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Otto Appel and his contributions to food quality and safety at the beginning of the 20th century

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Summary

Otto Appel (1867-1952) is best known for his research in the field of phytopathology, in particular for his discoveries on bacterial and fungal diseases of crops such as potato and cereals. His work ranged from fundamental research, like the discovery and description of pathogens and their ways to affect their host plants, to applied research on cultivation practices and storage methods. He published numerous scientific articles as well as practical recommendations for farmers in form of flyers and pocket books with the aim to improve yield and quality and to reduce losses and, thus, securing the supply with plant based food and materials. His commitment to applied research was also reflected in his long-term membership in the board of the Association for Applied Botany and later on in the awarding of Honorary Presidency of the Association. As director of the Federal Biological Research Centre for Agriculture and Forestry in Berlin, he was the key player in setting up an efficient and well-organized plant protection service in Germany.

Otto Appel's achievements significantly influenced agricultural practices and generally enhanced food quality and safety in Germany and beyond. They are still remembered today, when the Deutsche Phytomedizinische Gesellschaft awards the Otto Appel Medal to outstanding researchers in phytomedicine every two years.

Early Years

Being born on May 19th, 1867 in Coburg, Germany, into a merchant family, Friedrich Carl Lois Otto Appel developed a strong interest in botany and plant systematics in his youth. Intended to pursue a career with a scientific background, he became a pharmacy assistant. In his free time, he continued to collect and describe the morphology of the species *Carex* from the *Cyperaceae* family, which led to his first scientific publication of Caricological notes from the Hercynian territory (Appel, 1890). He was involved with several learned societies such as the Geographical Society of Thuringia to Jena, the Botanical Association of Entire Thuringia, the Botanical Society of Switzerland and the Botanical Association of Copenhagen. After his university studies in pharmacy in Breslau, he took over a pharmacy but continued his botanical studies on the side. Further publications and talks on *Cyperaceae* and the flora of the Black Forest and the Swabian Alb (Appel, 1891, 1893) gained him the attention of Professor Dr. Julius Sachs, a pioneer in experimental plant physiology, which eventually led to Otto Appel pursuing a doctorate. In his doctoral thesis "Über Phyto- und Zoomorphosen (Pflanzengallen)" (Appel, 1899) he examined both the causes of plant galls and their origin in various parts of the plant.

In the following two years, he deepened his knowledge in bacteriology at the Institute for Hygiene and Bacteriology of the University of Würzburg and as assistant at the Bacteriological Institute of the Agricultural Institute of the Albertus University of Königsberg. In 1899, at the age of 32, Appel followed the call of Prof. Carl von Tubeuf to the newly established Biological Department of Agriculture and Forestry of the Imperial Health Department in Berlin.

Discovering the connection of potato diseases in the field and potato storage

In Berlin, Appel investigated fungal and bacterial infections of potato and cereals, which were the most important crops for people's nutrition at that time. Compared to cereals, potatoes produced nearly the same amount of protein and even the double content of carbohydrates per unit area. Thus, he focused on potatoes first, where in his opinion, the greatest losses occurred and the fastest successes could be expected. In 1899, Appel started with his studies to optimize the storage of potatoes at the field station in Berlin-Dahlem, which resulted in a detailed recommendation on the construction of potato clamps (Appel, 1902a).

From his experiments, he concluded that many of the diseases had their origin in the field. He stated: In these investigations, as well as in a series of occasional observations, I became convinced that the diseases to be observed in the preservation of potatoes are at least partly related to the symptoms of the disease, which also occur during the growing season... (translated from German original Appel, 1903). It quickly became clear that he had to examine the whole cycle of the pathogen carefully, starting from storage to the subsequent culture, in order to prevent and interrupt further spreading of the disease. In 1901, Appel identified *Bacillus phytophthorus* (= *Pectobacterium atrosepticum*) in potatoes and, two years later, provided a detailed description: The *Bacillus phytophthorus* is a fairly thick, gram-negative rod. Its length is very variable; in rotting potatoes and also in the diseased tissue of the plant it occurs predominantly as a very short rod with an approximate length of 1.2-1.5 μ. ...mobility is extraordinarily large, especially in young cultures (translated from German original, Appel, 1903).

Appel noted that, in the case of blackleg potato disease, the infection always emanated from an affected tuber, and the bacteria spread through the conducting vessels into other plant tissues (Fig. 1). This was confirmed, when spraying the foliage several times with a bacterial suspension did not lead to an infection. At the experimental field in Berlin-Dahlem, Appel planted pre-infected tubers of the varieties cv. 'White Rose' and 'Dabersche' to further analyse transmission of the bacterial infection. At the time of harvest, crop failure by blackleg disease in cv 'White Rose' amounted to 62.11%, but in uninfected tubers it was only 4.29%. In contrast to that, cv. 'Dabersche' showed a rapid wound healing after infection treatment and, as a consequence, suppression of the infection. Losses due to blackleg disease in the pre-infected culture amounted to only 9.4% for this variety. According to the observation of Otto Appel, potatoes with a thick skin, higher starch content, and generally varieties with a late harvest date were more resistant than the others were. His studies corroborate impressively how important the choice of the right variety is in the fight against blackleg potato disease and how significantly resistance breeding can support the control of this pest. In further field trials, Appel also proved that infection of potato plants via the soil is possible. As a consequence, he recommended that potatoes should not be cultivated on polluted areas to avoid accumulation of the pathogen in the soil (Appel, 1903).

Appel's findings on blackleg disease have been summarized as follows in a yearly report on advances in phytomedicine (HOLLRUNG, 1903):

- It is not possible to combat blackleg in the field.
- For cultivation of potatoes, avoid fields where, one or two years before, a disease had appeared, as well as those on which beans, lupins, carrots, Teltow turnips or cucumbers were infected by the same pest.
- Do not use sliced potato tubers for planting, just whole tubers.
- Avoid strong nitrogen fertilization.
- An infection can be prevented by using new, healthy seeds.

Fig. 1: Blackleg disease on potato. Left: sprouting potato with symptoms of blackleg disease after cultivation in infected soil, specimen collected by Otto Appel and preserved in formalin (Phytopathological Collection of the Julius Kühn Institute; image by Manfred Gräfe und Djavad Taghizadhe, Stadtmuseum Berlin). Right: illustration in the pocket atlas of potato diseases, drawn by August Dressel (APPEL, 1926).

Investigations on *Fusarium*

Until the mid-19th century, phytopathogenic fungi were not regarded as the cause of plant diseases, but as their consequence. This view was corrected by Anton de Bary, who showed that it is not the plant that produces the fungus, but that the fungus infests the plant and causes the disease (DE BARY, 1861). Julius Kühn and other researchers came to a similar conclusion almost at the same time. The fact that pests were now accepted as independent organisms opened the doors for their targeted control. When Appel was promoted to laboratory director at the Biological Department of Agriculture and Forestry of the Imperial Health Department in 1903, his most intense period of research began (Fig. 2).

From all over Germany, reports of the occurrence of *Fusarium* species in various cultures arrived at Otto Appel's laboratory, accompanied by numerous submissions of infested plant material. Appel and his student Georg Schikorra focused their research activities on infections on legumes and pea in particular (SCHIKORRA, 1907). They produced pure cultures from isolated *Fusarium*, carried out retransmission experiments on pea and could prove the pathogenicity of this fungal pathogen. Appel and his colleague Hans Wilhelm Wollenweber extended these studies by including several other *Fusarium* species. Together they managed to prove that the *Fusaria* are not as variable as was previously thought, and that it is quite possible to distinguish the individual species sufficiently, without placing particular emphasis on the very uncertain feature of the substrate (paraphrased from German original: APPEL and WOLLENWEBER, 1910).

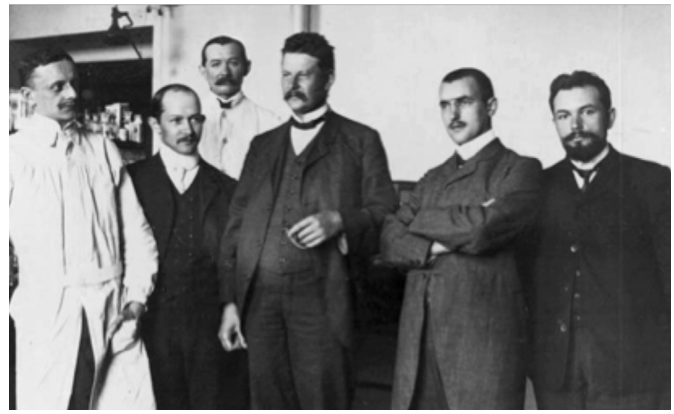

Fig. 2: Otto Appel (fourth from the left) and co-workers at the Botanical Laboratory in Berlin, about 1908 (image: archive of the Julius Kühn Institute).

When searching for specific media for the differentiation of the broadest possible spectrum of *Fusarium*, APPEL and WOLLENWEBER (1910) tested, among others: stems of potato (old mature stems), pea, apple (two-year shoots), rye, lupine, bean (*Vicia faba*), fruits of apple, pear, melon, banana, potato tubers, carrot roots, rye seeds and leaves of peas, potatoes and apple (Fig. 3). Artificial media based on nutrient salts and defined carbohydrate and protein sources have been investigated, too. On these standardized nutrient media, Appel and Wollenweber cultivated the *Fusaria* they had, described their properties and rearranged them. Furthermore, they assigned many hithero unknown pathogenic fungi (Tab. 1).

They summarized the most important results in the standard work "Grundlagen einer Monographie der Gattung Fusarium (Link)" (= Fundamentals of a monograph of the genus *Fusarium* (Link)) as follows (translated from German original APPEL and WOLLENWEBER, 1910):

- It has been proven that a better differentiation of *Fusarium* species is possible by using features that have not been previously applied or not sufficiently appreciated.
- A culture method was found for the cultivation of normal conidia. The criteria of the normal concept in conidia were derived from form, construction, colour, changes in content, and age of the individual conidia.
- As a result, cooked vegetables were able to produce normal forms of *Fusarium* species.
- The conidia were mainly detected on stems, but several exceptions occurred.
- For fruit types, conidia and chlamydospores were found in most species, the latter not necessarily, the former always

In addition to numerous *Fusarium* species, Otto Appel also described various other phytopathogenic fungi over the years (Tab. 1). Among them are several species obtained from the former German colonies Cameroon and Samoa, especially those collected from cocoa (APPEL and STRUNK, 1904; APPEL and LAUBERT, 1906). He also collected infestation symptoms of various pathogens, preserved them in formalin, and thus created an extensive wet collection of phytopathological features for research and teaching purposes (Fig. 4). This collection still exists today at the Julius Kühn Institute, the successor institution of the Biological Department of Agriculture and Forestry, and a digital catalog can be found at https://phytopath-sammlung.julius-kuehn.de/.

Fig. 3: Several *Fusarium* species after four weeks of different culture media (image taken from APPEL and WOLLENWEBER, 1910). 1. *Fusarium solani*, 2. *F. orthoceras*, 3a. *F. subulatum* on Agar No. 42 with orange colored conidia on pale aerial mycelium, 3b. *F. subultum* on Agar No. 46 with dark red thallus depicted from below, 4. *F. willkommii*, 5. *F. subulatum*, juvenile stage of the culture from 3b, 6. *F. coeruleum*, 7. *F. discolor*, 8a. *F. metachroum* on Agar No. 42 with orange colored conidia, 8b. *F. metachroum* on Agar No. 46 with dark red submerged thallus, 9. F. finely powdered, darker colored conidia on ochre colored, wrinkled thallus.

Fig. 4: Specimen of infected potato tubers preserved in formalin (collected and prepared by Otto Appel) – Left to right: Dying radicles caused by *Rhizoctonia solani*, Silver scurf caused by *Spondylocladium atrovirens* (= *Helminthosporium solani*), two examples of *Fusarium* infested tubers (Phytopathological Collection of the Julius Kühn Institute; images by Manfred Gräfe und Djavad Taghizadhe, Stadtmuseum Berlin).

The control of smut fungi

Aside from the genus *Fusarium*, the Biological Department of Agriculture and Forestry in Berlin also focused on methods to control the spread of smut fungi. These activities were further reinforced when in 1905 smut fungi appeared so strongly in the province Hanover that, according to a report, up to 50% of the wheat ears were destroyed (APPEL and RIEHM, 1911a). Appel tried to develop a method for combating the two most important smut fungi species, *Ustilago hordei* and *Ustilago tritici*. The special challenge here was that the fungus infects the embryo inside the seed and not the outside of the kernel, as with other smut fungi. Therefore, surface treatment of seeds with copper vitriol or 0.1% formalin solution or various hot water treatments proved to be ineffective (APPEL and GASSNER, 1907a). A production of smut fungi-free seeds was not possible in practice, since there were no pathogen free fields available. Only the use of less susceptible varieties proved to be a promising approach to control the further spread of smut fungus. It was found that varieties with a short flowering phase or only slightly opened flowers were much less affected (APPEL and RIEHM, 1911b). By breeding appropriate genotypes, the infestation pressure could thus be reduced.

However, this is a long-term approach, while Otto Appel was looking for a suitable solution with a shorter time frame. In literature, Appel came across the hitherto unregarded work of JENSEN (1891), who was able to create smut fungi free plants from previously infected seeds. Based on the assumption that germinating spores or seeds react more sensitively to external influences than resting spores or seeds, it was now necessary to determine which external conditions would be optimal to reduce the spores without harming the embryo within the seed. In this context, Appel gained deeper insights into the biology of airborne pathogens, in particular at which temperature or grain moisture the fungus germinated, at what time the germination took place and at which temperature the pathogen could be killed safely. As a result, he recommended the following sequence for a hot water treatment to combat the pathogen (APPEL and GASSNER 1906, 1907a, 1907b):

1) activation of the fungal mycelium by soaking of the seeds for 4 h in 27 °C water,
2) killing the mycelium by a hot water treatment (5 min in 52 °C water),
3) drying the seeds

The importance of resistance breeding

Otto Appel valued resistance breeding as a very useful tool for maintaining the health of crops. At that time, breeding was still performed by the selection of plants with desired traits from the available pool of crop plants, as it had been done for hundreds of years, but not by goal-oriented crossing. Although Appel had only little experience in plant breeding, he highlighted the enormous potential of this approach and repeatedly made this topic the subject of discussions. In a review published in "Science", he provided a detailed description of necessary breeding activities in order to receive disease-resistant varieties (APPEL, 1915). Here, he mentioned that the basis of resistance breeding is the existence of suitable resistant plant material, either in already existing varieties or in closely related wild plants. The transfer of the valuable features can be obtained via grafting or crossing. As possible aims of such breeding approaches he proposed: 1) wheat varieties with closed flowers to control loose smut, 2) short flowering time in cereals for controlling ergot, 3) small, hairy leaves in potato, which dry faster, to combat *Phytophthora*, 4) a few small lenticels in potato tubers to combat soft rot and 5), rapid cork formation in potato tubers to combat *Fusarium* (APPEL, 1915).

Feeding experiments with harmful feed

In addition to phytopathological investigations, Otto Appel also performed studies to answer the question whether crops affected by pests can be safely used as animal feed. While previous work mainly focused on food intake, Appel was also interested in whether pest infected feed could possibly cause changes to the digestive system, the associated glands and other internal organs, that led to a disease of the animals. Together with the veterinarian Franz Koske, he conducted feeding experiments on pigs, poultry and pigeons with wheat infested with common bunt (*Tilletia caries*) as well as tests on pigs and cattle with potatoes infested with potato blight (*Phytophthora infestans*) and tuber wet rot (*Pectobacterium atrosepticum*) (APPEL and KOSKE, 1907). In a subsequent autopsy, no changes were recognized in the internal organs of any of the animals, although the

Tab. 1: Phytopathogenic fungi identified by Otto Appel and colleagues. Where applicable, revised names according to Index Fungorum (www.indexfungorum.org, accessed 5th July, 2019) have been added.

name given by Otto Appel	reference	revised name
Acremonium sclerotiniarum Appel & Laubert	(Appel and Laubert, 1906)	
Colletotrichum theobromae Appel & Strunk	(Appel and Strunk, 1904)	
Corymbomyces Appel & Strunk	(Appel and Strunk, 1904)	*Sphaerostilbella* (Henn.) Sacc. & D. Sacc.
Corymbomyces albus Appel & Strunk	(Appel and Strunk, 1904)	
Diplodina corticola Appel & Strunk	(Appel and Strunk, 1904)	
Discella cacaoicola Appel & Strunk	(Appel and Strunk, 1904)	
Fusarium colorans De Jonge, Appel & Wollenw.	(Appel and Wollenweber, 1913)	
Fusarium discolor Appel & Wollenw.	(Appel and Wollenweber, 1913)	
Fusarium elegans Appel & Wollenw.	(Appel and Wollenweber, 1913)	
Fusarium gibbosum Appel & Wollenw.	(Appel and Wollenweber, 1913)	
Fusarium martii Appel & Wollenw.	(Appel and Wollenweber, 1913)	*Fusarium solani* (Mart.) Sacc.
Fusarium metachroum Appel & Wollenw.	(Appel and Wollenweber, 1913)	
Fusarium orthoceras Appel & Wollenw.	(Appel and Wollenweber, 1913)	*Fusarium oxysporum* Schltdl.
Fusarium rostratum Appel & Wollenw.	(Appel and Wollenweber, 1913)	
Fusarium rubiginosum Appel & Wollenw.	(Appel and Wollenweber, 1913)	
Fusarium subulatum Appel & Wollenw.	(Appel and Wollenweber, 1913)	
Fusarium theobromae Appel & Strunk	(Appel and Strunk, 1904)	
Fusarium ventricosum Appel & Wollenw.	(Appel and Wollenweber, 1913)	*Rectifusarium ventricosum* (Appel & Wollenw.) L. Lombard & Crous
Lasiodiplodia nigra Appel & Laubert	(Appel and Laubert, 1907)	
Pyricularia caudata Appel & Strunk	(Appel and Strunk, 1904)	*Trichoconis caudata* (Appel & Strunk) Clem.
Rhabdospora ramealis var. *macrospora* Appel & Laubert	(Appel and Laubert, 1907)	
Rhabdospora theobromae Appel & Strunk	(Appel and Strunk, 1904)	
Typhula stricta Appel	(Appel and Laubert, 1907)	
Typhula intermedia Appel & Laubert	(Appel and Laubert, 1907)	*Typhula variabilis* Riess
Ustilago dura Appel & Gassner	(Appel , 1912)	

discharged feces during the time of feeding had consisted mostly of spores. Appel and Koske (1907) concluded that, in the case of an unfavorable feeding effect, the detection of fungal spores is not sufficient to explain a possible harmfulness of a feed.
Faintness and diarrhea were observed in pigs and cattle for a short time during the experiments with dry and wet rotten potatoes, but these symptoms quickly disappeared. Disease symptoms did not occur, but the weight gain of treated animals was slightly lower than that of the control group. In addition, the texture of fat in the treated pigs was less firm. However, the appearance and taste of the meat was not affected in pigs or cattle (Appel and Koske, 1907).

Reorganisation of the plant protection service in Germany

A major outbreak of *Phytophthora infestans* halved the German potato harvest in 1916 and, complemented by halted trade due to World War One, led to mass starvation in Germany known as the Turnip Winter. This made the importance of an effective crop protection clear once more.
In 1919, Otto Appel held a talk on the future of plant protection in Germany at the meeting of the Association for Applied Botany. It was subsequently published as the very first article in the journal Angewandte Botanik (nowadays Journal of Applied Botany and Food Quality), the new central publishing organ of the Association with Paul Graebner, Ernst Gilg and Karl Müller as its first editors (Appel, 1919).
In this talk, he emphasized the necessity of a centrally organized plant protection service. He called for reliable statistics on the occurrence of plant diseases and for standardized efficacy testing of plant protection agents as well as for the application equipment. He argued that both, scientists and the practicians in plant protection would benefit from a closer collaboration and demanded that specialized professorships for phytomedicine should be created instead of treating this subject as a minor side interest.
When Otto Appel became director of his institute, now called Imperial Biological Research Centre for Agriculture and Forestry (Biologische Reichsanstalt für Land- und Forstwirtschaft) in 1920, he used his newly gained responsibility to reorganize the institution, established new branches and field offices throughout Germany, and reactivated the plant protection service, making it powerful and sustainable. At that time he had no longer time for his own scientific research, but was focused mainly on the creation of new positions in the field of crop protection and thus to continuously expand the research work of his institute.
Aside from plant protection, he also emphasized the importance of harvest protection as a national challenge (Appel, 1933a) and the impact of pest control on food products (Appel, 1932a). He suggested measures to increase agricultural production (Appel, 1932b) and contributed to a reformation of the training of technical assistants in plant protection (Appel, 1941). He referred to the enormous possibilities of resistance breeding for modern crop protection, repeatedly (Appel, 1915, 1927a, b, c, 1930). He was co-editor of several books such as "Handbuch der Pflanzenkrankheiten" (Appel, 1937), and of the journals "Deutsche Landwirtschaftliche Rundschau" and "Der Biologe". The "pocket atlases" published by Appel were received with great interest by farmers and quickly became standard works for the most important diseases and pests of crops and their control (Appel, 1925, 1926a, 1926b, 1928a, b, 1929a, 1929b, 1931, 1933b,

1934, 1944). In 1933, he retired from his position as director of the Imperial Biological Research Centre for Agriculture and Forestry at the age of 66.

His achievements were honored with honorary degrees from the Universities of Vienna, Sofia and Berlin. After being active in many learned societies in his field and being member of the Academy of Sciences Leopoldina, he was also Honorary President of the Vereinigung für Angewandte Botanik (Association for Applied Botany) in Germany and Honorary chairman of the Vereinigung Deutscher Pflanzenärzte (Association of German Plant Medics, which has later been re-organized into the German Phytomedical Society). On his 85th birthday on May 19, 1952, he became the first phytopathologist to be awarded the German Grand Federal Cross of Merit (Bundesverdienstkreuz, Fig. 5). Shortly thereafter, he passed away on November 10, 1952.

Otto Appel has met the challenges in phytomedicine of his time with perspicacity and enthusiasm, offered numerous solutions and revolutionized plant protection in many areas. His work on plant protection has made him known far beyond the borders of Germany. Today he is regarded as one of the most important phytopathologists in the first half of the 20th century and in remembrance, the Deutsche Phytomedizinische Gesellschaft awards the Otto Appel Medal to outstanding researchers in phytomedicine.

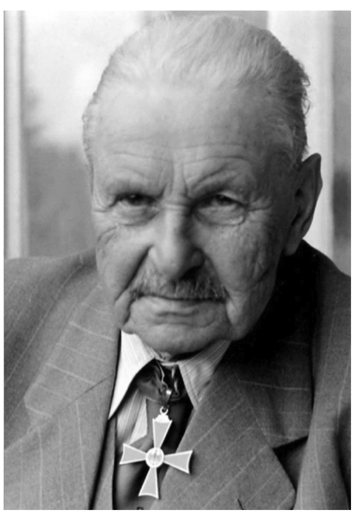

Fig. 5: Prof. Dr. Dr. h.c.mult. Otto Appel, honored with the German Grand Federal Cross of Merit in 1952 (Bundesverdienstkreuz).

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