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G. P. Darnell-Smith and the introduction of copper carbonate 'dry pickling' of wheat seed

G. M. Murray[A,*]

For full list of author affiliations and declarations see end of paper

*Correspondence to:
G. M. Murray
215 Brucedale Drive, Brucedale, NSW 2650, Australia
Email: gordonmur@gmail.com

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ABSTRACT

George Percy Darnell-Smith (1868–1942) was the second plant pathologist appointed to the New South Wales Department of Agriculture. Although he founded the Microbiology Branch (later Plant Pathology Branch) and wrote articles on many plant diseases, his noteworthy contribution was developing the 'dry pickle' treatment for common bunt of wheat during the 1910s. Darnell-Smith built on the knowledge gained over the previous 150 years on this disease. Common bunt was the first disease—plant, animal or human—whose cause and disease cycle were found. Mathieu Tillet pioneered scientific study of plant disease with his work on bunt in the 1750s. His microscopic examination showed that minute spores infected wheat seedlings leading to bunt developing in place of wheat seeds. His field experiments found that 'pickling' seed with copper solutions and other toxic chemicals prevented the disease. Farmers and researchers refined these wet treatments but they remained tedious to use and reduced seed germination and seedling emergence. Darnell-Smith developed an improved treatment with copper carbonate dust that gave effective control of both seed- and soil-borne inoculum. He patented a simple machine for on-farm use. His treatment had advantages over the wet pickles, being much simpler to apply and not affecting seed germination. After confirmation in the United States of America in the early 1920s, the treatment was rapidly adopted there and in other countries where by 1930 it had reduced bunt from a common disease to one rarely seen. Darnell-Smith said that he chose to work with copper carbonate based on studies by F. C. Clark in the United States of America. However, the German scientist Carl von Tubeuf had described its effectiveness as a dry powder against bunt in 1902. Darnell-Smith lectured in England before moving to Australia so it is possible that he knew of this work. Perhaps the considerable anti-German feeling in Australia during World War I dissuaded Darnell-Smith from acknowledging von Tubeuf.

Keywords: Australian wheat farming, common bunt, copper carbonate, phytopathology, plant disease aetiology, seed treatment, *Tilletia laevis*, *Tilletia tritici*.

Introduction

George Percy Darnell-Smith was appointed assistant microbiologist to the New South Wales Department of Agriculture in 1909,[1] four years after the resignation of the department's first plant pathologist Nathan Cobb.[2] Darnell-Smith formed and headed the department's Microbiology Branch in 1913 (later Biology Branch and then Plant Pathology Branch). From 1910 to 1924, he wrote at least 44 advisory articles on diseases of many plants. In 1924, he became Director of the Sydney Royal Botanic Gardens and retired in 1932.[3] As director, Darnell-Smith was active in publicising the work of the Royal Botanic Gardens and his portrait was an entry in the 1931 Archibald Prize. This prize is the major Australian award for portraiture and is given annually to the best

[1]Kuiper (1981).
[2]Blanchard (1957).
[3]Kuiper (1981).

Fig. 1. Portrait of George Percy Darnell-Smith by Mary Will-Slade entered for the Archibald Prize in 1931 (https://www.artgallery.nsw.gov.au/prizes/archibald/1931/18613/). Original painting now in the New South Wales Department of Primary Industries Plant Pathology & Mycology Herbarium at Orange (Herb DAR). Photograph of painting by Dr Jordan Bailey.

portrait, 'preferentially of some man or woman distinguished in art, letters, science or politics, painted by any artist resident in Australasia' (Fig. 1).[4]

Darnell-Smith is best known for his development of the 'dry pickling' treatment of wheat seed to control common bunt.[5] This quickly replaced the wet pickles as it was simpler for treating large quantities of grain and did not affect the viability of the seed (Fig. 2).[6]

Common bunt or stinking smut of wheat (*Triticum aestivum* L.) is caused by two closely related species of *Tilletia*, *T. caries* (de Candolle) Tulasne & C. Tulasne [syn. *T. tritici* (Bjerkander) G. Winter] and *T. laevis* Kühn. These bunts replace the wheat kernel with a bunt ball containing a mass of foul smelling teliospores. At harvest and during grain handling, the balls break, dispersing teliospores onto sound grain and contaminating soil. After the next wheat crop is sown, teliospores on seed or in soil can germinate and infect new seedlings. The growing plants show little or no symptoms until after anthesis, when greyish bunt balls develop in place of normal kernels.[7]

Fig. 2. Treating wheat seed with bluestone and limewater at the Wagga Experiment Farm about 1910. Photograph was found by the late Mr Jan Kuiper among a bundle of miscellaneous photographs taken at the Wagga Experiment Farm. Photographer unknown.

Although heavy infections of bunt reduce yield, the larger economic effect is on grain quality. Bunted grain and flour milled from it are grey with an unpleasant smell. Although not poisonous, tainted products are not appealing as food. Thus, the value of bunted grain is low and buyers may reject visibly contaminated grain.[8] Australian wheat receival standards have nil tolerance for bunt.[9] Murray and Brennan estimated that bunted grain was worth 27% less than sound grain because its only use was for on-farm animal feed.[10]

The understanding of common bunt's cause and control in wheat was a major contributor to the development of plant pathology as a scientific discipline.

Common bunt and the development of plant pathology

Wheat bunt was the first disease studied in experiments that found the cause to be an infective agent, with the infection process progressively understood as microscopes improved. Knowledge of the disease cycle enabled development of practical and effective controls.[11]

Seed for sowing seems to have been treated in various ways including soaking in water containing many different

[4]https://www.artgallery.nsw.gov.au/art/prizes/archibald/
[5]Fish (1970).
[6]Kuiper (1981).
[7]Wiese (1987).
[8]Wiese (1987).
[9]https://grains.graincorp.com.au/wp-content/uploads/2022/10/Wheat-Standards-2023_24.pdf
[10]Murray and Brennan (2009).
[11]Large (1962).

manures, salts, urine and other materials since at least Roman times. Francis Bacon reported his experiments with various seed treatments in 1628, although he was interested in accelerated germination and vigour of the seedlings and did not mention diseases.[12]

Bunt had become particularly severe in Europe by the eighteenth century so that much of the harvest was contaminated. Gingerbread disguised the taint and the colour making bunted wheat palatable. Explanations for bunt were many: sunstroke, 'pestilential mists', poor drainage, the moon, insects and sheep manure. There was even a principle ('emmiéture') that supposedly fell from the sky.[13]

Jethro Tull first mentioned the control of bunt by steeping seed in brine that began in England about 1660. When sown, seed that had been accidentally brined in a shipwreck produced crops free of bunt. Tull believed that smuttiness was an inherited quality of the seed and that the brining strengthened the grain, giving it the stamina to resist the cold wet summers that caused the bunt.[14]

By 1750, severe outbreaks of common bunt in France led the Academy of Arts and Sciences at Bordeaux to offer a prize for finding the cause and cure of the disease. Mathieu Tillet, Master of the Mint at Troyes and a farmer, responded. Tillet considered that careful observation in experiments with the various putative causes would help solve problems. This was a new way of thinking, rather than merely considering the opinion of classical writers.[15]

Tillet first listed the various putative causes and then designed a series of experiments to test each. He began with planting seed in pots, finding no difference in the bunt infection between waterlogged and free drained pots, and between bright sun and less sun. He noted that seed dirtied with the black power from bunt balls produced more bunted plants than cleaner seed. From this preliminary work, in 1751 he sowed a large field experiment to compare all combinations of the putative causes. Only the modification of dusting seed with bunt powder, or sowing into soil with added bunt powder, resulted in high levels of bunt irrespective of the other treatments. His experiment included various seed treatments with sea salt, lime and nitre. These wet seed treatments reduced the level of bunt. Tillet repeated his field experiments in 1752 and 1753 with the same results, showing that bunt was a seed and soil borne disease.[16]

Having concluded the bunt was seed-borne, Tillet looked for remedies. His lye solutions, probably prepared from wood ash, gave the best results but were expensive. He tried ammonia made from urine and found it almost as effective. Urine from animals and humans was abundant and cheap, and easy for farmers to prepare. Tillet had a profound appreciation of human behaviour and encouraged local farmers to try the method for themselves. The result was a rapid adoption of the practice first in France and then throughout Europe. The Bordeaux Academy awarded the prize to Tillet for his thesis.[17] Improvements in the seed treatment, particularly the drying of seed with lime, led to good control of bunt throughout the latter eighteenth century.[18]

Tillet then asked how such a little dust from bunt could cause plants to produce bunt balls. He examined the black powder with his primitive microscope and found it was a mass of minute, spherical particles, and proposed that these got into the seedling in some way.[19]

Fifty years later, improvements in microscope design allowed Bénédict Prévost to examine Tillet's 'spherical particles' in more detail. In 1807, he observed that these particles began to grow when soaked in water, first with a short tube that then grew a tuft of branches. He concluded that the particles were spores of a microscopic plant and speculated that the germinating spores were able to infect the wheat coleoptile. Prévost observed that bunt control was better when the pickles were prepared in copper vessels, and found that traces of copper in the water prevented germination of the spores. This gave him a simple test for finding what prevented the germination, leading to the discovery that copper sulfate in solution was an inexpensive control.[20]

Further improvements in microscopes allowed the Tulasne brothers to follow the germination process further in the 1840s and 1850s. They observed H-shaped conjugation between the sporidia followed by production of secondary sporidia, later found to be the sexual cycle. The brothers hypothesised that these sporidia could infect through the stomata of the coleoptile and infect the plant. Rapid progress continued through the latter half of the nineteenth century in understanding the sexual role of the primary sporidia and the host specificity of the smut and bunt fungi.[21] Despite increasing knowledge of bunt's disease cycle and control measures, bunt remained a serious disease in most wheat-growing countries including Australia in the late nineteenth century.

[12] Buttress and Dennis (1947) pp. 93–94.
[13] Large (1962).
[14] Buttress and Dennis (1947) p. 95.
[15] Large (1962).
[16] Large (1962).
[17] Tillet (1755).
[18] Large (1962).
[19] Large (1962).
[20] Large (1962).
[21] Large (1962).

Common bunt in Australia

In 1891, Nathan Cobb summarised the existing knowledge of the bunts and smuts for New South Wales farmers.[22] In his monumental work on smuts in Australia, Daniel McAlpine described six species of *Tilletia* on cereals and grasses and four species of smuts and bunts on wheat.[23]

While summarising the known effective seed treatments for control, Cobb recognised the difficulty of treating large quantities of seed with copper solutions or formalin and the negative effect these pickles had on seed viability.[24] Although subsequent treating of the seed with lime reduced the effect on seed germination, this made the treatment even more tedious for farmers.[25] Cobb tried exposing wheat seed to hot air, but this killed the seed before the teliospores.[26] Wheat breeder William Farrer also attempted unsuccessfully to improve seed treatments.[27]

G. P. Darnell-Smith and dry pickling for control of bunt

Shortly after his appointment as assistant microbiologist in 1909, Darnell-Smith recalled that 'Mr. H. Ross… was so impressed by the loss occurring through the use of copper sulfate solution that he urged me to look for a substitute'. Darnell-Smith knew that copper was effective at very low concentrations in water. He looked for a copper compound that was not absolutely insoluble and so provided a minute but effective amount of copper in solution. He thought that copper carbonate might be such a compound and knew that it could be applied as a powder to wheat. His preliminary experiments showed that a rate of 2 oz to the bushel (about 2 g/kg) gave effective coverage of the seed.[28]

Mr Jan Kuiper searched archival reports held by the New South Wales Department of Agriculture when preparing for his biography of Darnell-Smith.[29] These reports show that Darnell-Smith began experiments on bunt control in 1911. His first trials were in small plots of 100 seeds in Sydney. He treated seed of wheat cv. 'Bunyip' with water solutions of bluestone (with and without subsequent lime treatment), formalin, 'Fungusine' and 'Clarke wheat protector'. All gave good control of bunt except bluestone without lime, which reduced seedling emergence, confirming earlier work.

He repeated these experiments in Sydney in 1912, this time with three wheat cultivars, 'Federation', 'Comeback' and 'Bobs', with the addition of dry dusting of seed with copper carbonate or sulfur. While the sulfur treatment was ineffective, the dry copper carbonate was as effective as the wet pickles.

His 1913 experiments, again in Sydney, for some reason did not include dry dusting. He applied the copper carbonate as a suspension in water. It was equally or more effective at controlling bunt as the other wet treatments while still not affecting seedling emergence.

By 1914, Darnell-Smith was ready to run larger experiments in the field at the Wagga Experiment Farm. He designed the experiment and relied on the farm manager to sow, manage and evaluate the results. As in 1913, he applied copper carbonate as a water suspension, and it was equally effective as the other wet treatments.

The 1915 experiment, again done at the Wagga Experiment Farm, compared the copper carbonate dusting of seed with the wet copper carbonate and copper sulfate treatments. The manager's report on the experiment concluded: 'Copper carbonate appears to be effective in killing bunt spores although not as effective as copper sulfate and lime. The slight increase in bunty plants is easily compensated by the easy method of treatment and it is to be hoped that subsequent trials will prove its effectiveness as many thousands of bushels of seed are wasted annually by wrongly treating with bluestone'.[30]

Field experiments continued in subsequent years at the experiment farms at Wagga Wagga and Cowra, all showing the effectiveness of the dry pickle with copper carbonate without the deleterious effect on seedling emergence of the wet pickles. These experiments included sowing seed into soil with added bunt spores as well as seed contaminated with spores. Copper carbonate dust was effective against both sources of inoculum. Darnell-Smith reported these results in a series of articles in the *Agricultural Gazette of New South Wales*.[31] He also developed a simple device that farmers could make to treat grain on farm.[32]

Darnell-Smith's work was widely reported in the rural press throughout Australia. A search of newspapers held by the National Library of Australia from 1915 to 1919 found 83 newspaper articles, ranging from 30 in Western Australia to two in Tasmania, which reported the findings across Australia.

Despite the clear advantages of the dry treatment, uptake in Australia was slow, with many doubting that a dry,

[22]Cobb (1891).
[23]McAlpine (1910).
[24]Cobb (1891).
[25]Darnell-Smith (1923).
[26]Cobb (1896).
[27]Farrer (1900, 1903, 1905). Farrer and Sutton (1905).
[28]Darnell-Smith (1923).
[29]Kuiper (1981).
[30]Wagga Experiment Farm Manager's Report for 1915.
[31]Darnell-Smith (1915*a*, 1915*b*, 1917).
[32]Darnell-Smith (1919).

insoluble powder could work. Arthur Perkins, the South Australian Director of Agriculture, held the common view that Darnell-Smith's conclusions had 'been hastily drawn', and makes the case for continuation of the bluestone treatment.[33] This conservative view largely prevailed despite clear evidence from several years of field-testing.

The *Agricultural Gazette of New South Wales* was widely distributed in the United States of America, where agricultural scientists became interested in Darnell-Smith's work and confirmed his findings.[34] American farmers quickly adopted the dry dust treatment with 10% of the crop treated in 1925.[35] This treatment gradually became accepted in Australia. A newspaper report in 1925 describes Mr Beecher of Narrandera extolling the benefits of using clean seed treated with the new dry treatment.[36]

Alf Hannaford and Company developed a commercial model of the drum treatment device designed by Darnell-Smith and Ross suitable for on-farm use.[37] These dry pickling machines allowed treatment of seed wheat on-farm and their use rapidly spread. By 1933, district agronomists in New South Wales reported that bunt was no longer a problem due to the widespread use of copper carbonate (annual plant disease survey records held in the New South Wales Department of Primary Industries Plant Pathology & Mycology Herbarium at Orange (Herb DAR)).

Von Tubeuf, the original discoverer of copper carbonate as a fungicide

Carl von Tubeuf was a well-known German plant pathologist in the late nineteenth and early twentieth centuries. His textbook on plant diseases was available in English and included descriptions of *Tilletia* spp. (pp. 306–311).[38] In 1902, he published extensive studies on the efficacy of various treatments for the control of common bunt.[39] He found that treatment of seed with dust of copper carbonate was highly effective. In 1923, Mackie and Briggs acknowledged von Tubeuf as the first to describe copper carbonate dust and Darnell-Smith for his studies. They wondered why its use was not continued until Darnell-Smith published his findings.[40]

Darnell-Smith reported the efficacy of copper carbonate in a series of popular articles but did not give his source or reason for choosing copper carbonate.[41] This lack of providing references is usual in farmer-oriented magazines. However, in 1923 Darnell-Smith acknowledged J. F. Clark for his work in 1902 on the fungicidal properties of various concentrations of copper in solution. Although working at the same time, Clark did not reference von Tubeuf.[42] Darnell-Smith credits Clark's finding that very low concentrations of copper in solution were sufficient to be lethal to fungi, which led him to consider copper carbonate.[43]

Did Darnell-Smith know of von Tubeuf's finding? Darnell-Smith lectured in chemistry and biology in Bristol, England, from 1893 to 1907 and was a fellow of the Royal Institute of Chemistry. His appointment as assistant microbiologist in the new Bureau of Microbiology in Sydney suggests that he had expertise in microbiology. His background in teaching, chemistry and biology makes it possible that he was aware of von Tubeuf.[44]

Why then would Darnell-Smith fail to acknowledge von Tubeuf? Darnell-Smith's bunt studies were during World War I, when anti-German feeling was high in Australia. Perhaps Darnell-Smith considered that mention of a German pioneering the work would be another argument against adopting copper carbonate.

After Darnell-Smith

Darnell-Smith established the criteria for which seed treatments are selected: efficacy, ease of use and low cost. He recognised the unpleasantness of the dust and advised users to protect themselves against breathing it in. Copper carbonate was withdrawn later because of health risks. There are now several fungicidal seed treatments to control bunt that also control other seed-borne and seedling infecting diseases of wheat. These are liquid based which avoids any dust problem.[45]

There are several genes for resistance to *T. caries* and *T. laevis* with corresponding genes for virulence in the bunts. Andrews and Ballinger found there was potential to breed for resistance with Australian wheats,[46] although

33 Perkins (1920).
34 Mackie and Briggs (1923).
35 Large (1962).
36 Anonymous (1925).
37 Anonymous (1924).
38 von Tubeuf (1897).
39 von Tubeuf (1902).
40 Mackie and Briggs (1923).
41 Darnell-Smith (1915*a*, 1915*b*, 1917, 1919).
42 Clark (1902).
43 Darnell-Smith (1923).
44 Kuiper (1981).
45 Matthews and others (2023) p. 178.
46 Andrews and Ballinger (1987).

there are eleven pathogenic races within Australian collections of the two *Tilletia* spp.[47] The large number of pathogenic races of the two *Tilletia* spp. makes breeding for resistance more difficult compared to the low cost of seed treatment.[48] As a result, seed treatment remains the dominant control used in Australia.[49]

Common bunt is now only occasionally observed in Australia,[50] but it remains at a low level. Ballinger and Gould found spores were present in 29% of wheat deliveries tested in Victoria by washing and microscopic examination.[51] G. M. Murray and K. A. Wratten (unpublished data) used their technique to find that spores of the two bunt species were present in 18% of the 1992/93 wheat deliveries in central New South Wales and in 6% in southern NSW.

Bunt has caused market rejection of wheat several times since the 1930s. Usually these are single crops where there has been no fungicide treatment of the seed for some years. Bunt reappeared in 1945 following the general failure to apply treatments during the Second World War (annual plant disease survey records held in Herb DAR, Orange). The second major outbreak was during the 1960s with the appearance of a hexachlorobenzene resistant strain of *T. laevis*, the first record of a pathogenic fungus developing resistance to a fungicide.[52]

The rapid reappearance of bunt after failure to apply effective control measures or the failure of a current control option through fungicide resistance means that vigilance is required. A new challenge has arisen with the growth in organic agriculture to develop an acceptable organic treatment.

Conclusion

Although von Tubeuf first reported the efficacy of copper carbonate as a bunticide, Darnell-Smith tested it rigorously under field conditions in Australia, promoted it to farmers, and devised an effective way of treating large quantities of seed on-farm. Darnell-Smith's work was recognised internationally and was the foundation of modern fungicidal seed treatments of cereals.

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Data availability. Copies of all historical records used to prepare this manuscript are lodged in the New South Wales Department of Primary Industries archive section of the New South Wales Archives.

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Author affiliation

[A]215 Brucedale Drive, Brucedale, NSW 2650, Australia.

[53]Murray (1989).