo: A. Hermansen). Available at: https://plantevernleksikonet.no/l/oppslag/473/.*

*1.4.9 Black spot (*Rhexocercosporidium carotae *(syn.* Acrothecium carotae*)*

Rhexocercosporidium carotae causes black spots in cold stored carrots (Kastelein et al., 2007). *R. carotae* was first described by Åsavoll in 1965, and has since been reported in several European countries (Wikström et al., 2011). The disease was previously considered important in Norwegian carrot production (Hermansen, 1993). Wikström et al. (2011) have found evidence that incidences of *R. carotae* can be linked to harvest conditions, surface damage of carrot roots, and presence of other umbelliferous plants.

*1.4.10 Ring rot (*Phytophthora *spp.)*

Ring rot in carrot is caused by the soil borne Oomycete of the species *Phytophthora* (Hermansen, 1993). *Phytophthora* spp. cause minor damage in carrot production, although they may cause significant problems upon waterlogging in the field (Davis & Raid, 2002). Symptoms of ring rot consist of one or more spots of dark discoloration merging and forming a ring-like lesion around the carrot root (Fig. 8) (Hermansen, 2008).

Fig. 8: *Symptoms of* Phytophthora *spp. on carrots. (Photo: A. Hermansen, NIBIO). Available at: https://plantevernleksikonet.no/l/oppslag/1290/.*

1.3.1 Tip rot of carrot

Tip rot is a disease complex caused by several biotic agents, including fungi, and with possible interaction with other microorganisms and physiology of the carrot root (Mohamad, 2021). The main candidate pathogens found are *Mycocentrospora acerina*, *Cylindrocarpon* spp., *Dictyolstelium* spp., and *Fusarium* spp. (Mohamad, 2021; Nærstad, 2015). Additionally, fungi like *Alternatia* spp., *Botrytis cinerea*, *Mucor* spp., *Phoma* spp., *Rhizoctonia* spp., and *Rhizopus* spp. may interact with the disease development as well. The disease can be detected at harvest but is commonly identified after storage. Symptoms are described as decay initiating from the very end of the taproot progressing upwards and into the storage root. The rot is typically dark but can be lighter at the initial stages of the disease development (Asalf et al., 2021). The development of the disease is affected by factors such as temperature, secondary invaders, and by the root physiology linked to long term storage (Mohamad, 2021).

Tip rot has been known among Norwegian carrot producers for many years. Producers' knowledge and experience are essential in the process of finding solutions on how to manage the disease. Nærstad (2015) reported speculations and discussions on possible causal factors for tip rot. Farmers have experienced patterns of increased problems with carrot production in sandy soils, and some claim that earlier cultivars are more susceptible. Moreover, there are claims that drought during the growing season may result in increased susceptibility, although other farmers have experienced incidences in humid years as well.

1.5 Utilizing carrot producers' knowledge and experience

Carrot producers have first-hand experience with tip rot occurring in their production. Their knowledge is valuable in the process of identifying the causal agent(s) of tip rot and which factors are influencing the disease. Information about the extent of the tip rot problem and the link to agronomic practices can be investigated through qualitative and quantitative methods such as focus group interviews and questionnaires. The qualitative data obtained from focus group interviews are an important part of this thesis.

A focus group interview is a well-known qualitative research method used to obtain broad and in-depth information about a topic (Kvale & Brinkmann, 2015). A focus group commonly consists of a small group of people guided by a moderator (Chrzanowska, 2002). The moderator is responsible for facilitating the verbal exchange in the group through an open-ended discussion on a focusing topic. The interviewing is done in a non-steering manner with the goal of bringing forth different views about the topic. The respondents discuss anything in relevance to the introducing topic, on which the moderator ask more probing and open-ended questions, providing both information and understanding to the topic (Chrzanowska, 2002; Kvale & Brinkmann, 2015). An advantage of such interviews are the group discussions where an exchange of different opinions and a discussion around various claims and experiences takes place. Statements of one participant can trigger new thoughts and ideas with the other participants, enhancing the in-depth understanding on the topic. This would not be as easily achievable through a one-to-one interview between the moderator and one participant alone. In this way, focus group interviews contribute to obtaining more background information about tip rot. Although this qualitative method is commonly used in social research and not in natural sciences, it can be of great value for finding answers related to the tip rot problem by identifying trends and patterns in the carrot producer's perception of the disease.

Producers' knowledge on the disease and information about their agronomic practices can provide a basis for new hypotheses on why tip rot occurs and what can be done to reduce the incidence of the disease. Focus group interviews can help in survey development by generating response categories and identifying which questions should be asked and the response options which should be included in the survey. A questionnaire provides the possibility to gather responses from a high number of people in a systematic way.

1.6 Objectives and hypothesis

The main objective of this thesis was to determine the prevalence of the tip rot problem in Norwegian carrot production, and to gain knowledge on producers' awareness about the disease, causal agents, and factors related to agronomic and climatic conditions.

The specific objectives of this thesis were:

- To determine the extent and incidence of tip rot and other storage diseases in selected carrot producing regions in Norway.
- To gain in-depth understanding of the tip rot problem in Norway from purposely selected carrot producers (focus group informants).
- To better understand and gain detailed insights on the impact of agricultural practices on tip rot development through quantitative survey questions.

2. Materials and methods

2.1 Incidence of tip rot and other storage diseases

2.1.1 Area of study

A survey was conducted to determine the common post-harvest diseases of carrot in key carrot producing regions in Norway. The study was conducted in 16 storages within the regions Innlandet, Rogaland, Trøndelag and Viken in 2019 to 2021. Post-harvest assessments were conducted in collaboration with the Norwegian Agricultural Extension Services (Norsk Landbruksrådgiving, NLR) and the Norwegian Institute of Bioeconomic Research (NIBIO). The assessments were conducted at the end of the storage period. I was involved in two of the assessments in Trøndelag in March and April of 2021.

2.1.2 Sampling from cold stores and sorting of diseases

Sampling of carrots from random fields and storages: The extension agents made prearrangements with growers that had problems with tip rot. At the end of each storage season, the extension agents went to the storages and assessed the incidence of tip rot and other storage diseases. Random samples of carrots were collected from six storages. The samplings were conducted during March to May of each year, after long-term storage of 5-7 months. At each cold storage, four storage boxes were randomly chosen. The upper 20 cm of the carrots were moved to the side and a total of 100 carrots were randomly taken out from each of the four boxes and put in labelled bags for each box.

***Fig. 9**: Procedure of post-harvest assessment for determining occurrence of diseases in carrots sampled from cold storage (**A**) washing of carrots before weighing and sorting. (Photo: T. Aspeslåen). (**B**) sorting and categorizing carrot samples into healthy carrots and different disease categories. (Photo: M. Halvorsrud). (**C**) carrot tips were cut in half to determine the incidence and severity of tip rot symptoms. (Photo: M. Halvorsrud).*

From each bag, the 100 carrots were washed, weighed, and registered in a registration form (Fig. 9.A). The carrots were sorted and categorized into healthy carrots, carrots with tip rot symptoms, and carrots infected with other diseases such as grey mould, liquorice rot, cavity spot, fusarium dry rot, crater rot, cottony rot, black rot, and an "other diseases" category (Fig. 9.B). Disease identification was conducted using the identification guide provided in advance and experienced extension agents. The number of carrots in each category were counted, registered into a form, and symptoms photographed. To determine the presence and severity of tip rot, the tips of the taproots were cut in half (Fig. 9.C). These carrots were then sorted into type 1 (light brown), type 2 (brown) and type 3 (dark) rot based on the appearance of the symptoms (Fig. 10). These were again registered into the form and photographed. To investigate the difficulty in identifying the presence of tip rot, incidence of tip rot was registered both before and after cutting the carrot tips in half. Representative samples of the infected carrots from each disease category were picked out and sent to NIBIO at Ås for verification and further identification of diseases that were not identified or sorted as "other diseases". Additionally, background information about the agronomic practices and storage conditions that growers followed were gathered in a form.

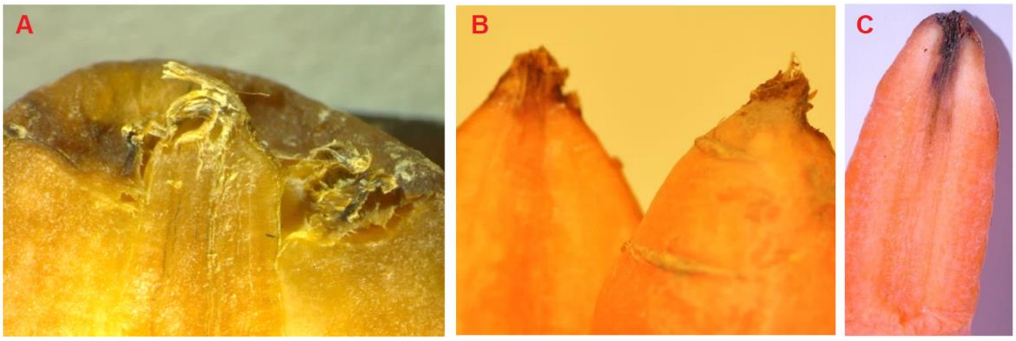

***Fig. 10**: Pictures provided as a guideline for categorizing the tip rot types 1-3 during sorting; (A) Light brown, (B) Brown, and (C) Dark tip rot. Photo: B. Asalf.*

Sampling of carrots from fixed fields and storages: In addition to the random samples, carrot samples from four fixed fields were used for incidence investigation. In each region, carrots fields that had problems with tip rot were selected and samples were taken at mid-growth stage, at harvesting and after storage. The fixed fields were also used to sample soil for the analysis of plant parasitic nematodes. Carrot samples were taken out at five points from each field following an M-pattern (Fig. 11). The fields were minimum 1 hectare in size. For each field, a total of 1,000 carrots (200 from each sampling point) were harvested in September/October and put into mesh bags (two from each sampling point) holding 100 carrots each and marked corresponding to the five sampling positions (M1.1, M1.2, M2.1, M2.2, M3.1. M3.2, M4.1, M4.2, M5.1 and M5.2). Each mesh bag with 100 carrots was weighed and placed inside the producer's carrot storages at a depth of about 30 cm from the top of the box. One bag per box was put in the middle of the box and cold stored for 4-5 months. After storage, the bags were removed from the boxes and weighed. The carrots were then washed and sorted into healthy carrots and the disease categories described above (following the disease identification guide provided to the extension agents).

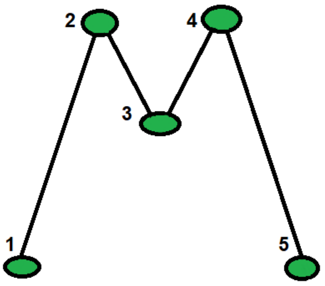

Fig. 11*: Carrot sampling following a M-pattern in the field, with positions M1 to M5.*

2.1.3 Verification and identification of diseases

Morphological identification of the fungal pathogens from the carrot samples were conducted at NIBIO in Ås. I was involved in verification and identification of the samples from Trøndelag for the 2021 season. Upon analysis for each disease category, the carrots were sorted and marked from least to most severe symptoms and photographed. Morphological identification was conducted using visual observation and with the help of stereo and compound microscopes looking for symptoms and signs of the pathogens on the carrot root tissue. In cases where further verification methods were needed, the infected tissue was moist incubated and isolated on appropriate fungal growth media to identify typical structures of the pathogen.

Carrots were prepared for moist incubation and isolation by surface sterilization using the following the procedure: (1) Carrot tissue containing the pathogen, preferably the root tip, was cut. (2) For surface sterilization, the tissue was submerged in 70% ethanol for 10 seconds followed by submersion in a 0.5% sodium hypochlorite (NaOCl) solution for 90 seconds. Then, (3) the samples were thoroughly rinsed under distilled water.

The surface sterilized tissue was then placed in a laminar flow bench equipped with a cutting board, a knife, scalpels, and tweezers. Both the laminar flow bench and the equipment was sterilized prior to the procedure. Using a knife, the carrot tip was carefully split into two without touching the tissue of interest. Carrot tissue from the border between healthy and infected tissue was cut out from one of the parts. The tissue of each carrot sample was then plated out onto two 9cm Petri dishes containing Potato Dextrose Agar (PDA) and Potato Carrot Agar (PGA), respectively. The agar plates were sealed and incubated at room temperature. The rest of the surface sterilized carrot tissue was placed in sealed plastic trays lined with sterile filter paper which was wetted with distilled water. The plastic trays were put in room temperature for wet incubation. The diseases and pathogens were identified and verified both from the wet incubated carrot tissues and from the isolation.

The samples were checked regularly for identification of typical structures of the pathogen. The results were registered in a form.

2.1.4 Data analysis

Prevalence data of tip rot, carrot diseases, and healthy carrots were sorted and analysed using Microsoft Excel and MINITAB.19. The number of carrots from each assessment was assumed to be 100, and the incidence data was treated as a proportion of the total carrot sample. Carrots in each category of tip rot severity (light brown, dark brown, and black rot) were treated as a proportion of total tip rot incidence. Mean values and standard error (SE) of the means were found for years and regions, and for region within years. Normality tests were conducted to determine whether the data was fit for analysis of variance (ANOVA). The data was subjected to mixed effects ANOVA to investigate the interaction between the fixed effects region and year on the incidence of tip rot before cutting, tip rot after cutting (total amount of tip rot), of light brown, dark brown, and black tip rot, healthy carrots, and of major carrot diseases. Data from random fields and fixed fields were treated in combined means for the regions within years as no statistical differences were found between the treatments. Mean separations and grouping were conducted using Tukey pairwise comparison tests with 95% confidence interval (P-value = 0.05). Due to various reasons, some of the incidence data could not be provided (data from Trøndelag 2019 and Innlandet 2021). It was not possible to conduct the statistical analyses for years and regions combined (year and storage interaction) due to the missing data. Therefore, years and regions were treated separately for ANOVA and Tukey tests. Bar graphs were made in Excel, using SE of means adjusted for the upper and lower confidence limits of a normal distribution (95%).

2.2 Focus group interviews

To obtain qualitative data on the root cause of the problem in Norway, focus group interviews were carried out in 2019 in collaboration with NLR. A group of carrot producers were gathered for each of the four carrot producing regions, Innlandet, Rogaland, Trøndelag, and Viken. The number of participants, excluding the moderator(s) were: three from Innlandet, four from Rogaland, five from Trøndelag, and three from Viken. The selection of participants was made by the NLR advisors, who also conducted the focus group interviews. The selection was made to get farmers with some years of experience with carrot cultivation, and representing different types of cultivation (farm sizes, soil type etc.). Throughout the interview, the participants shared and exchanged their attitudes towards and experiences with tip rot occurring in their fields.

The interviews followed an interview guide developed in collaboration between researchers at NIBIO and the advisors at NLR (Appendix 1) comprising questions such as producers' experiences linked to tip rot, and how and when the disease was discovered. The growers were also questioned about their theories on causes of the disease and on their opinion about different hypotheses on possible causes of biotic nature (such as fungal pathogens, bacteria, nematodes, or cultivar susceptibility) and of abiotic nature (lack of mineral nutrients, drainage, drought stress, or soil type). Lastly, the growers were asked about suggestions for possible means to reduce the incidence of tip rot.

The recorded interviews were transcribed and anonymized by an external transcriber. For this thesis, I have used the transcribed interviews to categorize the data into generalized answers from the interviews following the questions provided in the interview guide. Although the data from these interviews are qualitative, in order to present the results in a clear manner, I have chosen to present the data through tables including the generalized and categorized answers from the interviews, further elaborating the data through text and quotations from the growers included in the interviews.

2.3 Survey

Based on the information provided by the focus group interviews, a questionnaire was developed to identify the relationship between various production factors and incidence of tip rot. The final questionnaire comprised of 28 questions to gather information about field conditions and agricultural practices for one field with and one field without known incidences of tip rot disease. The questions dealt with factors such as soil type, production type, tillage, seedbed, sowing and harvesting, cultivar, crop rotation, irrigation, and storage. The questionnaire was developed by NIBIO in collaboration with the agricultural extension workers of NLR. I was involved in the last revisions, creating the design of the questionnaire, and in further discussions concerning the scope of the questions included in the survey.

The quality of the initial survey, comprising 31 questions, was tested with one producer to get feedback on how manageable it was to fill out. In December of 2020, the questionnaire was sent out to Norwegian carrot producers through NLR. Feedback from the producers stated that the questionnaire was too long and time consuming to fill out. The survey was later cut down to 28 questions, and some of the answer alternatives were revised to ease the response process. The revised questionnaire was then sent to the carrot producers once more.

Tip rot is often first discovered after the storage period, instead being discovered at carrot packaging plants during washing, polishing, and packing of the carrots. The packaging plants had the task of obtaining information about the incidence of tip rot as the diseased carrots were discovered throughout the storage and distribution period. This information was then to be communicated to the producers. This was crucial information for the farmers to fill out the questionnaire for fields with known incidences of tip rot. Fields without tip rot were chosen based on tip rot not being reported to have been found by the farmer or at the packaging facilities up until 1st of February the year after harvest.

The questionnaire data was originally to be used in statistical analyses comparing data from fields with and without tip rot, hopefully providing valuable information about possible causes of the disease and possible measures to be implemented against the disease. Due to several factors however, too few questionnaires were filled out and sent back for analysis. In this thesis I have therefore not further analysed the questionnaire data. The data is instead treated and presented as qualitative information. The survey results were sorted and categorized using Microsoft Excel. A code book was created for plotting and categorizing the data. Tables and graphs were created for presenting the data.

3. Results

3.1 Prevalence of tip rot and other storage diseases in Norway

3.1.1 Storage losses of carrots

The percentage of healthy carrots (free of disease) varied significantly among years (P=0.002) and regions (P=0.008) (Fig. 12). Rogaland and Trøndelag had the lowest percentage of healthy carrots throughout all assessment years, ranging from 21-38% and 24-47%, respectively (Fig. 12). Total storage losses can be determined. All regions experienced less than 70% healthy carrots corresponding overall storage losses higher than 30%. Moreover, pooled data from all years and regions reveal an estimated percentage of carrot storage loss of 58% contributed to diseases.

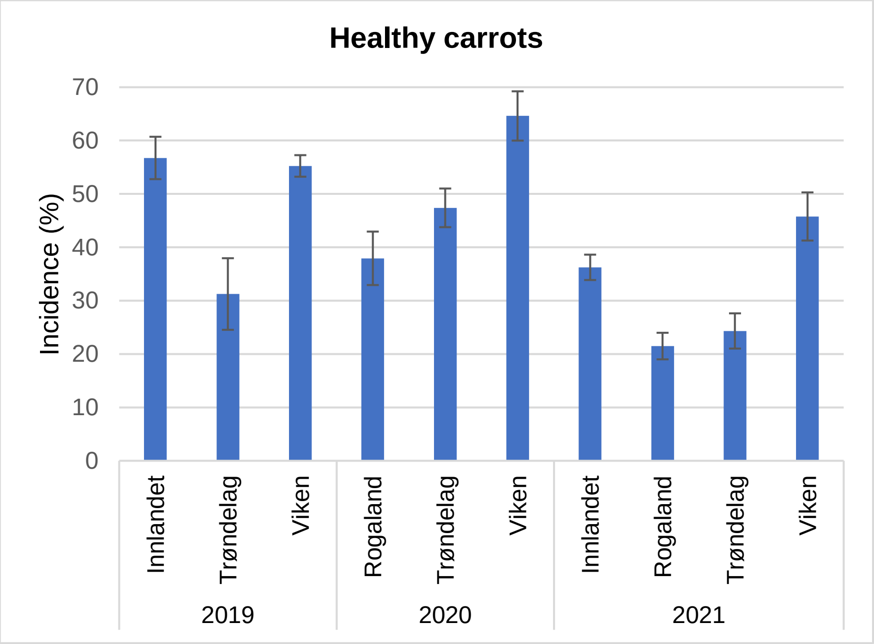

Fig. 12*: Mean percentage of healthy carrots (disease free) for regions Innlandet, Rogaland, Trøndelag, and Viken registered at post-harvest assessments during the seasons 2019, 2020, and 2021.*

3.1.1 Incidence of tip rot

Data from post-harvest assessments conducted in the regions Innlandet, Rogaland, Trøndelag, and Viken throughout the seasons 2019 to 2021 revealed significant differences in tip rot incidence among regions ($P < 0.001$), ranging from 12-48%. Means and statistical differences are presented separately for the years 2019 to 2021 (Table 1).

***Table 1**: Mean values for tip rot data from post-harvest assessments conducted in 2019 to 2021 in the regions Innlandet, Rogaland, Trøndelag, and Viken. Incidence of tip rot before cut and tip rot after cut (total amount of tip rot) are presented as a proportion of the total carrot sample (%). Incidence of tip rot within the severity categories are presented as proportion of total amount of tip rot (%). Significant differences in incidence data between regions are marked with P-values from mixed effects ANOVA (α = 0.05). Statistical differences are marked within each column + year. Means that do not share a letter are statistically different (α = 0.05).*

Region	**Tip rot before cut (%)**	**Tip rot after cut (%)**	**Tip rot symptom severity (%)**		
		Total tip rot.	**Light brown**	**Brown**	**Dark**
2019					
Innlandet	41.75 ab	40.75 a	68.87 a	24.28	6.85 b
Trøndelag	44.75 a	46.25 a	54.89 a	36.01	9.1 ab
Viken	19.75 b	12.5 b	12.55 b	51.2	36.2 a
P-value	*0.029*	*0.002*	*0.002*	*0.138*	*0.034*
2020					
Rogaland	18.22 b	20.06 b	22.78 a	50.02 b	27.52 b
Trøndelag	85.4 a	48.1 a	16.99 a	80.55 a	24.64 c
Viken	18.75 b	11.86 b	3.07 b	12.06 c	84.87 a
P-value	*< 0.001*	*< 0.001*	*< 0.001*	*< 0.001*	*< 0.001*
2021					
Innlandet	41.25 a	42.5 a	54.75 a	34.79 b	10.46 b
Rogaland	18.9 b	35.3 a	6.11 b	59.97 a	33.92 b
Trøndelag	46.5 a	40.42 a	8.84 b	61.69 a	29.47 b
Viken	14 b	14.33 b	5.89 b	34.11 b	60 a
P-value	*< 0.001*	*< 0.001*	*< 0.001*	*0.002*	*< 0.001*

Mean comparisons between regions revealed a higher tip rot incidence in Trøndelag and Innlandet when compared to Rogaland and Viken (P < 0.001). There was a tendency towards differences in prevalence between years, but these differences were not significant (Fig. 13). Trøndelag and Innlandet consistently had the highest tip rot incidence, ranging from 40-48% and 41-43.5% respectively (Table 1). The lowest incidences were recorded from Viken throughout all assessment years (Fig. 13), ranging from 12-14% tip rot (Table 1). Pooled data for all years and regions reveal that tip rot can be estimated to cause a mean storage loss of 29% in Norwegian carrot production.

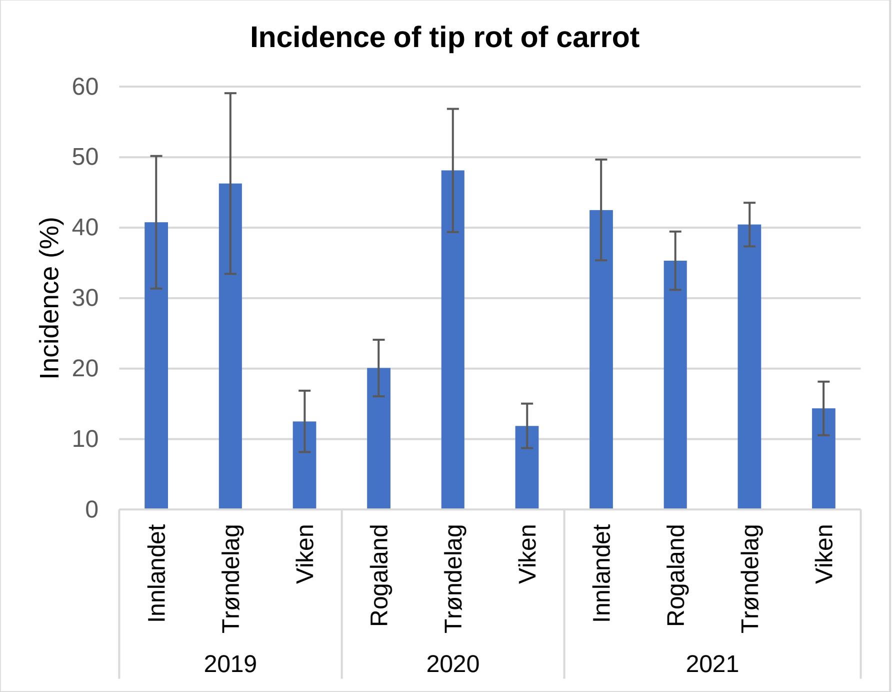

Fig. 13*: Mean incidence of tip rot for the regions Innlandet, Rogaland, Trøndelag, and Viken registered at post-harvest assessments during the seasons 2019, 2020, and 2021. Not all regions are represented for each year due to missing data.*

Tip rot incidence registered before and after cutting the tip root tip was assessed to determine the difficulty of identifying presence of the disease. The incidence was both over and underestimated before cut compared to the total amount of tip rot (after cut), although in most cases the differences were minor (Table 1).

The type of tip rot symptom (discoloration) ranged from light brown to brown and dark rot. Incidence of symptom types varied among the assessed regions and years (Fig. 14). The highest proportion of light brown tip rot symptoms were registered for Innlandet, with 55-69% light brown rot, followed by Trøndelag with up to 55% light brown rot (Table 1), although the proportion varied between years (Fig. 14). Trøndelag and Rogaland experienced the highest proportion of brown symptoms, ranging from 36-81%. Furthermore, the highest proportion of dark brown rot were reported from Viken throughout all assessment years, ranging from 36-85% dark rot (Table 1).

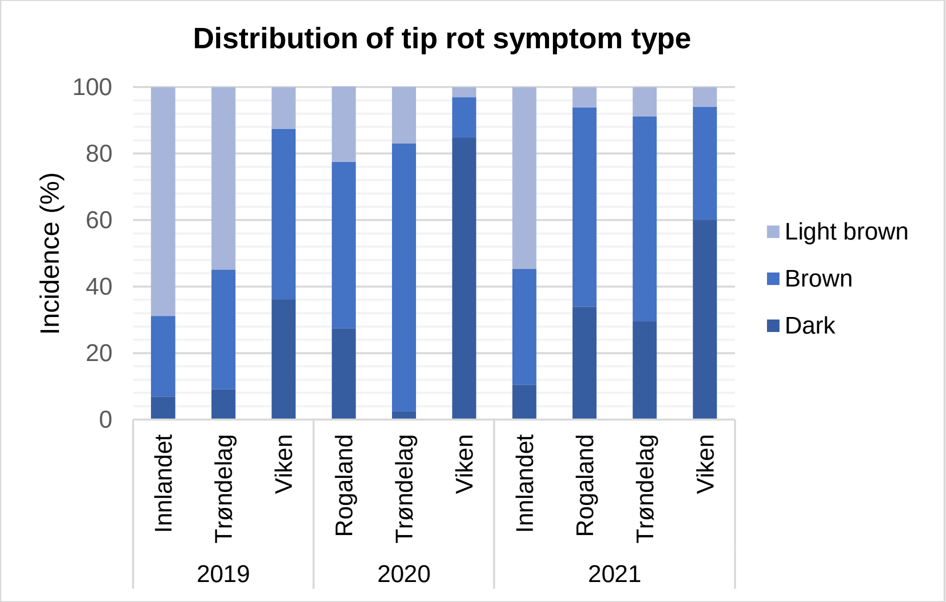

***Fig. 14**: Distribution of tip rot infected carrots sorted into the symptom (discoloration) categories light brown, brown, and dark rot. Values are mean incidences for the regions Innlandet, Rogaland, Trøndelag, and Viken within the assessment years 2019 to 2021.*

3.1.2 Incidence of post-harvest diseases

One or more than one pathogen was identified on a symptomatic carrot after 5-7 months of cold storage. In total, more than 15 pathogens were identified throughout post-harvest assessments in 2020 and 2021. Distribution of the identified carrot diseases after storage is presented in Fig. 15. Data from 2019 post-harvest assessments are excluded as it was not distinguished between individual diseases other than tip rot during the registrations for that year.

The dominating diseases detected were tip rot, followed by grey mould (*B. cinerea*), cavity spot (*Pythium* spp.) and liquorice rot (*M. acerina*) (Fig. 15). Further pathogens found were carter rot (*F. carotae*), dry rot (*Fusarium* sp.), ring rot (*Phytophthora* spp.), cottony rot (*S. sclerotiorum*) and black spot (*A. carotae*). The category “other diseases” includes pathogens such as black root rot (*Chalaropsis thielavioides*), Cylindrocarpon root rot (*Cylindrocarpon* spp.), sour rot (*Geocandidum* spp.), black scurf (*Rhizoctonia solani*), violet root rot (*Rhizoctonia crocorum*), and common scab (*Streptomyces* spp.). It should be noted that *Cylindrocarpon* was widely identified among the carrots.

The percentage of each pathogen varied significantly among regions and years. Grey mould was found in all regions accounting for up to 50.2% decay, with the highest incidences registered in Rogaland followed by Viken. Cavity spot was registered for most regions. The highest incidences of cavity spot were registered for Trøndelag (29.9%) and Viken (19.8%) in 2021. Liquorice rot was found in all regions, accounting for up to 12.6% decay. Other carrot diseases were less abundant throughout regions and years (Fig. 15).

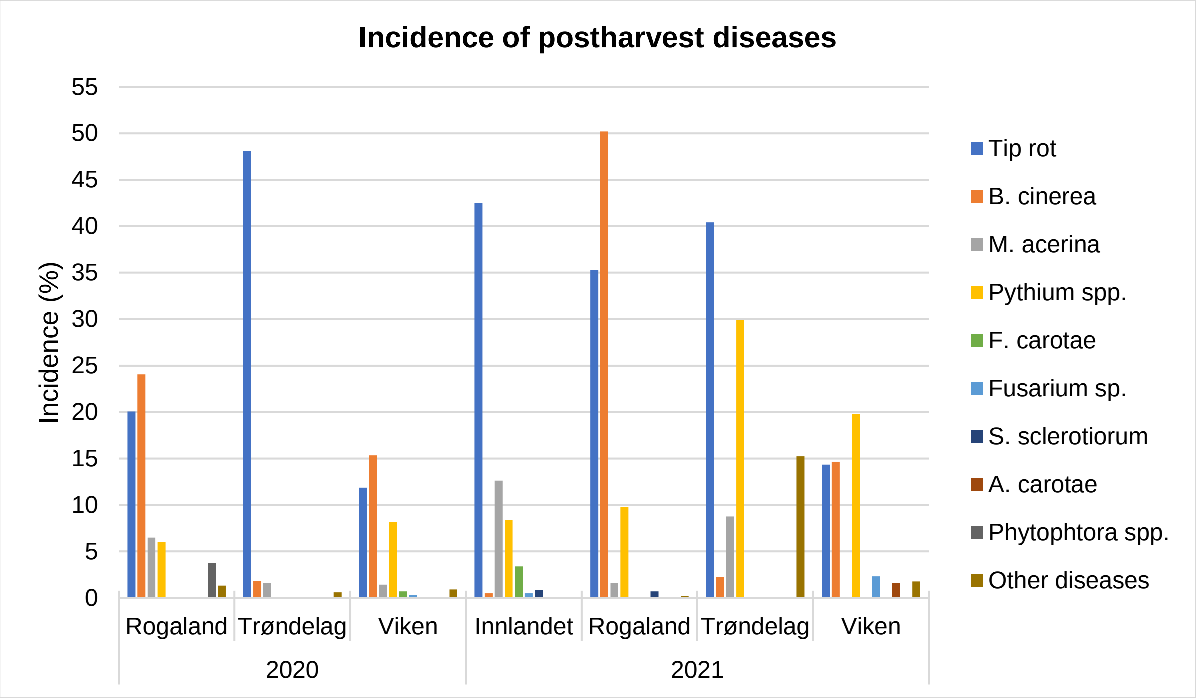

Fig. 15*: Prevalence of post-harvest diseases found in carrot at post-harvest assessments conducted after 5-7 months of cold storage in the seasons 2020 and 2021. The values are presented as mean proportion of affected carrots of carrot samples for each region Innlandet, Rogaland, Trøndelag and Viken.*

3.2 Focus group interviews

Focus group interviews provided valuable insight in carrot producers' experience with tip rot, their thoughts on hypothesized causal factors of the disease, and possible measures against it. To provide a clear overview, the results are categorized and presented as generalized answers in Table 2 and 3, following the questions from the interview guide. Results within each topic are further elaborated and presented with quotations from the producers' thoughts and experiences shared throughout the interviews.

Table 2*: Results from the focus group interviews addressing carrot producers experience on tip rot, and their knowledge and thoughts about possible causes for and measures against the disease. The data is presented as generalized answers from the producers included in the questionnaire.*

Question	Answer(s)
Experience with tip rot	
How many of you have had problems linked to tip rot?	All farmers were familiar with tip rot.
When during the season was the tip rot discovered?	During the storage period, commonly between late December to January. In some cases, later.
How and where was it discovered? (In field, storage, at packaging or in store).	During storage, on top of and throughout storage boxes. During washing, polishing, and packaging. After packaging, in store.
Were you sure it was tip rot?	Early stages of infection are difficult to distinguish from other, similar diseases. Uncertain which symptoms to look for.
Causes of tip rot	
What are possible causes for tip rot?	Difficult to answer. Possibly something from field. Latent infections were mentioned.
Hypotheses on the causes of tip rot:	*See Table 2.*
Measures against tip rot	
Suggested measures against tip rot?	Optimize conditions for growth and development of carrot in field. Optimize storage conditions.
Could UV radiation reduce development of tip rot?	Not sure.
Could better packaging and lower storage temperatures in stores reduce the risk of tip rot development?	Split answers. One farmer believes it is too late but could slow down development.

3.2.1. Carrot producers' experience with tip rot

Carrot producers participating in the focus group interviews were familiar with tip rot and had varied experience with the disease. They recognized the symptoms in the provided reference photos, although there were some disagreements linked to the definition of tip rot and which symptoms to link to the disease, as the phenomenon had likely existed before the term "tip rot" was introduced. Most identified tip rot as rot initiating from the very tip of the root, gradually expanding into the storage root developing from light towards dark rot. One farmer distinguished between two types of tip rot: (1) rot initiating from the root tip growing inwards the root, developing over time, (2) observed as root tip turning brown starting to rotten within 3 to 5 days after washing.

The producers were asked about the extent of tip rot in their productions, which was revealed to vary among farms and, at the farm level, between years and crop rotations. Some farmers had experienced close to complete yield losses, while others were not familiar with tip rot occurring in their production or were unsure whether their losses could be linked to the disease. The importance of the packaging facilities providing feedback about disease incidences was mentioned.

Tip rot infections could first be detected during storage, rarely before late December, and the incidences increased and became more severe at later stages of the storage period. The disease could be discovered in storage boxes, during or after washing, polishing, and packaging or even in store. Difficulties linked to determining whether early symptoms could be linked to tip rot were discussed. Several producers expressed difficulties with linking symptoms to tip rot and how these symptoms could be distinguished from other, similar diseases. Often, they were unable to link infections to tip rot before the damage was too severe. Moreover, several farmers expressed that initiating symptoms were in some cases impossible to detect. One of the producers stated, *"It can be difficult to detect the disease during the process of packaging. There are cases where it is not discovered until later, when the carrots are in the plastic packaging"*. Several of the producers had experienced carrot batches which looked healthy right up until the carrots were washed and packaged, and for these batches to develop symptoms quite rapidly during further storage.

3.2.2. Causal agents and factors linked to tip rot

When addressing possible causal agents of tip rot, several of the focus groups drew attention to latent infections, and that the disease was caused by something present in the field. Hypotheses linked to causal factors of the disease were discussed. Most farmers pointed to factors causing stress and restricting carrot growth throughout the growing season, in turn causing reduced storability and increased susceptibility to diseases. Factors such as drought stress, nutrient imbalance and stress linked to inappropriate applications of chemical weed control during the growing season were stressed. Several producers thought it was difficult to link the carrot to specific production practices or conditions. One farmer explained that they had believed one theory for a long time, until the opposite was proven: *"For a long time we thought that saturated areas of a field resulted in tip rot, until we started to see the exact opposite where tip rot occurred on carrot from dry field areas"*. An overview of farmers thoughts on possible causal factors of tip rot is provided in Table 3.

Several producers linked tip rot to fields with poor soil. They had experienced an increased amount of tip rot occurring from fields with infertile soil, nutritional imbalance and low pH causing uneven carrot growth throughout the season. Lack of mineral nutrients was considered a possible factor for tip rot, as it causes irregular growth and weakens the cell walls of the carrots. Some farmers emphasized that a superficial access to nutrients could result in poor storability as well.

Incidences were detected in carrots from both heavier and lighter soils. Some farmers hypothesized that tip rot problems were more likely to occur in lighter, sandier soils. One of the focus groups concluded that there were clear differences between soil types, as farmers had mostly experienced less tip rot on heavier soils. Poor drainage was not directly linked to tip rot, although it was emphasized that sufficient drainage and oxygen supply was beneficial for root growth. Drought was addressed as an important factor accelerating the development of fungal diseases during storage.

The producers were asked about the impact of herbicide treatments on tip rot. Uneven growth had been observed after frequent treatments stressing the carrot plants and stagnating their growth. This resulted in reduced storability and accelerated the tip rot incidence. In connection to weeds, tip rot was more frequent in fields with problems linked to the presence of the liquorice rot host *Viola arvensis*. This was observed by several farmers.

In connection to harvest, several farmers had experienced clear differences in tip rot between different temperatures and humidity. Warm and dry conditions were linked to drought stress. Dry soil during the pulling of carrots was found to injure the root tissue, providing gateways for infections by fungal and bacterial diseases. One grower called this "the sandpaper effect". The importance of a careful handling during harvest was stressed. One producer told, that *"A carrot harvested in dry weather and at high temperatures have a much poorer storability. Sufficient soil moisture prior to harvest is important for the carrot not to suffer from drought stress during and after harvest. This is an absolute advantage related to tip rot"*. Moreover, moist soil and cooler temperatures were found beneficial for carrot storability both avoiding stressing the produce during harvest and the moist soil covering the carrots providing a protective layer during storage.

Table 3*: Results from focus group interviews addressing Norwegian carrot producers' thoughts on different hypotheses on possible causal factors for occurrence of tip rot. The data is presented as generalized answers to whether the farmers believe the factors play a role in influencing tip rot incidence.*

Hypothesis	Farmer's opinion
Poor drainage	Split answer. Some thought that it was generally beneficial with good drainage, while others did not recognize a linkage between drainage and tip rot.
Drought	Yes, this is an important factor. Drought accelerates development of fungal diseases.

Conditions during harvest	Yes, warm weather stresses the carrots, reducing its shelf life. Dry soil at harvest results in higher damage to the root.
Harvesting method	Yes, careful handling reducing damage and stress is important.
Treatment after harvest (including storage and packaging material)	Yes, suitable storage conditions (temperature, RH, and air circulation) are important, as well as packaging material with the right degree of perforation.
Soil type	Split answer. Some hypothesize a lower incidence at heavier soil types, others are not known with differences between soil types.
Herbicide use	Yes, inappropriate applications (high doses or frequent applications) may inhibit carrot growth and stress the carrot plant, increasing susceptibility to disease.
Fungi	Yes, possibly.
Bacteria	Yes, possibly.
Nematodes	Unsure, but possibly.
Lack of minerals	Yes, possibly. Nutritional imbalance results in uneven growth and weaker cell tissue, reducing shelf life and increasing susceptibility to diseases.
Cultivar	Yes, possibly. One focus group agreed on differences between cultivars. Tip rot registered on a range of cultivars, uncertain which are more affected.
Other factors	Sufficient crop rotations are important as latent infections may be introduced in the field. Developmental stage of the carrot.

Post-harvest treatment was emphasized as an important factor for preserving the carrot quality and slowing down the development of diseases. This included transition from field to cold storage and reducing the temperature of the produce, as well as the storage conditions (temperature, RH and air circulation). Several farmers stated that sufficient air flow in and out from the storage boxes was important, relating to the perforation of the storage box plastic lining. In another focus group, the role of soil covering of the roots during storage for protection and retaining moisture was emphasized. However, the soil layer could have a negative impact due to a slower and more energy demanding cooling of the produce, in addition to carrying possible disease candidates.

Upon discussing possible causal agents of tip rot, one of the focus groups discussed the possibility of several fungal pathogens affecting the carrot, and that the disease could be linked to latent infections and weakened plant tissue. Latent infections were emphasized by several focus groups. Bacterial pathogens were also considered a possible agent of tip rot. However, nematodes were not linked to tip rot as damage caused by nematodes is not expected to be concentrated on the root tip alone.

Apart from the hypotheses provided in the interview guide, crop rotation was brought forward as an important measure to reduce the disease pressure in field. Additionally, one farmer thought developmental stage of the root influenced the tip rot incidence, although this was not elaborated further.

3.2.3. Measures against tip rot

The focus groups were asked if they had propositions for measures that could help combat tip rot. One focus group stressed the need for facilitating overall good field conditions for growth and development of the carrot plants. This included choice of soil type, fertilization, soil acidity (pH) and crop protection. Common measures to ensure storage quality were discussed, including optimal conditions in the storage such as proper airflow through the storage boxes. Furthermore, diseased carrots should be sorted out at early stages of the decay as tip rot can develop rapidly, within a few days, from light brown rot to dark rot after washing and packaging causing loss or returns of carrot lots from storage.

When asked about the potential effect of treatment with UV-light at the packaging facilities, some farmers considered it to not have a sufficient impact on the tip rot incidence, although it was not mentioned whether the farmers had any experience with this kind of treatment.

Improved packaging material and lowered in-store temperatures were considered as potential measures to slow down tip rot development, although not preventing the decay altogether. One farmer had experienced an increased incidence of fungal decay linked to too dense packaging material hindering proper air flow in and out of the packaging.

3.3 Survey

The results from the survey are based on 14 replies comprising data from seven fields with tip rot and eleven fields without tip rot (Table 4). The dataset is too small for the intended regression analyses to determining relationships between field conditions or cultivation practices and the incidence of tip rot. Additionally, the data is not representative of the total Norwegian carrot production. However, valuable information can still be retrieved from the existing data, assisting in enhancing knowledge on the cause of tip rot and in the development of possible measures against the disease. The results in the following sections are grouped and presented qualitatively. Results are marked with number of respondents.

***Table 4**: Number of respondents based on county and field type (field with or without tip rot) as basis for the results from the questionnaire.*

County	Number of respondents	Respondents for fields with tip rot	Respondents for fields without tip rot
Innlandet	1	1	0
Rogaland	11	4	10
Trøndelag	2	2	1

3.3.1 Farmers experience with tip rot

Of the 14 respondents, seven had found tip rot on carrots grown in 2020, identified by the growers themselves (5), by storage employees (2), or by agricultural extension workers (1). The incidences were registered at different stages in the production, most often after Christmas during storage (3) and washing (6). One farmer answered that they identified tip rot at harvest and before Christmas during storage and washing. Furthermore, a respondent explained that most of their incidences were registered during washing and that the affected carrots were sorted out.

When asked to estimate the extent of affected carrots from the field with tip rot, the respondents answered approximately 5% (3) and 30% (1). One farmer answered that the overall incidence was low, but that it was difficult to identify tip rot at harvest. Another respondent commented that most of their carrot lot was not delivered to the packaging facility due to rot in the tip of the root. It was not specified whether the decay was linked to tip rot.

Several farmers had identified the first cases of tip rot in their overall carrot production relatively recently, dating between 2017 and 2021 (6). Other farmers were familiar with the disease in their production for a longer time, dating their first incidences back to over 13 years ago (2) and over 30 years ago (1). Two of the respondents commented that incidences “come and go” with some extended time periods between them. Most respondents completely agreed that the tip rot problem varied between years (Fig. 16) Few farmers had a strong opinion on the disease becoming an increasing problem in their production.

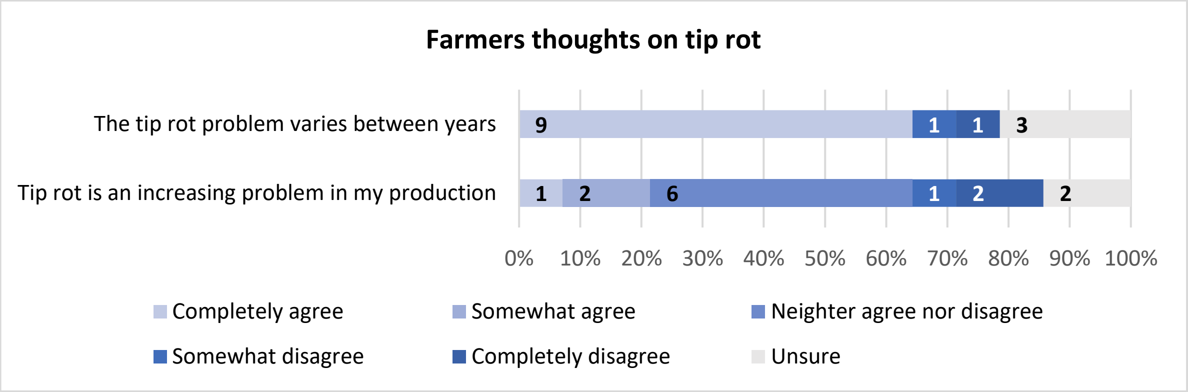

Fig. 16*: Carrot producers' opinion on statements about tip rot occurring in their production. The graph shows the numbers of answers within each category from completely agree to completely disagree and unsure.*

3.3.2 Production practice and field conditions

Few major differences could be found in production practices and field conditions between fields with tip rot and fields without tip rot based on the existing data. The extended results from this part of the questionnaire can be found in Appendix 2.

Carrots were grown in a variety of soil types: mineral mixed humus, silt, silty medium grained sand, and in fine sand. The fields without tip rot tended to have lighter soil types (7 out of 11) compared to fields with tip rot (1 out of 6). Conventional production dominated among the producers. Most tillage was carried out during spring and linked to seedbed preparations. The seedbed types commonly used were ridges and wide beds. A variety of cultivars were grown in fields both with and without tip rot. Most producers treated their seeds (seed coating). Sowing was carried out during May, apart from one farmer sowing on both field types during the first half of June. Most farmers did not water the fields after sowing, and left their soil uncovered.

The producers were asked about preliminary cultivation and the number of years since carrots were last grown on the field. Grass production dominated for fields without tip rot for both years prior to carrot cultivation. One farmer commented that they had grown celery in the field registered with tip rot an unknown number of years prior to cultivating carrot. All farmers had a crop rotation of at least five years, but there were no major differences in duration of the crop rotation between field types.

When asked about cases of stagnated growth in carrots during the growing season only one case was reported, for a field with tip rot. The farmer linked the incidence to problems with weed growth.

In early and mid-season, most fields had sufficient water supply, with some cases of limited supply. Near harvest, all fields without tip rot had sufficient water supply, whereas two of the fields with tip rot leaned towards excess water supply.

Harvesting was done mechanically in all fields and was carried out from mid-August until mid-October. Two farmers reported harvesting until late October in healthy fields. Temperatures during harvest were commonly between 8 to 15˚C, but one farmer reported temperatures down to 4˚C for both field types. No frost was reported at harvest. Most carrots were ripe at harvest, although carrots from some fields were harvested at young age. One farmer commented that some carrots from their healthy field were overripe due to uneven germination. None of the respondents reported broken carrot tips at harvest. Some carrot lots from fields with tip rot (3) and from healthy fields (6) were sorted after harvest, although the sorting was carried out for reasons other than tip rot. Most carrot lots were cooled directly down to 0˚C. Some carrot lots, however, were left outside for over 5 hours in temperatures greater than 10˚C between harvest and storage (3), most of which were from fields without tip rot (2).

The carrots were mainly stored at 0˚C (± 0.5) and at RH between 89 to 98%. All respondents used storages with cooling systems, most with traditional air circulation storage with an evaporator at the rear wall (10), followed by air circulation storage with a centred evaporator (2) and grimme storage (1). One farmer, without known incidences of tip rot in the current season, reported unstable storage temperatures due to lack of sufficient air circulation throughout the storage.

3.3.3 Factors affecting tip rot incidence

Respondents (6) agreed on the statement “tip rot is caused by field conditions, but the symptoms develop during storage”, while the rest were unsure (5). Farmers were asked about their thoughts and opinions linked to factors potentially influencing the incidence of tip rot in carrots. Fig. 17 shows the number of answers (very unlikely to very likely, and unsure) for each potential causal factor. The most prominent factors believed to have an impact on tip rot were storage conditions, amount of soil in storage boxes, too short duration of crop rotation, carrot cultivar, moist conditions during harvest, drainage, and soil type.

Some factors were elaborated on by the respondents. One respondent stressed the importance of providing favourable growing conditions, ensuring even growth of the carrot plants, and avoiding stress upon the plants. Providing proper drainage and oxygen supply was mentioned by several farmers. The importance of crop rotation was emphasized. Moreover, some farmers thought soil type was a possible factor influencing tip rot. Crop cultivar was mentioned, although the respondents were not sure which cultivars to link to of tip rot incidences. One farmer commented that ‘Romance’ may be more tolerant to tip rot. The cultivar

‘Natalje’ and “earlier cultivars” were suggested as more susceptible to infection. Furthermore, conditions during harvest should be favourable, including avoiding high temperatures and extremely dry or wet periods. One farmer commented that mechanical harvest is more harmful than hand harvest. Several farmers stressed the importance of sufficient air flow through the storage boxes, explaining that insufficient perforation of the storage box plastic liners could lead to favourable conditions for development of tip rot due to lack of air flow. Similarly, sufficient stacking of storage boxes was considered important. One respondent commented that soil in storage boxes positively influences the carrot storability.

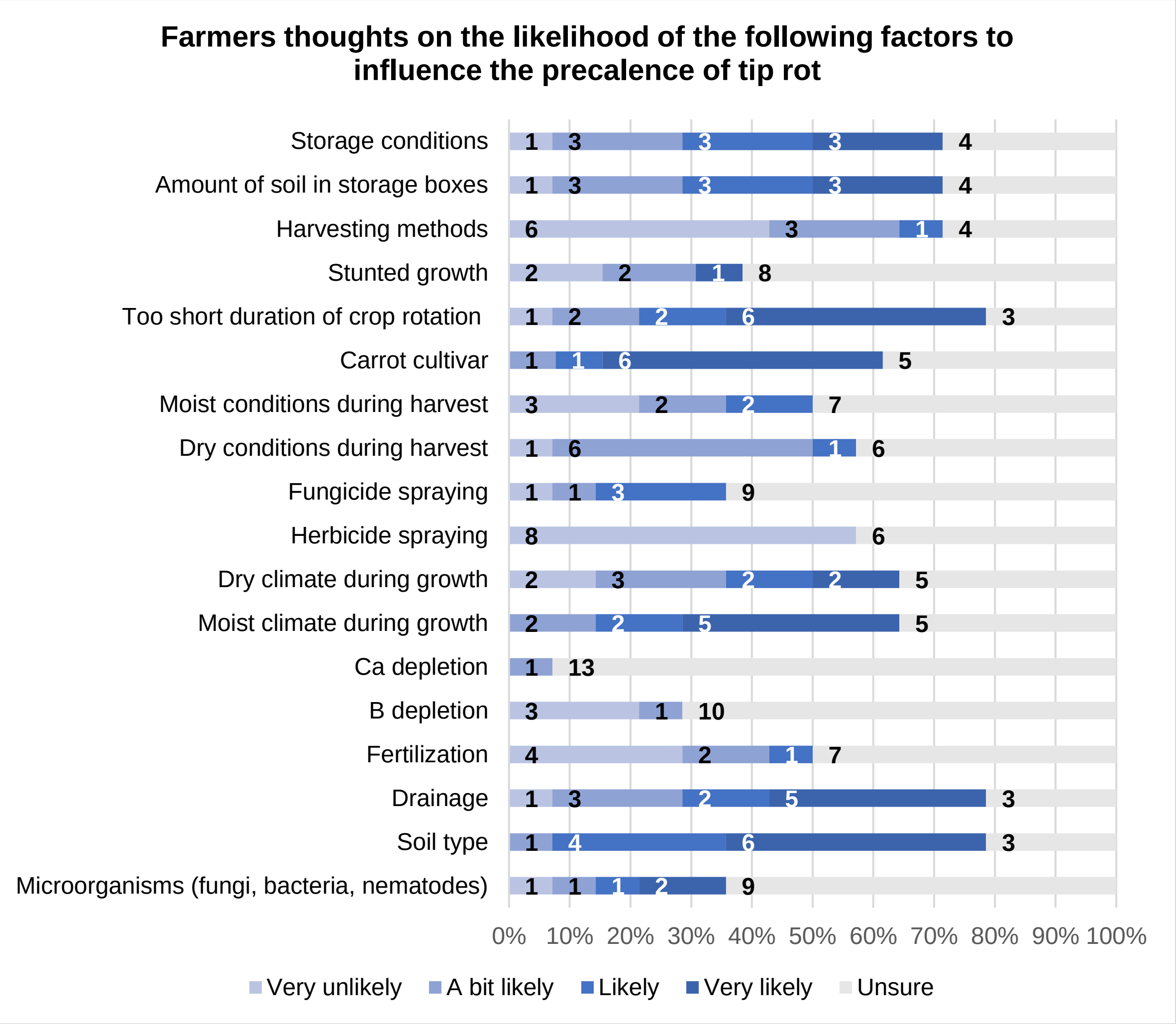

***Fig. 17**: Farmers thoughts on the likelihood of various factors influencing the prevalence of tip rot, based on their experience. The graph shows the number of respondents for each answer category from “very unlikely” to “very likely” or “unsure” for each of the 17 factors hypothesized to influence tip rot prevalence.*

3.3.4 Implemented measures against tip rot

Farmers were asked about current measures they are implementing to reduce incidences of tip rot. Several of the respondents did not implement measures directed towards tip rot alone (4). Other farmers responded that they carried out spring tillage when the soil was ready for tillage (2), chose carrot cultivars they thought were more tolerant to tip rot (1) ensured sufficient subsurface drainage and drainage in ridges (2), implemented suitable crop rotations (3), harvested during the right conditions (2), and used storage box plastic liners with sufficient perforation (1).

4. Discussion

Post-harvest assessments revealed mean storage losses of 58% linked to pathogens. These losses were much higher compared storage loss reported in previous studies (Franke et al., 2013) indicating increasing impact of storage diseases on Norwegian carrot production. Post-harvest losses have a great economic impact due to the extra costs of several production and handling steps throughout the carrot production chain added on top of costs of preharvest production (Thomsen et al., 2019). It is hence important to reduce post-harvest losses. In the current study, tip rot was the main problem in stored carrots, accounting for 29% of the storage loss alone. Identifying possible measures against tip rot could thereby greatly aim in the process of reducing said losses.

In the current study, major post-harvest pathogens registered in stored carrots were tip rot, followed by grey mould (*B. Cinerea*), cavity spot (*Pythium* spp.), and liquorice rot (*M. acerina*). Additionally, Cylindrocarpon root rot (*Cylindrocarpon* spp.) was widely identified among stored carrots. Tip rot incidence varied significantly between regions, ranging from 12-48% incidence. Symptoms of tip rot were light brown, brown, and dark brown rot, and the distribution of symptom type varied among years and regions. Observed variations between storages suggest that soil conditions, implemented agronomic practices, and storage conditions all influenced the abundance and development of tip rot in stored carrots. Norwegian carrot producers have shared their knowledge and experience on tip rot, possible causal factors, and measures against the disease. Disease incidence was commonly discovered after several weeks of cold storage and was linked to latent infections in the field pre-harvest. In previous studies, pre- and post-harvest factors which influence storability of carrots included some of the same factors discussed by the farmers in the focus group and survey. Comparisons between fields with and without tip rot showed few differences in agronomic practice, field conditions, or storage conditions based on the limited data, although some incidences may be linked to tip rot.

4.1 Carrot producers’ experience with tip rot

Tip rot is a known phenomenon among Norwegian carrot producers. Producers’ experiences revealed that the first incidences of tip rot were mainly discovered after several weeks of storage. Latent infections were discussed, and several farmers agreed that tip rot is caused by field conditions, but that the symptoms develop during storage. Common post-harvest pathogens in carrots result from latent infections occurring from field. This corresponds well with identified candidate pathogens such as *M. acerina*, *Cylindrocarpon* spp., *Dictyolstelium* spp. and *Fusarium* spp. linked to the disease (Mohamad, 2021) most of which infect through weakened or damaged plant tissue (Korsten & Wehner, 2003).

Farmers expressed difficulties with symptomatic identification of tip rot, especially at early stages of the infection. According to literature, symptoms of the fungi involved in tip rot development are described to vary between the pathogens (Davis & Raid, 2002; Hermansen, 2008) although early-stage symptoms might look similar between the causal agents. Moreover, Mohamad (2021) found tip rot symptoms to develop through the root core, not easily exposed at early stages of decay. This was reflected in post-harvest assessments of the current study. Tip rot incidences were in some cases both over and underestimated before cutting the root tip, exposing the core to determine presence of tip rot symptoms. Hence, cutting the carrot tip may aid in determining presence of tip rot at early stages of the decay. It may however not be an option for growers and packaging facilities to examine the carrots at such extent as it is labour demanding and mechanically damaging the carrots. Acquired knowledge on causal agents of tip rot and common symptoms found in carrots is crucial for correct identification of the disease aiding in implementing suitable measures against the disease.

4.2 Causal factors linked to tip rot

Norwegian carrot producers shared their thoughts and experiences on various causal factors affecting incidence and development of tip rot in their production. The answers pointed to factors compromising carrot quality and storability and increasing the susceptibility towards diseases. Some of the prominent factors according to the respondents were linked to carrot cultivar, soil type, drought stress, conditions during harvest, storage conditions, and crop rotation.

Tip rot has been registered in a range of cultivars. Farmers had experienced differences between them, although they were not certain which cultivar was more or less affected by the disease. Some farmers claimed that earlier cultivars were more susceptible. Several studies indicate that genetic variation between cultivars influence storability as well as incidence of post-harvest diseases in carrots (Heltoft & Thomsen, 2020; Thomsen, Johannesen, et al., 2019). Moreover, variations in tip rot severity has been found to vary among cultivars (Mohamad, 2021). In future studies, it would be interesting to further compare cultivars in regards to tip rot incidence in future studies.

Farmers have previously reported patterns of increased tip rot incidences in carrots grown in sandy soils (Nærstad, 2015). The same trend was discussed in the current study, although some producers were not familiar with this pattern and had experienced tip rot in carrots grown in heavier soil types as well. Results from the survey show a tendency towards less tip rot in coarser soils, although no conclusions can be drawn from this. The lack of clarity regarding the influence of soil on tip rot indicate that further research is needed to identify any statistical differences between soil types.

Drought was considered an important factor stressing the carrot plant and influencing development of storage diseases. Some farmers claim that drought during the growing season increased susceptibility to tip rot, although others have experienced incidences in humid years as well, as reported by (Nærstad, 2015). Findings from a study investigating the effect of water conditions in soil linked to prevalence of tip rot show that drought towards the end of the growing season increased the number of tip rot infected carrots (Thomsen, 2021). The study also found a tendency towards increased abundance of *B. cinerea* in water-logged soil. It would be interesting to investigate correlation between tip rot incidences found in carrots from Norwegian production sites and the precipitation data prior to harvest to further reveal relationships between tip rot and conditions drought or wet periods prior to harvest.

Conditions during harvest were considered having a great impact on tip rot, and several farmers had experienced clear differences among temperatures and humidity. Dry and warm conditions are linked to drought stress and may cause mechanical stress. Moist conditions may on the other hand, benefit infection of several storage pathogens as found in Thomsen et al. (2019). Furthermore, Suojala (2000) has reported educed problems of *M. acerina* and *B. cinerea* at delayed harvesting dates during cooler conditions (over 0˚C) amongst others providing a more effective transition to cold storage when the soil and carrot roots have an initial low temperature.

Treatment after storage and storage conditions are crucial to preserve carrot quality and limiting losses contributed to pathogens, as emphasized by several respondents from the interviews and survey. Indegård et al. (2019) found significant influence of storage conditions and storage type on carrot quality and abundance of post-harvest diseases. Moreover, the severity of the candidate pathogens involved in tip rot develop significantly slower in low temperatures (0˚C) (Mohamad, 2021) indicating that low and stable temperatures may reduce losses link to tip rot during storage. It would however be interesting to further investigate the relationship between tip rot incidence and storage temperature in future studies.

Crop rotation was stressed by the farmers as an important measure against carrot diseases, including tip rot, reducing inoculum in the field. Literature on candidate pathogens of tip rot confirm this (Hermansen et al., 2008; Davis & Raid, 2002). Appropriate crop rotations, concerning length of rotation and choice of crops, should be implemented considering survival of fungal resting structures in soil as well as alternative hosts. Several farmers reported problems with tip rot in fields linked to problems with the weed and *M. acerina* host plant *Viola arvensis*. Weeding and herbicide treatments could be implemented, although considering avoiding rapid or high-dose applications stressing the carrot plant and making it more susceptible to pathogens.

4.3 Measures against tip rot and advice to farmers

Implemented measures should focus on providing good conditions for growth and development of the carrot plant in field, avoiding factors weakening plant tissue (stress or mechanical damage), and optimizing storage conditions throughout the winter months. Cultivars with good storability should be implemented. Future measures should recognize the identified pathogens involved in the tip rot projects. Most post-harvest diseases result from latent infections that occur in field, and measures against tip rot should therefore consider both pre- and post-harvest factors found to influence the incidence of tip rot.

4.4 Considerations

I want to mention some implementations that should be considered for future research: (1) The questionnaire generated only few responses due to several possible reasons, one of them being that the survey itself was too long and comprehensive to fill out. The survey should be properly quality checked by several people filling out the form and providing feedback on the experience. Further, our questionnaire should be reduced to fewer and more direct questions concerning the research topic(s). This may have improved the number of respondents. (2) The post-harvest assessments showed the importance of regular and close contact between the different partners in order to circumvent errors such as loss of data due to various factors. Further, subjectivity in the prevalence data should be considered, as the perception of tip rot symptom may vary between individuals conducting the survey within each region.

5. Conclusion

This thesis has investigated the prevalence of tip rot and carrot producers' awareness linked to the problem in Norway. Post-harvest assessments revealed that tip rot was the major problem in stored carrots, followed by grey mould (*Botrytis cinerea*), cavity spot (*Pythium* spp.), and liquorice rot (*Mycocentrospora acerina*). Furthermore, *Cylindrocarpon* was widely identified as a disease in stored carrots. Variation in incidence among regions suggest that factors such as soil conditions, implemented agronomic practices, and storage conditions influence the incidence of tip rot. Carrot chain actors have shared their experience and knowledge, including possible causal agents and measures against the disease. Several patterns could be identified. The results may contribute to the development of effective management strategies against tip rot. Pre- and post-harvest causal factors of carrot disease should be considered in measured implemented against tip rot.

4.5 Further research

Future research should further investigate the hypothesized causal agents of tip rot as proposed by the producers, such as field studies investigation the correlation between drought or precipitation (weather data) on production site with the incidence of tip rot, or correlation analysis between storage conditions on tip rot incidence.

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Appendix

***Appendix 1**: Interview guide for focus group interviews. (Translated from Norwegian).*

Interview guide for focus groups on carrot production

Introduction

Everyone states:

- Their names
- How long they have produced carrots
- The size of their carrot production area

Experiences with tip rot

Q1 - How many of you have had problems linked to tip rot?

Show reference photos.

Photo: Kari Aarekol.

Q2 – For the ones with tip rot problems, could you share how you experienced this problem (for the whole period of carrot production):

- At which time during the season was it discovered?
- How and where was it discovered? (On field, storage, at packaging or in store).
- Are you sure that it was tip rot?

Causes of tip rot

Q3 – What are possible causes of tip rot, based on both your own and on others experience?

Q4 – In the current project, we are working with various hypotheses for the cause of tip rot. I'm now going to present these hypotheses, one by one. Speak up if you think that these hypotheses are correct or incorrect.

- Poor drainage (or a lot of precipitation).
- Drought
- Harvesting method
- Treatment after harvest (including storage and packaging material)
- Soil type
- Carrot variety
- Temperature during harvest
- Chemical treatment against weeds
- Fungal diseases
- Bacteria
- Nematodes
- Lack of minerals
- Other hypotheses?

Measures against tip rot

Q5 – Do you have any propositions for measures that could help combat tip rot?

Q6 – Do you believe that UV irradiation can reduce the development of tip rot?

Q7 – Do you believe that improved packaging and reduced storage temperature in stores can reduce the risk of in store development of tip rot?

Appendix 2*: Results from the questionnaire for fields with tip rot (N = 7) and for fields without tip rot (N = 11). Carrot farmers were asked about field conditions and agricultural practices. The number of respondents is presented in parenthesis for each answer category.*

Question	Field with tip rot (N)	Field without tip rot (N)
	Soil conditions	
Soil type	Mineral mixed humus (2) Silt (3) Silty medium grained sand (1)	Mineral mixed humus (1) Silt (3) Silty medium grained sand (5) Fine sand (2)
	Agronomic practice	
Production type	Organic (1) Conventional (6)	Organic (0) Conventional (11)
Tillage autumn	Ploughing (2)	Ploughing (0)
Tillage spring	Ploughing (5)	Ploughing (11)
	Rock picking (1)	Rock picking (1)
	Harrowing (2) Rotary harrow (1)	Harrowing (0)
	Rotary tilling (4)	Rotary tilling (7)
Seedbed type	Ridge (3) Wide bed (2) Flat land (2)	Ridge (7) Wide bed (2) Flat land (2)
Sowing date	07. May – 10. June	07. May – 31. May
	Preliminary cultivation	
2018	Cereals (3) Grass (3) Ley (1)	Cereals (1) Grass (8) Ley (1) Swede (1)
2019	Cereals (4) Grass (2) Ley (1)	Cereals (2) Grass (8) Ley (1)
Years since carrots grown on field	5 years (2) 25 years (1) > 30 years (3) First time cultivating carrots on the field (1)	5 years (2) 6 - 9 years (3) 13 years (1) > 30 years (2) First time cultivating carrots on the field (2)
	Seeds and sowing	
Cultivar	Allyance (1) Brilliance (1)	Cadence (1) Dailyance (2)

	Namdal (1) Dailyance (1) Jerada (1) Napoli (1) Panther (1) Romance (2) Triton (1)	Jerada (4) Natalje (1) Nominator (1) Panther (3) Romance (4)
Seeds coating	Yes (5)	Yes (11)
Watering	No watering (5) Infrequently with large amounts of water (2)	No watering (9) Infrequently with large amounts of water (1) Frequently with smaller amounts of water (1)
Soil cover	Horticultural fleece (2) Insect netting (1) No cover (5)	Horticultural fleece (1) No cover (10)
Water supply		
Early season (first week after sowing)	Sufficient (5) Too low (2)	Sufficient (9) Too low (2)
Mid-season	Sufficient (5) Too low (2)	Sufficient (8) Too low (3)
Late season (last four weeks before harvest)	Too high (2) Sufficient (7)	Sufficient (11)
Harvest		
Date	16. August – 17. October	17. August – 25. October
Method	Mechanical	Mechanical
Treatment after harvest	Directly cooled down to 0˚C (6) Left outside over 5 hours in temperatures greater than 10˚C (1)	Directly cooled down to 0˚C (9) Left outside over 5 hours in temperatures greater than 10˚C (3)
Temp. at harvest	8 – 15˚C One respondent reported temperatures down to 4˚C.	8 – 15˚C One respondent reported temperatures down to 4˚C.
Ripeness	Young (3) Ripe (5)	Young (3) Ripe (9) Overripe (1)
Sorting carrots after harvest	Yes (3) Not due to tip rot	Yes (6) Not due to tip rot

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