Claviceps Purpurea, the Salem Witch

A study of *C. Purpurea* and its influence in the Salem witches trials

In late December 1691, in Salem village (Massachusetts), about eight girls started to have symptoms such as convulsive fits, "crawling and tingling sensations", disorderly speech, vomiting and diarrhoea. More villagers had similar symptoms later in the year. The accepted explanation was witchcraft. Suspects were arrested and trials were conducted. As a result, 20 people were executed and at least two died in prison by autumn 1692. Symptoms suddenly stopped by the end of 1692 and trials ended.

In the following years, all of the court magistrates and jurymen involved admitted errors of judgment and to not understanding the cause of the symptoms observed in Salem. In a public apology, the 12 jurymen said:

> "We confess that we ourselves were not capable to understand nor able to withstand the mysterious delusion of the Powers of Darkness […] we do hereby declare that we justly fear that we were sadly deluded and mistaken". (Upham, 1867)

The Salem witches

Since that time researchers have tried to explain what happened in Salem. Upham (1867) thought the girls' symptoms were faked to get notoriety. However these symptoms were difficult if not impossible to mimic. Starkey's theory (1950, cited in Caporael 1976) was hysteria but he does not explain how eight girls became hysteric at the same time. The latest explanation by Caporael (1976) seems the most probable. She believes "convulsive ergotism may have been a physiological basis for the Salem witchcraft". Ergotism is caused by the mycotoxins produced by a fungus called *Claviceps Purpurea*.

The physical symptoms of convulsive ergotism are crawling sensations in the skin, prickling in the fingers, vertigo, tinnitus aurium, headaches, disturbances in sensation, hallucination, vomiting, diarrhoea and epileptiform convulsions (painful muscular contractions). The psychological symptoms are mania, melancholia, psychosis and delirium. All of these symptoms are mentioned in the trial records. Gangrenous ergotism also exists and it involves loss of limbs. However, it did not appear in Salem. Children are more sensitive to ergotism than adults and females more than males, thus explaining why the first "bewitched" were young girls. (Hudler, 2001)

Weather conditions favourable to *Claviceps Purpurea* growth

C. Purpurea can grow in wheat, barley, oat and rye. Rye was considered as the most reliable grain and it was widespread in New England. Due to the cold winters, rye was sown in April and harvested in August. It was then stored for months to be threshed before Thanksgiving, in end of November (Caporael, 1976). *C. Purpurea* growth is promoted by warm and humid conditions. From a villager's diary, we know that spring 1691 was wet and mild, and summer was hot and stormy (Samuel Sewall, 1674-1729, cited in Caporael 1976). In other words, conditions were ideal for the growth of the fungus. The first symptoms appeared in December when the 1691 grain was used. Symptoms only appeared in people growing rye in humid fields (located near streams or facing north) (Caporael, 1976). The year after, the weather was dry and the fungus did not grow, explaining the sudden disappearance of the symptoms.

Growing conditions

C. Purpurea is an ascomycete – a sac fungi. During the winter *C. Purpurea* is stored in the form of sclerotia, which is resistant to extreme temperatures (step 1 on figure 1). This enables it to survive several years in soil until conditions are propitious for its growth. A sclerotium is made of an organised structure of aggregated hyphae. The structure is made of an outer layer, outer cortex and inner medulla. The outer layer is made of thick walled and pigmented hyphae. The outer cortex is made of dense cytoplasm containing cells. The inner medulla is made of very large hyphae, which contain large amounts of organelles probably implanted in a matrix. It stores water and nutrients for germination. (Isaac, 1992)

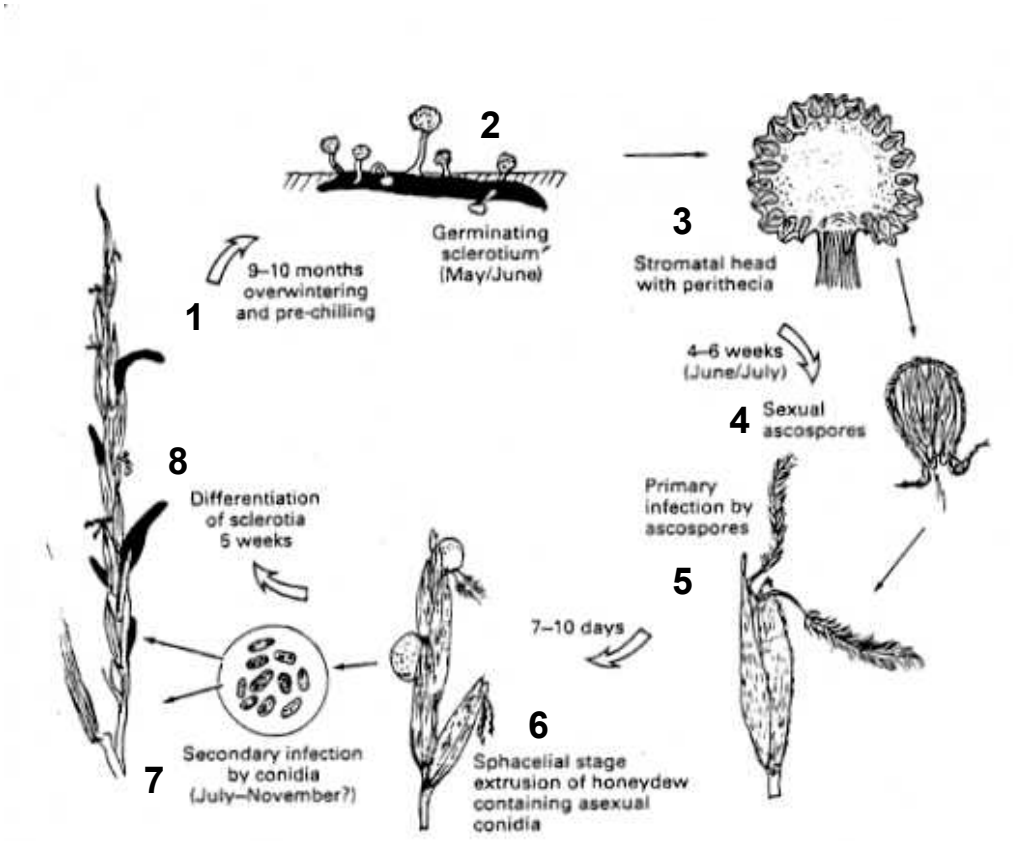


Figure 1: Life cycle of Claviceps Purpurea (Adapted from Newell)

Sexual reproduction

In spring sclerotia germinate to give spherical perithecial stomata (step 2 on figure 1). They carry perithecia on the head of the stromata (step 3 on figure 1). An Ascus containing ascospores (sexual spores) protrude from the ostiole (opening) of each perithecium (figure 2). Each ascus contains eight ascospores, which are then dispersed by wind from asci, which then collapse (step 4 on figure 1). Other asci at later stage of development then replace it. (Carlile, 2001)

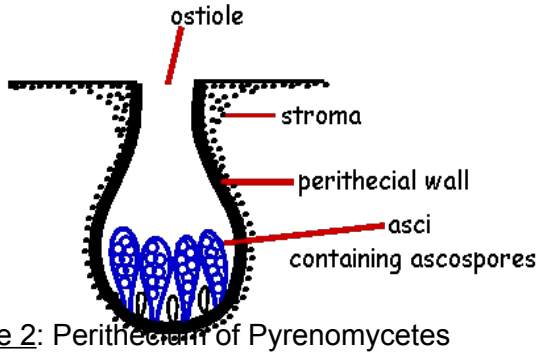


Figure 2: Perithecium of Pyrenomycetes (fungionline)

The formation of an ascus all starts with one cell, the ascus mother cell. The nuclei in the ascus mother cell assemble to produce a diploid nucleus. Meiosis of the latter forms four haploid nuclei, which each divide by mitosis to yield eight haploid nuclei. Each nucleus is then surrounded by photoplasm and a wall before maturing to form an ascospore. (Figure 3)

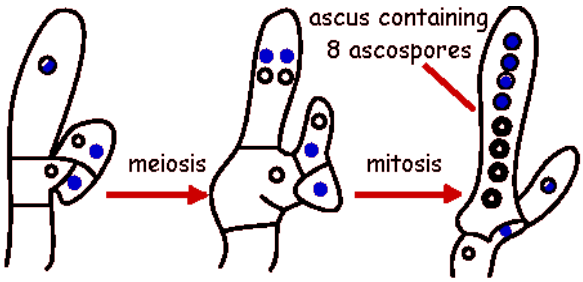


Figure 3: Ascus and ascospores formation (fungionline)

A few of these spores land in the flowers of grasses and cereals (e.g. Rye), which is the only place where they can grow (step 5 on figure 1). These primary spores germinate and their hyphae penetrate and colonise the ovaries of the host (Carlile, 2001). The hyphae produce a large amount of secondary spores (asexual conidia) at the surface of the ovary within two weeks of infection. This will initiate asexual reproduction by conidia to infect more hosts crops.

Asexual reproduction

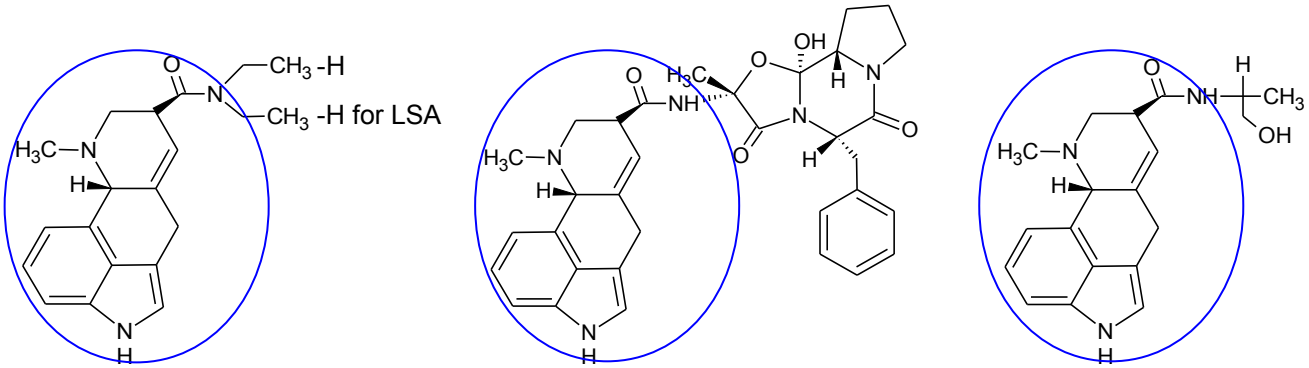
Conidia produce an exudate rich in sugars and amino acids called “honeydew”. It accumulates in floral cavity and sometimes overflows (step 6 on figure 1). Honeydew has two functions; it supports further fungal growth and attracts pollinating insects. These insects collect the exudate along with a few spores. They then collect more nectar in original flowers, losing conidia in the process and spreading the fungus even more (step 7 on figure 1). The conidia can also be spread by contact or rain splash.

When the host plants stops growing, the fungus infected ovary becomes a hard dark mass of hyphae called a sclerotium at each infection site instead of the crop seed (step 8 on figure 1). The sclerotium can be harvested along with the healthy grain or falls on the soil to wait for

winter's end and a new host. Until now C. Purpurea is not harmful (except for a lower crop yield). It is only when the sclerotium is harvested and consumed by humans or cattle that it causes problems.

Compounds responsible of symptoms

C. Purpurea produces mycotoxins called ergot alkaloids. Alkaloids are nitrogen-containing basic compounds. Some of them are hallucinogens such as lysergic acid amide (LSA) and lysergic acid hydroxyethylamide. They are responsible for symptoms of vomiting, diarrhoea, crawling sensations, hallucinations and epileptiform convulsions (Hudler, 2001). Alone they could explain the symptoms in Salem. They both have a structure close to LSD (figure 4). Ergotamine is mainly responsible for constriction of blood vessels in limbs causing gangrenous ergotism (Hudler, 2001). Different proportions of these alkaloids in the fungus causes either convulsive or gangrenous ergotism.



Lysergic acid diethylamide (LSD) Ergotamine Ergometrine

Figure 4: Structures of a few alkaloids in Ergot (Southon, 1989)

However, useful chemicals can be extracted from a fungus which has done so much damage. Two alkaloids extracted from *C. Purpurea* are used as medical treatment. Ergotamine and its derivative dihydro-ergotamine are used to treat migraines. Ergometrine and its derivative methyl-ergometrine is an oxitocic agent used in childbirth. They both work by vasoconstriction of dilated veins in the brain (migraine) or in the uterus (by stimulating uterine smooth muscle).

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