The Interaction between Goldenrod (*Solidago candensis*) and Leaf Rust (*Coleosporium asterum*)

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Abstract:

Leaf rust is a common heteroecious parasitic fungus that relies on two hosts to carry out their life cycle. Their primary host is the pine tree, and the secondary host is the goldenrod. Leaf rust is known to cause necrosis to the leaves of the goldenrod. When the pustules form on the leaf, they coalesce and form large necrotic areas on the leaf due to damage to the leaf’s mesophyll. This project addressed five questions pertaining to the interaction between leaf rust and goldenrod. It was found that leaf rust grew more readily on the bottom of the long leaf plants than the short leaf plants. However, in this study, the majority of the short leaf plants were highly senesced at the bottom. Overall, the short leaf plants had a higher amount of leaf rust growth on the entire plant in comparison to the long leaf plants. There was more leaf rust growth found on senescing plants than nonsenescing plants. When separate clones were assessed, differences were found between the clones, leading to the idea of differential resistances.

Introduction:

Plant and fungi, like many other organisms, can have symbiotic, mutualistic, or parasitic relationships. Fungi require a carbon and energy source to survive. Environmental conditions also play a large role in the development of fungal diseases as fungi require free water or a certain level of humidity. Non-parasitic fungi obtain these resources from dead organic matter while parasitic fungi obtain this from feeding off plants. Coleosporidium asterum is a parasitic heteroecious rust fungus. A heteroecious rust is a rust fungus that has two hosts and a long life cycle. Coleosporidium asterum is an obligate parasite meaning that it needs its hosts to survive. In this case, Coleosporidium asterum’s primary host species are pine trees and their secondary hosts are goldenrod (Solidago candensis) (Oregon State U 1999). Any reference to leaf rust in this paper will be referring specifically to Coleosporidium asterum and any reference to goldenrod will be referring to Solidago candensis.
Leaf rust begins its life cycle on the pine tree where it forms orange blisters on the pine needles. Windborne spores then erupt from the blisters and infect its secondary host such as goldenrod or aster during the early summer. The spores land on the leaves of the goldenrod and form little orange-yellow pustules on the underside of the leaf. The spores produce germ tubes that enter the plant and form a mycelial network. When the pustules form on the leaf, they coalesce and form large necrotic areas on the leaf due to damage to the leaf’s mesophyll (Wise 2004). The formation of necrotic tissue causes the plant to senesce. The windborne spores spread among the goldenrod, and the goldenrod infects one another from June to August. Before the winter, the spores burst on the goldenrod and infect pine needles. The needle rust overwinters and produces spores the next spring, completing the life cycle (U.S. Forestry Service 1966, 2015). Goldenrod is also a rhizome plant species, meaning it forms groups of individual plants called ramets that share a single root system that are genetically identical to one another. These groups are known as clones. A study was conducted to answer five questions that addressed the interaction between leaf rust and two types of goldenrod, long leaf and short leaf plants. The questions are as follows, is there more leaf rust growth on the top, middle, or bottom of goldenrod with short leaves, is there more leaf rust growth on the top, middle, or bottom of goldenrod with long leaves, is there more leaf rust growth on the long leaf plants or short leaf plants, is there more leaf rust growth on senescing or nonsenescing plants, and is there a difference in the amount of leaf rust found on each clone?

**Methods:**

In order to answer the five questions at hand, a leaf rust abundance scale was created to determine the amount of leaf rust found on the underside of the leaves (Figure 1). This scale ranged from zero to three. If a leaf was given the number zero, no leaf rust was found on the
underside of the leaf (0% coverage). If the leaf was given the number three, the leaf was
maximally covered with leaf rust on its underside (75% or more coverage). The number one was
used if there was at least one spot of leaf rust to a minimal amount (1%-25% coverage). The
number two was used when the leaf was about half covered (50% coverage). To answer the first
question, is there more leaf rust growth on the top, middle, or bottom of goldenrod with short
leaves, twenty short leafed goldenrod plants were selected randomly to sample from. The plants
were divided into three equal sections, top, middle, and bottom. Five leaves from each section
were sampled at random and given a number from the abundancy scale. The values from each
section were averaged and then graphed. To answer the second question, is there more leaf rust
on the top, middle, or bottom of the goldenrod with long leaves, the same methods as stated for
question one were used. Both data sets were analyzed by running an ANOVA. Question three, is
there more leaf rust growth on the long leaf plants or short leaf plants, was addressed by
collaborating the data from the results of question one and two. The results were graphed
together and analyzed by running an independent sample t-test. In order to address question four,
is there more leaf rust growth on senescing or nonsenescing plants, nine nonsenescing plants and
nine senescing plants were selected at random to sample from. Five leaves from the entire plant
were chosen at random, and they were given a number from the leaf rust abundancy scale. The
values were averaged, graphed, and an independent sample t-test was run to look for any
significant differences between the samples. To answer question five, is there a difference in the
amount of leaf rust found on each clone, eleven different clones were selected at random. Clones
were considered to be large clusters of goldenrod plants that were separated by 10-15 feet. From
each clone, four different ramets were selected to sample from. A ramet is an individual plant
within the clone. From each ramet, seven leaves were selected at random. A number from the
abundancy scale was given to each leaf. The average abundance was calculated for each clone and graphed. An ANOVA was run to assess the data for any significant differences between the clones. All of the data was collected at Mill Cove from September to October.

Figure 1: Leaf rust abundancy scale, ranging from zero to three.

Results:

The largest amount of leaf rust was found on the top section of the short leaf goldenrod plants (Figure 2), with an average value of 1.9, compared to 1.11 and .67 found on the middle and bottom sections respectively. A one-way ANOVA was run on these results and gave a p-value of .000.

The largest amount of leaf rust was found to be on the bottom section of long leaf goldenrod, with an average value of 1 (Figure 3). The middle and top of the long leaf goldenrods averaged .738 and .538 respectively. A one-way ANOVA was run and gave a p-value of .004.

The short leaf goldenrod plants were found to have the largest amount of leaf rust when compared to the long leaf goldenrod plants (Figure 4). The short leaf goldenrod plants had an
average value of 1.23 while the long leaf goldenrod plants were found to have an average value of .758. An independent sample t-test was run on the results and gave a p-value of .005.

Senescing goldenrods were found to have the largest amount of leaf rust, with an average value of 2.09 (Figure 5). Non-senescing goldenrods were found to have an average value of .600. An independent sample t-test was run on the results and gave a p-value of .022.

The average amount of leaf rust found on different clones varied greatly (Figure 6). The average values ranged from 2.71, seen on clone 4, to .382, found on clone 9. A one-way ANOVA was run on the results and gave a p-value of .000.

![Graph](image.png)

**Figure 2:** Average amount of leaf rust among three different plant sections (top, middle, bottom) of short leaf goldenrod plants. p=.000
Figure 3: Average amount of leaf rust among three different plant sections (top, middle, bottom) of long leaf goldenrod plants. $p=.004$

Figure 4: Comparison between long leaf and short leaf goldenrod plants $p=.005$
Figure 5: Average amount of leaf rust found on senescing plants vs. nonsenescing plants. p=.022

Figure 6: The average amount of leaf rust found among 11 different clones. p=.000
Discussion:

Since leaf rust is considered to be fungi we expected to find the largest amount of leaf rust on the bottom sections of the plant. Which was found to happen on the long leaf goldenrod, as seen in Figure 3. Leaf rust, as fungi, prefers moist environments, little airflow, and not much exposure to sunlight. All of those factors should increase the growth of leaf rust on the bottom sections of the leaves (Wise 2004). Top leafs are exposed to more sunlight, more airflow and are typically less moist, which lowers the growth of leaf rust. However on the short leaf goldenrod the results (Figure 2) do not show this. The largest amount of leaf rust was found on the top sections of these goldenrods. The reason for this most likely has to do with the life cycle of leaf rusts. Spores from leaf rust fall from the pine trees and are more likely to land on the top leaves of goldenrod (U.S. Forestry). The amount of leaf rust that lands on the top section of goldenrod may be large enough to overcome its preferences. A more likely reason for finding the largest amount of leaf rust on the top sections of short leaf goldenrods, however, is that the leaves at the bottom of these plants were already senesced. The bottom sections of these plants were most likely senesced due to interactions with leaf rust, which caused necrosis. However, since these leaves were already necrosed no leaf rust could be found. It is possible that after the leaf rust attacked the bottom section of short leaf goldenrods the leaf rust released spores, which then traveled up the plant with the help of wind or animals (Wise 2004).

In this study it was found that the largest amount of leaf rust was present on the short leaf goldenrod then the long leaf goldenrod (Figure 4). There are many possible reasons for these findings. The most likely reason is that the two plant types may have been different subspecies, a short leaf, and long leaf subspecies. If the two plant types were different subspecies, it is possible that they have different levels of resistance to leaf rust (Heath 1992). This difference in
resistance may have led to the different levels of leaf rust found on the different plant types. Since if long leaf goldenrods are more resistant to leaf rust, leaf rust would have a harder time colonizing it and there would be lower amounts of leaf rust on the plant.

Leaf rust causes damage to the mesophyll when it forms on goldenrod, which leaves large necrotic spots on the leaves (Wise 2004). These large necrotic spots make it difficult for the plant to photosynthesize which will eventually lead to the death of the plant. This usually occurs after the spores have already been released, and the plant is no longer needed. This causes senescing of the plant that correlates with our results (Figure 5) which shows that there was more leaf rust on the goldenrod that was senescing than was on the nonsenescing plants.

Goldenrod is a rhizome plant species; each patch of golden rod is considered to be a clone. Clones share the same genetic material, meaning that any resistance genes will be shared among the ramets of that clone (Heath 1992). There was found to be a difference between the amounts of leaf rust on each clone (Figure 6). Some clones presented with very little leaf rust on each ramet, while other clones, like clone 4, presented with large amounts of leaf rust. These findings imply that there may be different levels of resistance in each goldenrod clone looked at. The level of resistance to leaf rust should be the same within a clone. However, this was not looked into in this study.

Leaf rust on goldenrod represents a broader relationship in parasitic plant-fungi interactions. The relationship between parasitic fungi and plants often lead to the death of the plant involved. This study and other research may lead to the idea of differential resistance genes within clones, which helps to protect them from fungal attacks. Further research should be done to look at the genomics of different leaf rust and plant species, to see if there is a genetic reason for the different levels of resistance seen within different clones.
Literature Cited


