A PHYSIOLOGICAL METHOD OF DISTINGUISHING CRONARTIUM RIBICOLA AND C. OCCIDENTALE IN THE UREDINIAL STAGES[1]

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INTRODUCTION

A differential investigation has been undertaken to separate physiologically the white pine blister rust (*Cronartium ribicola* Fischer) and the piñon blister rust (*C. occidentale* Hedge., Beth., and Hunt (*7*)[3]), which are morphologically very similar, on species and horticultural varieties of Grossulariaceae. This study was necessary because the uredinial stages of the exceedingly detrimental white pine blister rust and the native piñon or nut pine blister rust, which economically has little importance, are macroscopically indistinguishable, and because both rusts occur in the Pacific Northwest where a control campaign is now being conducted against the recently introduced white pine blister rust, which threatens the highly valuable stands of western white and sugar pines (*Pinus monticola* D. Don. and *P. lambertiana* Dougl.) in the forests of that region. The biometric method recently described by Colley (*4*), by which the uredinial stages of *C. ribicola* and *C. occidentale* in most cases can be separated on the basis of differences in the average lengths and wall thicknesses of the urediniospores, has been shown to be fairly good, but fallible because some specimens are so near the biometric border line separating the two species that their identity became dubious.

To obtain differential hosts, many species and horticultural varieties of foreign and native Grossulariaceae were assembled for propagation. The species of Ribes herein reported include the foreign species and varieties, a group in which the best differential hosts were discovered. Differential results with a group of Ribes from the Pacific Northwest have been reported (*5*).

HOST PLANTS TESTED

The foreign species and varieties of Ribes tested include horticultural varieties of the common red and white garden currant, horticultural varieties of *R. nigrum* L., and miscellaneous species.

The considerable number of varieties of the common garden currant tested in these experiments have been grouped for convenience under

[1] Received for publication Apr. 18, 1929; issued January, 1930.

[2] The writer is under obligation to members of the Office of Forest Pathology for advice and assistance in conducting this investigation; to the late C. S. Sargent, formerly of the Arnold Arboretum, Jamaica Plain, Mass.; to Paul Thayer, of the Ohio Agricultural Experiment Station, Wooster, Ohio; to R. E. Horsey, of Rochester Park, Rochester, N. Y.; to W. H. Alderman, of University Farm, St. Paul, Minn.; to George M. Darrow and Miss M. R. Newman, of the Office of Horticultural Crops and Diseases; to George G. Hedgcock, of the Office of Forest Pathology, for Ribes material for inoculating purposes; to E. P. Meinecke, of the latter office, to J. S. Boyce and the late Ellsworth Bethel, both formerly of that office, and to members of the Office of Blister Rust Control, for culture strains of rusts; and to Carl Hartley, of the Office of Forest Pathology, for valuable assistance in the preparation of the manuscript.

[3] Reference is made by number (italic) to "Literature Cited," p. 120.

the name *Ribes sativum* (*R. vulgare*) until they can be assigned to the proper species. Bunyard (*2*) in his study of this group concluded that certain varieties sprang from the following species: *R. vulgare* Lam., *R. petraeum* Wulf., and *R. rubrum* L. This opinion was also held by Wilmott (*15*) and Thayer (*13*, *14*). To quote the latter (*14*, *p. 316*):

It so happens that the first of the species [*R. vulgare*] given * * * in which we are interested is historically first so far as introduction is concerned and also first in commercial importance, for there are but few varieties in general cultivation that do not show the influence of this species.

On the other hand, Berger (*1*) and other authorities considered *R. sativum* (Rchbch.) Syme the preferred name for the garden currant. According to Berger, the subgenus representing the group of red currants comprises 15 more or less closely related species, natives of the Northern Hemisphere; *R. sativum* occurs in western Europe and in North America, where it has escaped from cultivation and is subspontaneous from Massachusetts to Ontario and Wisconsin, south to Virginia, and in Oregon and British Columbia. For the most part the varieties studied in these differential tests were obtained from nurserymen; hence certain of the varietal names herein quoted can not be taken as thoroughly dependable because of the possibility that varieties obtained from this source may not always be true to name.[4] Certain varieties are still to be assigned their proper designations. Where names of varieties were uncertain or not found listed, the writer has indicated these facts by quotation marks.

Carefully named varieties of red and white currants were obtained from the following sources:[5] From Paul Thayer: 11 B, London Market; 14 A, Victoria; 28, Holland; 51 B, Wilder; 58 B, White Dutch; 67 B, Transparent. From George M. Darrow: White Versailles, Goliath, and Holland. A variety cited as "Ginkgoides" is a new unnamed variety which originated in the garden of the late Ellsworth Bethel, Denver, Colo. Bethel regarded it as a sport or variety of the common garden red currant.

Horticultural varieties of *Ribes nigrum* were also tested. The black currant, unlike the red, appears to be derived from a single species which has certain variations, as stated by Hatton (*6*). The varieties investigated included Champion, "Carter," Victoria, Black Naples, "Black Dutch," Boskoop Giant, and Blacksmith. The last two varieties were received from Paul Thayer.

Other species tested from the following sources included: From C. S. Sargent: *Ribes succirubrum* Zabel, *R. culverwellii* MacFarl., *R. alpestre* Decaisne, *R. tenue* Jancz., *R. carrierei* Schneider, *R. giraldii* Jancz. From R. E. Horsey: *R. carrierei*, *R. fasciculatum* Sieb. and Zucc., and *R. luridum* Hook and Thom. From G. M. Darrow: The hybrid Van Fleet gooseberry (regarded for convenience as *Grossularia reclinata*). From Block Island, R. I.: *R. alpinum* L.

[4] In attempting to determine the proper names to be applied to each variety investigated by the writer the difficulty just alluded to has been increased by the great confusion that exists in the nomenclature of the common garden currant. The wide distribution of the currant varieties in this country and in Europe, under different names, and the fact that the names sometimes appear, as presented in this paper, in a foreign language, and at other times in the translated form, makes the determination of the correct name exceedingly difficult. There is even further difficulty because of the conflict of opinion among authorities as to priority among the names by which a variety should be known. In general, the names of varieties used in the present investigation are those listed by Thayer (*14*).

[5] Cuttings from a number of varieties were received through the kindness of W. H. Alderman. Unfortunately, these cuttings failed in propagation.

SOURCE OF THE INOCULUM

The inoculum used in the tests was derived from various geographical sources. Uredinial culture strains of *Cronartium ribicola* were obtained from aecia occurring on *Pinus strobus* L. from New England (FP[6] 37073, 38380, 38382, 40300, and 41012), on *P. monticola* from British Columbia (FP 38805), and on *P. monticola* from Scotland (FP 38801). Those of *C. occidentale* were obtained from aecia on *P. edulis* Engelm. from Colorado (FP 36704, 38418, and 41391) and on *P. monophylla* Torrey and Fremont from Nevada (FP 36028, 36922, 38381, and 41365). Uredinial culture strains of *C. occidentale* were also obtained from uredinia occurring on *Ribes aureum* Pursh. from California (FP 36921, 38386) and from Wyoming (FP 38112).

BEHAVIOR OF THE RUSTS IN THE GREENHOUSE

The behavior of the white pine and piñon blister rusts in the uredinial stages in the greenhouse has been described in an earlier paper dealing with the Pacific northwestern Ribes (*5*). The statements made there apply equally well to the present investigation. Leaves of *Ribes sativum* (*R. vulgare*) proved to be susceptible to *Cronartium ribicola* for only a limited period; immature leaves did not become infected, nor did leaves that had commenced to harden. This limited period of receptivity of *R. sativum*, already referred to in the consideration of the closely related wild red currant (*R. triste* Pall.) in the Northwest (*5*), appears to be a very constant physiological character, bearing out the observation of York,[7] who found in his greenhouse tests that plants of *R. triste* from the eastern part of the United States did not develop rust infection from *C. ribicola* until the leaves were two-thirds mature.

On *Ribes nigrum*, *Cronartium occidentale* gave an even more characteristic reaction. Repeated trials with this rust showed that it would infect only scantily, or not at all, very young or middle-aged leaves of *R. nigrum*, whereas it infected moderately and even heavily fully matured leaves at the base of the shoot and produced a large number of telia and uredinia during the fall.

Rust infection in the greenhouse proved much more successful in late summer and fall than at other seasons. This was particularly true for *Cronartium ribicola* on *Ribes sativum*, and for *C. occidentale* on *R. nigrum*. These observations corroborate those of Stakman and Piemeisel (*12*), who reported that *Puccinia graminis* Pers. developed unusually well in late September and early October, a period they found ideal for rust development in the greenhouse; and those of Spaulding (*11*), who found in his investigation with *C. ribicola* that leaves produced from buds developing in late summer or fall readily become infected.

Trouble was experienced with mildew (*Sphaerotheca mors-uvae* (Schw.) Berk. and Curt.) on certain of the species tested, particularly the varieties of *Ribes nigrum*, making it impossible at times to use the plants for the experiments. Even the very susceptible *R. nigrum* would barely become infected with *Cronartium ribicola* when the leaves were attacked by mildew. Fortunately, *R. sativum* variety Fay (Fay's Prolific), with which these experiments were largely

6 Collection number of specimens for study, Office of Forest Pathology, Bureau of Plant Industry.

7 YORK, H. H. FIELD STUDIES OF CRONARTIUM RIBICOLA IN THE WHITE MOUNTAINS OF NEW HAMPSHIRE. [Unpublished manuscript.]

concerned, was not affected with mildew. This freedom from mildew shown by the Fay variety was reported by Salmon and Wormald (*9*) in England; they observed that a severe outbreak of the American gooseberry fungus occurred on Raby Castle, while the Fay variety in the immediate neighborhood remained uninfected.

So far as the writer observed, there was no apparent difference in the length of time required for the first signs of rust infection to appear on susceptible leaves and on resistant ones of the same species or variety. Fertile pustules matured in a shorter period on susceptible leaves than on resistant ones; aborted or abnormal pustules developed after a somewhat longer period of time. Peltier (*8*) cited a somewhat similar condition as the result of his infection studies with stem rust of wheat.

METHODS

The methods followed in obtaining the results set forth in this paper have already been described (*5*). As previously stated, these methods were based upon those used by cereal-rust investigators but adapted to the requirements of the Ribes host.

PRODUCTION OF INOCULABLE LEAVES BY MEANS OF COLD STORAGE

Since the differential study involved in the main an extensive experimentation with varieties of *Ribes sativum* (*R. vulgare*), it was necessary to have plants with inoculable leaves for all times of the year, particularly in the fall. Normally, *R. sativum* produces a single crop of leaves in the spring, which by fruiting time become fully matured and hardened, thereby being rendered unfit for inoculation purposes. To insure leaves for continuous inoculation purposes, a cold-storage method was used. Plants of *R. sativum* which had passed through their active growing period or were in a dormant condition were sunk in damp sphagnum moss in flats and placed in a cold-storage room where the temperature was kept approximately at the freezing point. Such plants required watering about every three weeks to prevent their drying out. Plants thus kept at low temperature for two or preferably three months break into leaf readily upon withdrawal from the storage room. They should at first be kept in a cool room after repotting in fresh soil and gradually be taken to warmer sections of the greenhouse. Plants so treated will produce leaves within a month or longer, the length of time depending upon the season of the year. Plants placed in storage during late spring or early summer can thus be made available for fall work, and plants kept over winter can be utilized during the early spring months. Inasmuch as field scouting in the Pacific Northwest, where the piñon and white pine blister rusts are to be found, is carried on mainly during the late summer and fall, this procedure for insuring inoculable leaves at this time is an essential part of any method of identifying by inoculation tests the Cronartium specimens which the scouts find on Ribes.

RECORDING DATA

The inoculated plants were classified by infection types, based on the pathologic symptoms produced by the rusts on Ribes leaves. The symbols indicating these inf tion types and the relative quantity or abundance of uredinia produced on the infected leaves have been fully described in a paper recently published (*5*). The symbols indicating the types of infection are described briefly as follows:

Resistant types:
Immune—
○ No uredinia formed; hypersensitive or necrotic areas present or lacking.
Resistant—
◑ Uredinia minute; associated with hypersensitive or necrotic areas.
Susceptible type:
● Uredinia normal size; no hypersensitive or necrotic areas.

The relative quantity or abundance of uredinia produced on the infected leaves was also expressed in the note taking by symbols. They are described briefly as follows:

=, *Trace.*—Uredinia bare trace, or very few in number.
−, *Slight.*—Number of uredinia below normal, scanty.
±, *Moderate.*—Medium production of uredinia; normal infection.
+, *Heavy.*—Infection heavier than medium.
++, *Very heavy.*—Extremely abundant production of uredinia.

In recording the abundance of uredinia produced on each host species or variety tested, a rating was given the plant as a whole.

CORRELATING DATA

The symbols indicating the abundance of urediniospores on uredinia-bearing leaves of a given Ribes species or variety were reduced to a numerical basis and averaged (*5, p. 672*). Table 1 gives the numerical expression for each symbol.

TABLE 1.—*Mathematical as related to symbolic expression of the abundance of uredinia production*

Symbols for relative abundance of uredinia produced on infected leaves	Equivalent	Range of class [a]	Mid value of class [a]	Abundance of uredinia
		Per cent	*Per cent*	
=	(X)	Less than 5	2.5	Trace.
−	X [b]	5–35	20.0	Slight.
±	XX [b]	35–65	50.0	Moderate.
+	XXX [b]	65–85	75.0	Heavy.
++		85–100	92.5	Very heavy.

[a] The percentage values are rational expressions of the abundance of uredinia production based on the maximum uredinia development on completely infected leaves of *Ribes nigrum*, under favorable conditions, which were taken as a standard. In converting the symbols into numbers, each was assigned the mid value of the class that it represents.
[b] Symbols used in previous white pine blister rust investigations. See Spaulding (*11*). Range percentage and mid values of classes do not apply to these symbols.

In obtaining the averages shown in Figures 1 and 2, the rating for each plant tested was weighted by the number of spore-producing leaves on the plant.

PHYSIOLOGICAL COMPARISON OF CRONARTIUM RIBICOLA AND C. OCCIDENTALE

ON MISCELLANEOUS FOREIGN RIBES SPECIES

In the differential study of the white pine and piñon blister rusts on foreign species and horticultural varieties, a number of miscellaneous foreign species were tested. The study also included 62 plants (367 leaves) of *Ribes nigrum* inoculated with *Cronartium ribicola* and 72 plants (466 leaves) inoculated with *C. occidentale*, together with 250 plants (1,713 leaves) of the group *R. sativum* (*R. vulgare*) inoculated with the first-named rust, and 344 plants

FIGURE 1.—Results of inoculations with *Cronartium occidentale* and *C. ribicola* on horticultural varieties of *Ribes nigrum*. The black bar shows the average abundance of fertile uredinia of *C. occidentale* for all the leaves inoculated. In averaging, the results on the different plants were weighted according to the number of spore-producing leaves. The figures above the bars show the total number of leaves inoculated. The symbols at the left margin are explained on page 109. The figures at the left margin are on a scale on which 100 is the maximum uredinia production for *C. ribicola* on fully susceptible leaves of *R. nigrum*. The shaded bar shows the same for leaves inoculated with *C. ribicola*

(2,364 leaves) inoculated with the latter. The results are given in Figures 1, 2, and 3 and in the discussion following.

Among the miscellaneous foreign Ribes species tested with *Cronartium ribicola* and *C. occidentale*, negative results were obtained for both rusts on each of the following: *Ribes luridum* (3 plants, *C. ribicola*; 3 plants, *C. occidentale*); *R. alpestre* (2 plants, *C. ribicola*; 1 plant, *C. occidentale*); *R. diacantha* (1 plant, *C. ribicola*; 1 plant, *C. occidentale*); *R. alpinum* (11 plants, 109 leaves, *C. ribicola*; 8 plants, 55 leaves, *C. occidentale*); *R. culverwellii* (5 plants, *C. ribicola*; 6 plants, *C. occidentale*); *R. giraldii* (9 plants, *C. ribicola*; 3 plants, *C. occidentale*).

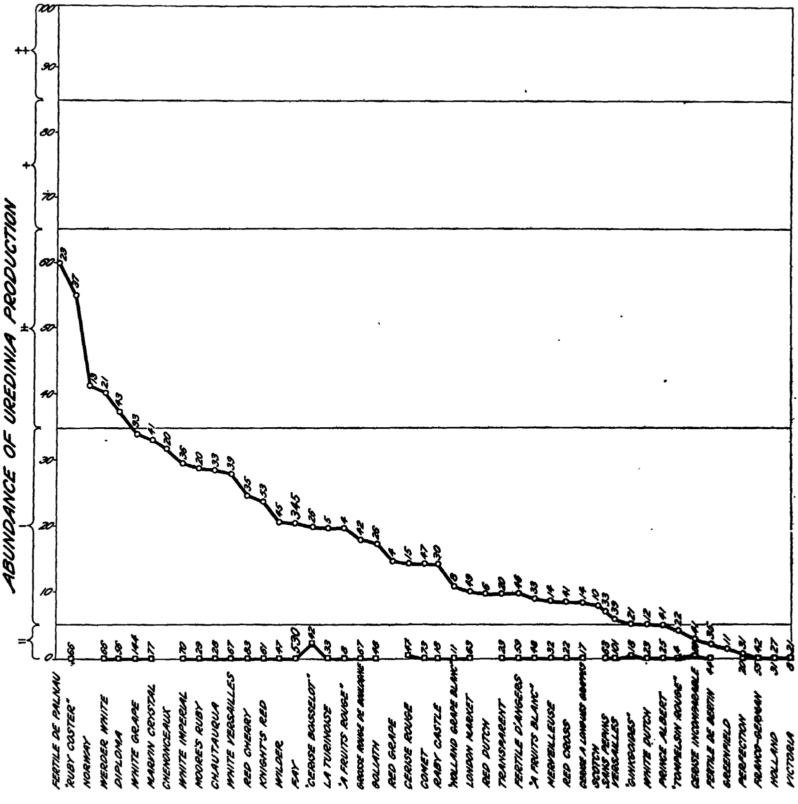

FIGURE 2.—Results of inoculations with *Cronartium ribicola* and *C. occidentale* on horticultural varieties, grouped under the name *Ribes sativum* (*R. vulgare*), stated in terms of the average abundance of uredinia production. In averaging, the results on the different plants were weighted according to the number of spore-producing leaves. The figures above the points on the graph show the total number of leaves inoculated. The symbols at the left margin are explained on page 109. The figures at the left margin are on a scale on which 100 is taken as the maximum uredinial production for *C. ribicola* on fully susceptible leaves of *R. nigrum*. Hollow circle indicates *C. ribicola*; hollow square, *C. occidentale*

Clinton and McCormick (*3*) reported negative results with *C. occidentale* on *R. alpestre*, *R. alpinum* ♀, *R. giraldii*, and *R. luridum*. They also gave negative results with *C. ribicola* on all these hosts except *R. luridum* which averaged fair minus (F −) in 15 tests, and *R. alpinum* ♂, fair minus (F −), in 11 tests. Spaulding (*11*) reported negative results for this latter host species. *R. alpinum* in Europe was said by Schellenberg (*10*) to develop 70 to 90 per cent of infection with *C. ribicola*. These findings do not agree with the results of investigators in this country working with

R. alpinum. Apparently within the species *R. alpinum* there are strains which differ in susceptibility.

Both Cronartiums produced a heavy amount of normal uredinia on *Ribes carrierei* and *R. succirubrum.* A moderate infection of the same type with both rust species was obtained on the hybrid Van Fleet, and a very heavy infection on the Poorman gooseberry varieties, respectively. Spaulding (*11*) cited Poorman as a moderate host for *C. ribicola;* Clinton and McCormick (*3*) reported poor

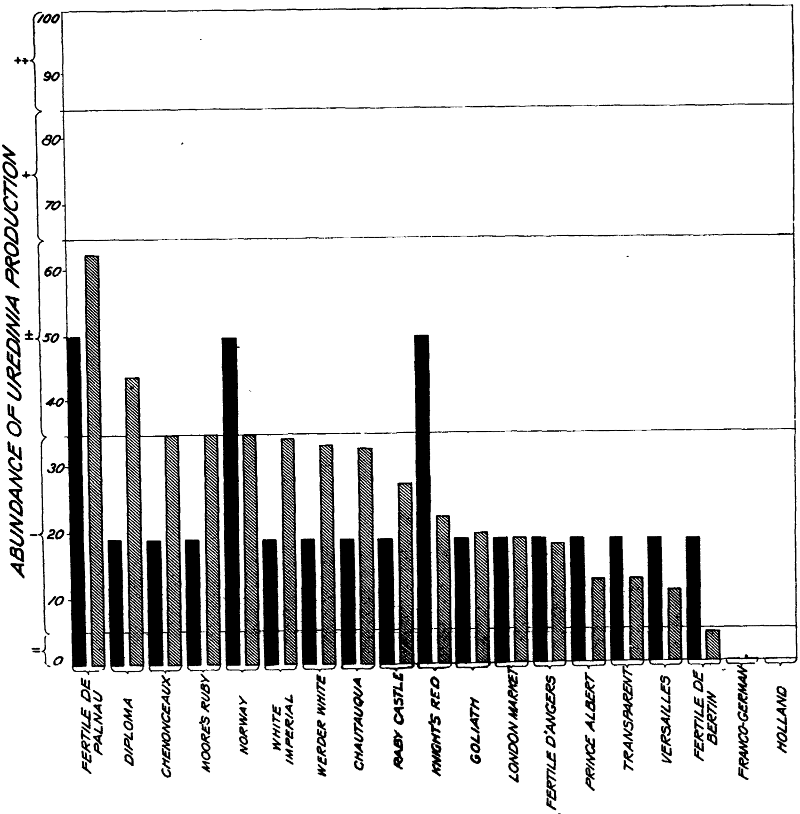

FIGURE 3.—Comparison of results of greenhouse inoculations with *Cronartium ribicola* on horticultural varieties of the group *Ribes sativum* (*R. vulgare*) obtained by the writer and those obtained by Spaulding and his associates. In averaging the writer's results for each variety compared, each plant inoculated was given a mathematical rating equivalent to the mid-point of the degree of infection class to which each belonged. The symbols at the left margin and their conversion to an arithmetical basis are explained on page 116. The shaded bar shows the average abundance of uredinia for the total number of plants inoculated by the writer. The black bar shows the average abundance of uredinia for the total number of inoculated plants reported by Spaulding. The conversion of infection ratings to a basis comparable with the writer's ratings is explained on p. 116

results on a large gooseberry and Smith (gooseberry) for both Cronartiums.

Results on *Ribes fasciculatum* (5 plants, 44 leaves) and *R. tenue* (3 plants, 52 leaves) were negative for *Cronartium occidentale.* On the former host (5 plants, 34 leaves) and on the latter (6 plants, 72 leaves) *C. ribicola* produced a slight (−) infection. The average abundance of uredinia production for these 72 leaves of *R. tenue* gave a numerical value (based on the scale of 100 for completely infected leaves of *Ribes nigrum*) of 6.5. Clinton and McCormick (*3*) reported poor plus (P+) results for *R. tenue* with *C. ribicola* in 10 tests, and Spaulding (*11*) obtained heavy infection on this host in two tests. Possibly there are also in this instance within the given Ribes species strains which differ with regard to rust susceptibility.

ON HORTICULTURAL VARIETIES OF RIBES NIGRUM

In Figure 1 are given the results of a physiological comparison of *Cronartium ribicola* and *C. occidentale* on horticultural varieties of *Ribes nigrum*, a host which is extremely susceptible to *C. ribicola* and which remains highly susceptible throughout the growing season. The European black currant can be regarded as a nurse plant for white pine blister rust. So serious a danger is it to the production of white pine timber that it is now regarded as a definite menace to the white pine timber supply of this country.

Ribes nigrum varieties, Blacksmith and Boskoop Giant, failed to become infected with *Cronartium occidentale*. Infection (type ●) on the other varieties tested with piñon rust was secured on the older fully matured leaves at the base of the shoot. Among the varieties extensively tested, Champion proved to be the most susceptible to *C. occidentale*, but only during the fall period; 73 (27 per cent) susceptible leaves of the 273 tested leaves of this variety produced a moderate amount (±) of uredinia. The average uredinia production calculated for these 73 leaves alone was 64.6 (based on the scale of 100 for completely infected leaves of *R. nigrum*). This numerical value was somewhat lower than the value calculated for the amount of uredinia (+) produced by *C. ribicola*, 76.3, for 182 (86 per cent) susceptible leaves out of 211 leaves tested for the same host. Clinton and McCormick (*3*) obtained only poor results for inoculation of *C. occidentale* on *R. nigrum* and *R. nigrum aconitifolium;* the uredinial stage from *R. gracillimum* on *R. nigrum* failed. Hedgcock, Bethel, and Hunt (*7*) list *R. nigrum* as one of the poorest hosts for *C. occidentale* in their inoculation tests.

ON HORTICULTURAL VARIETIES OF RIBES SATIVUM (R. VULGARE)

In Figure 2 is shown the comparison between *Cronartium ribicola* and *C. occidentale* with respect to the amount of uredinia produced on varieties of *Ribes sativum* (*R. vulgare*) for the total number of leaves inoculated. With the exception of four varieties—Cerise Incomparable, Cerise Rouge, "Cerise Boisselot," and "Ginkgoides"—on all of which *C. occidentale* produced infections of the resistant type, the other tested varieties of *R. sativum* were apparently quite immune (type ○) to *C. occidentale*. Positive results on *R. vulgare* (*R. sativum*) with *C. ribicola* have been published by Spaulding (*11*) and by Clinton and McCormick (*3*). In written communications to the writer, Bethel reported that he had found the "Ginkgoides" variety to be only slightly susceptible to *C. occidentale* under field conditions, and N. Rex Hunt stated that on September 15, 1918, he observed, at Bayfield, Colo., *R. aureum* heavily infected with *C. occidentale*, associated with a red currant almost every leaf of which was infected with the same rust. Hunt did not report the varietal name of this currant or the degree of infection of the rust. He also observed cultivated gooseberry and *Grossularia inermis* (Rydb.) C. and B. infected with *C. occidentale*. Clinton and McCormick (*3*), as a result of their rust-infection studies of leaves in Petri dishes, and of pot inoculations, reported negative results for infection with *C. occidentale* on *R. sativum* variety Fay, small currant, and white currant.

The largest number of tests in the present study were made on *Ribes sativum* variety Fay with culture strains of *Cronartium ribicola* from New England and British Columbia on 61 plants (345 leaves). The following culture strains of *C. occidentale* were tested on 100 plants (530 leaves) of the same host variety: One strain from Colorado, on 25 plants (130 leaves); two strains from California (Monrovia), on 29 plants (143 leaves); and three strains from Nevada (Minden), on 46 plants (257 leaves). All the horticultural varieties of *R. sativum* producing fertile uredinia of *C. ribicola* could be classified as belonging to the susceptible type ●. (See p. 110.) Of the 48 varieties tested with *C. ribicola*, 36 produced normal uredinia; 9 produced only resistant-type uredinia; 3 remained immune. The 9 varieties which were resistant (type ◑) under the conditions of the inoculation experiments were: "A Fruits Rouge," "Tompelsin Rouge," "Ginkgoides," Fertile de Bertin, London Market, Perfection, Red Grape, La Turinoise, and White Dutch.

So far as tested, the three varieties Franco-German, Holland, and Victoria were immune (type ○) to both rusts. Further experimentation may duplicate the results already obtained with these three varieties, which so far have proved immune to both Cronartiums, and eventually they may be conclusively regarded as valuable red currants for planting in localities where the growing of this Ribes is desired along with that of white pines. Spaulding (*11*) listed varieties of red currant tested under the following varietal names as resistant to *C. ribicola* but not entirely immune: Eyatt Nova, Franco-German, Holland, London (London Market), Rivers (Rivers Late Red), and Simcoe King. The stock of Franco-German and Holland tested by the writer and found to be immune did not come from the same source as that used by Spaulding.

The three currant varieties listed above by the writer as being immune to *Cronartium ribicola* under the conditions of the foregoing inoculation experiments belong to two of the large groups into which the cultivated currants have been classified (*1, 2, 14*). The Victoria variety belongs to the group "*Ribes rubrum* and hybrids" and was reported by Thayer (*14, p. 386*) as being resistant to disease. In this group is also found the London Market (London) variety, which both Spaulding (*11*) and the writer found to be resistant but not immune.

In the group "*Ribes petraeum* and hybrids" are found the Holland (Long Bunch Holland) and Franco-German varieties, the latter regarded by Thayer (*14, p. 391*) as synonymous with Holland. Concerning the Holland variety, the chief value of which is in its extreme lateness and great resistance to heat and drought, Thayer stated that in the prairie region this variety had done very well.

Prince Albert (Rivers Late Red), which Spaulding (*11*) found to be resistant but not immune to *Cronartium ribicola*, is also in the *Ribes petraeum* group. The same investigator reported (*11, p. 19*) a moderate degree of infection on *R. petraeum*. Until further information is available, it is not wise to favor the cultivation of the Prince Albert (Rivers Late Red) variety, as Thayer suggests (*14, p. 394*), on account of the seeming resistance of *R. petraeum* to the blister rust, for both Spaulding (*11*) and the writer have found that variety to be susceptible (type ●), although only a slight infection (—) was secured. Further experimentation will be necessary, however, before a final, definite opinion concerning the disease resistance of this variety can be obtained.

During a visit to Norway the writer had the opportunity to observe a variety of red currant known as "Red Dutch," which was highly resistant to white pine blister rust. This variety was observed in August, 1927, in the nursery of the Agricultural College at Ås, Norway, growing in immediate proximity to the White Dutch variety, which was heavily infected with the rust. Conditions for rust infection were particularly favorable during 1927 in Norway, and a heavy production of fruiting bodies of species of rusts generally was observed at that time. An examination of plants of the Red Dutch variety did not reveal the presence of sori on any of the leaves. Had the variety been susceptible at all, it is reasonable to believe that it would have become infected during 1927.

Mr. Ivar Jørstad, State mycologist of Norway, Botanisk Museum, Oslo, and Professor Doctor Hagem, of the Botanisk Museum, Bergen, Norway, both regard the Norwegian Red Dutch variety as highly resistant to the white pine blister rust. Jørstad, in correspondence with the writer, has given the following information concerning the synonymy of this variety:

> I can inform you concerning the synonymy of the red-currant strains in question. I have conferred with Mr. P. Stedje, leader of the Pomological Experiment Station at Hermansverk in Sogn. He is our best specialist in this matter and has even quite a few American red-currant strains in culture (these he has obtained from Paul Thayer in Ohio).
>
> Mr. Stedje tells me that there is a great confusion concerning the names of one and the same strain. The Norwegian "Rød hollandsk druerips" (i. e., Red Dutch grape currant), which is the one resistant to *Cronartium ribicola*, is not identical with the Danish "Rød hollandsk druerips," but with their "Rød spansk" (i. e., Red Spanish). Our "Rød hollandsk druerips" is further not identical with the American "Red Dutch," neither with Long Bunch Holland nor Victoria, but it is very similar to Prince Albert and to Rivers Late Red (the two latter are possibly identical). Our "White Dutch," which is susceptible to the rust, is, according to Mr. Stedje, not closely related to our "Red Dutch," and the same is the case with the American "Red Dutch." Although the two latter possess the same name, they are entirely different.

From observations and inquiry made in Norway, the writer is inclined to regard the Norwegian Red Dutch variety of red currant as having great possibilities as a horticultural variety, particularly for planting in white pine areas of the United States when the growing of Ribes is desired along with that of white pine. Comprehensive artificial-inoculation experiments will be necessary, however, to demonstrate completely the apparent immunity of this particular variety under cultural conditions in the United States, before it can be recommended for use in this country.[8]

Figure 3 shows a comparison between the greenhouse inoculation results published by Spaulding (*11*) for certain varieties grouped under the name *Ribes vulgare* (*R. sativum*) and those obtained by the writer on the varieties of the same group, of which more than a single plant was tested. To make the results reported by Spaulding

[8] Preliminary inoculation experiments performed in 1929 at the Royal Botanic Garden, Edinburgh, Scotland, in which plants of the Norwegian Red Dutch currant were inoculated with a Scottish strain of *Cronartium ribicola* under rigorously controlled conditions demonstrated the Norwegian variety to be immune to white pine blister rust. See HAHN, G. G. PRELIMINARY REPORT ON A VARIETY OF RED CURRANT RESISTANT TO WEYMOUTH PINE RUST. Trans. Bot. Soc. Edin. 30: 137–146, illus. 1929.

and his associates comparable with those of the writer, it seeemd best to reduce the infection rating given by them to a numerical basis, on a scale in which 100 represents the abundance of uredinia on completely infected plants of *R. nigrum* with *Cronartium ribicola* under favorable conditions. The symbol of a cross within parentheses (×) was interpreted to indicate a degree of infection more than O but less than 5 per cent (trace of infection); × for 5 to 33 per cent (slight infection); ×× for 33 to 67 per cent (medium infection); and ××× for 67 to 100 per cent (heavy infection). This interpretation was approved by Spaulding. The midpoints of the classes are therefore as follows: (×), 2.5; ×, 19; ××, 50; and ×××, 83. This method of reducing ratings to a numerical basis is practically the same as that used by the writer in averaging his own data (see p. 109), and the converted results of the two investigations conducted under greenhouse conditions show a reasonable agreement.

Ribes sativum can be considered only a fair host for *Cronartium ribicola*, for it produces fewer uredinia than most Ribes species even when infected under the most favorable conditions. Clinton and McCormick (*3*), in averaging their results for infection of *C. ribicola* on *R. vulgare* (*R. sativum*) in Petri dishes and with pot inoculations, reported the following: On *R. vulgare*, F− in 22 tests; on Fay, F− in 24 tests; on *R. vulgare* (small), F− in 18 tests; on *R. vulgare* (white), F in 15 tests. The symbols used by Clinton and McCormick are as follows: O, failure; P, poor; F, fair; G, good; and E, excellent. To quote these writers:

> As a rule poor indicates that fewer than five sori developed. Excellent implies the development of 40 or more on a leaf or leaves in a Petri dish and an even greater total number on the leaves of a plant in a pot. Good and fair are intermediate terms.

So far as a comparison between the Petri-dish method of inoculation of *R. sativum* (*R. vulgare*) and the pot inoculations was concerned, somewhat better results were obtained with the latter method.

IMPORTANCE OF RIBES SATIVUM (R. VULGARE) AS A DIFFERENTIAL HOST

A consideration of the foregoing results indicates that among the horticultural varieties of the group *Ribes sativum* (*R. vulgare*), certain varieties tested upon a comparative basis—Chautauqua, Comet, Diploma, Fay, Fertile d'Angers, Goliath, Grosse Rouge de Boulogne, Knight's Red, Marvin Crystal, Raby Castle, Red Cherry, Red Cross, "Ruby Coster," Moore's Ruby, Werder White, White Grape, White Imperial, White Versailles, and Wilder—have shown themselves to be good differential hosts. The most extensive comparative tests were made with the variety Fay (Fay's Prolific). Repeated tests with Fay have shown it to be a most dependable separating host, provided due attention is given to the securing of suitable leaves for inoculation purposes; the variety lends itself readily to propagation both in and out of the greenhouse. Its freedom from mildew and its adaptability to the cold-storage methods above described make it indispensable as a differential host.

Differences obtained on other host species were not definite enough to be relied upon. The attempts to infect *Ribes nigrum*, varieties Blacksmith and Boskoop Giant, with *Cronartium occidentale* should be carried farther before the immunity of these varieties herein reported can be unqualifiedly accepted. The readiness with which

C. ribicola infects species of Grossulariaceae generally has made it impossible so far to find a species which is resistant or immune to *C. ribicola* and not to *C. occidentale.* Whenever Ribes species have shown resistance to *C. ribicola,* they have manifested the same reaction to the piñon rust. Where Ribes have shown a difference in reaction between the two, this difference has consisted in better production of uredinia by *C. ribicola* than by *C. occidentale.*

METHOD OF DIAGNOSING AN UNKNOWN CRONARTIUM ON RIBES

It has already been demonstrated (*5*) that the native Pacific northwestern Ribes in areas where the two Cronartiums are expected to intermingle are generally susceptible to both rusts. Any Cronartium found on Ribes in Idaho and the adjoining region is therefore an unknown. Upon receipt of such a specimen from the field, slides of the spores of the unknown Cronartium are made for measurement and the remainder straightway inoculated upon *Ribes sativum* (*R. vulgare*) variety Fay. *R. aureum,* a congenial host, is inoculated at the same time. Such an inoculation determines the viability of the unknown spores which are to be tested and also is the means of securing a vigorous stock culture for any further investigation which may be necessary. As an added check, duplicate plants of the Fay variety in the same condition of leaf are also inoculated, as a parallel test, with a known strain of *C. ribicola.* This check on the test of the unknown shows whether the leaves of the variety of *R. sativum* are in the right condition for inoculation; a precaution such as has been pointed out is highly desirable with this host. Results should be obtained within 14 days, the length of time necessary for fertile pustules to appear. The interpretation of the results is explained in Table 2.

TABLE 2.—*Method of interpreting results of inoculation tests with an unknown Cronartium from Ribes*

[Positive denotes the production of uredinia (type ●) on some of the inoculated leaves; negative denotes absence of uredinia]

Result of—			Interpretation
Inoculations with unknown Cronartium		Parallel inoculations with C. ribicola on Ribes sativum (vulgare) variety Fay	
On Ribes sativum (vulgare) variety Fay	On Ribes aureum		
Positive	Positive	Positive	The unknown is C. ribicola.
Negative	do	do	The unknown is C. occidentale.
Do	do	Negative	The leaves of the variety Fay were not in a receptive condition; the test must be repeated on better host material.
Do	Negative	Positive	The spores of the unknown are not viable; no determination possible.

For decisive negative results, it is of course desirable to use several plants in each category, or to repeat the entire test a few days later. If, for example, the infection with *Cronartium ribicola* on Fay is not very abundant, a failure of the unknown on a single plant of the same host might easily be the result of a slight difference in condition of susceptibility between the different plants of Fay; or it might mean that the spores of the unknown were in a less vigorous condition than those of the known *C. ribicola;* in either case, if there were no replication of the plants in the experiment, obviously it would be unsafe to attempt to name the unknown.

LIMITATIONS OF THE METHODS OF DISTINGUISHING THE TWO RUSTS

The diagnosis of an unknown Cronartium upon a physiological basis under the conditions worked with by the writer is a somewhat slow process when immediate results are required. Good spore material can be identified by the inoculation method in approximately two weeks; but if the material is poor and must first be cultured on a congenial host, e. g., *Ribes aureum, R. odoratum* Wendl., or *R. gracillimum* C. and B., to secure a supply of spores for the differential test, an additional two weeks' delay results. The number of conditioning factors also complicate the procedure of diagnosis. As already stated, inoculable leaves must be available and the proper environmental conditions of temperature, humidity, and light supplied. Ordinarily the high temperatures of summer, particularly in the greenhouses, make it difficult to get satisfactory results, unless such temperatures are controlled.

It must also be kept in mind that in the experiments herein reported only a comparatively few culture strains, representing a limited number of geographical sources, of each species were tested. There is the possibility that certain strains of *Cronartium ribicola* might be found which would not infect *Ribes sativum* (*R. vulgare*) var. Fay, the variety investigated most extensively. There is also, of course, the possibility that a strain of *C. occidentale* might be found which would infect Fay.

Other methods of differentiating the two Cronartiums have been studied. For tentative diagnosis the quicker but less certain biometric differential method of Colley (*4*), discussed in an earlier part of the paper, can be used and supplemented with the physiological test.

It may be noted that neither the physiological nor the biometric method which has been developed for distinguishing the two rusts is of much use for unknown specimens collected late in the season in the Pacific Northwest. Such material commonly shows teliospores only. Both the methods above referred to require the presence of urediniospores. The need of the blister-rust control workers for a method which will enable them to recognize *Cronartium ribicola* whenever and wherever they find it will not be fully met till a method is found of distinguishing between it and *C. occidentale* in the telial stage. G. G. Hedgcock, as a result of long experience with the *C. occidentale*, is able in most cases to distinguish readily by inspection this fungus from *C. ribicola* in the telial stage, both by the color (*7*) and by the number and vigor of the telial columns. Of 32 specimens of the former and 12 of the latter species, on Ribes hosts common to both, he correctly identified all but 2 without seeing the labels. The writer was able to identify correctly by inspection 37 of these 44 specimens. The macroscopic differences between the two rusts in the telial stage are so slight, particularly in weathered specimens, and so difficult to describe, that they are inadequate for general diagnostic use. An effort is now being made in the Office of Forest Pathology to develop a microscopic method of distinguishing between the telia or sporidia of the two species, but no constant difference has thus far been found.

SUMMARY

Foreign Ribes species and horticultural varieties were inoculated with a number of strains each of *Cronartium ribicola* and *C. occidentale* in the greenhouse at Washington, D. C., to discover physiological differences between the white pine and piñon blister rusts, which morphologically are very similar in their uredinial and telial stages. In the Pacific Northwest, where a control campaign is now being conducted against the recently introduced serious and menacing white pine rust, workers are faced with the perplexing problem of distinguishing macroscopically this detrimental rust on Ribes from the native piñon rust which economically has little importance.

Essential physiological differences were established between the two Cronartiums in the uredinial stage under artificial greenhouse conditions. A large number of horticultural varieties of the common garden currant, grouped for convenience under the name *Ribes sativum* (*R. vulgare*) were found to be immune to *C. occidentale* and susceptible to *C. ribicola*. Extensive and thorough tests with the Fay variety (Fay's Prolific) have demonstrated this variety to be particularly adaptable for experimental use as a dependable differential host. More limited comparative tests with other currant varieties indicated similar relations. Of 48 varieties inoculated with *C. ribicola*, all except 3 became infected; of 41 varieties inoculated with *C. occidentale* only 4 became infected, and these to a negligible degree, producing only uredinia of the resistant type.

The three varieties of the group *Ribes sativum* (*R. vulgare*)—Franco-German, Holland, and Victoria—which proved to be immune, so far as tested, to both rusts, may eventually after further examination prove to be valuable red currants for planting in localities where the growing of this Ribes is desired along with that of white pines. Further rigorous inoculation experiments will be necessary, however, to demonstrate completely the apparent immunity of these three varieties.

Ribes nigrum, the most receptive of all uredinial hosts to *Cronartium ribicola*, developed only scant infection with *C. occidentale* in the total number of tests made. *C. occidentale* further differed from *C. ribicola* in its reaction on this host, in that it infected fully matured leaves only during the fall period much more readily than it did younger leaves, which were fully susceptible to *C. ribicola*. Of the varieties of *R. nigrum* extensively tested, Champion was most susceptible to *C. occidentale*. In the limited number of tests made the Blacksmith and Boskoop Giant varieties were immune to *C. occidentale*.

Tests with 12 miscellaneous foreign Ribes species showed only two *R. tenue* and *R. fasciculatum*, which were susceptible to *Cronartium ribicola* and immune to *C. occidentale*. These two hosts should be further tested to determine the constancy of the very limited differential results obtained.

The procedure for diagnosing unknown uredinial material on Ribes from the Pacific Northwest by the greenhouse method is described. The physiological method of differentiating the white pine and piñon blister rusts, performed in accordance with the conditions under which the writer worked, while somewhat slow, appears much more certain than any other method now available of distinguishing *C. ribicola* and *C. occidentale* in the uredinial stages.

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