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Breeding for Multiple Root Rot Resistance in Snap Beans[1]

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Abstract. **Inheritance of resistance to *Pythium, Fusarium,* and *Rhizoctonia* in snap beans, *Phaseolus vulgaris* L., was studied for three populations involving a common resistant parent (Cornell 2114-12) and 3 different susceptible parents. *Pythium* resistance was strongly associated with colored seed but resistance was found in some white seeded segregants and was widely influenced by degree of susceptibility of white seeded parents. In contrast to the widely accepted theory that colored seed and resistance to *Rhizoctonia* are tightly linked, *Rhizoctonia* resistance seemed to be independent of seed color. Heritability for *Rhizoctonia* resistance was 0.75 and 0.65 for broad and 0.32 and 0.29 for narrow sense heritability. Resistance to all three diseases was independent and quantitatively inherited. Correlations for resistance to *Pythium* and *Fusarium* in F_4 with F_3 selections (r = 0.557**) were in line with heritability expectations. In the *Rhizoctonia* selections, generation to generation correlation was high (r = .90**) among those with the best resistance but only moderate among those with moderate resistance. In view of the low narrow sense heritability, selection for resistance in later rather than earlier generations should be more effective.**

The root rot complex of beans encompasses several major diseases. Initially, resistance was sought to *Fusarium solani* (Mart.) Appel. & Wr. sp. *phaseoli* (Burke) Snyd. & Hans. (2, 7, 15), then *Thielavioplis basicola* (Berk.) Ferr. (15), and more recently to *Pythium ultimum* Trow (5, 17) and *Rhizoctonia solani* Kuhn (6, 11, 12). Resistance, especially to *Pythium* and *Rhizoctonia* (6, 11, 12), has been associated with colored seed (13) but the association of colored seed and *Pythium ultimum* resistance can be broken (5, 17). Phenolic compounds in the exudates from germinating seeds and seedlings are reported to be responsible for resistance in peas to *Asochyti pisi* (4) and beans to *F. solani* (13). However, Kraft (9) found seedling exudates from both susceptible and resistant colored seeded plant introduction (PI) lines contained comparable amounts of phenols. Resistance to *Fusarium* (1, 2, 7, 14) is conditioned by 4-6 genes and in one study (7) was found independent of resistance to *Thielaviopsis* which is conditioned by 3-4 genes (8), whereas *Pythium* resistance involves several other genes (5, 17).

This study assesses inheritance of resistance to *Rhizoctonia, Pythium,* and *Fusarium,* in crosses between several susceptible lines and Cornell 2114-12, which is resistant to all 3 pathogens. We report segregation patterns in the same population for resistance to each of the 3 root rot organisms.

Materials and Methods

Cornell 2114-12, a bean with colored seed derived from a cross of *P. vulgaris* with *P. coccineus* (2), was used as the source of resistance. It was crossed to G4, a white seeded wax bean

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breeding line which is highly susceptible to all 3 pathogens. Cornell 2114-12 was also crossed with G924 and G959, good horticultural white-seeded lines possessing some *Fusarium* and *Pythium* resistance derived from PI 165435. G959 was superior to G924 for tolerance to *Pythium* and *Fusarium*. The F_1 and backcrosses were made in the greenhouse. The F_2, backcross, and parental populations were field grown with a low infestation of *Pythium* and *Fusarium*. Individual plants were harvested as the pods ripened.

Heritabilities were estimated using the backcross and F_2 variances for the narrow sense (NSH) estimates (16) and F_2 and parental variances for broad sense (BSH) estimates (10). The variances were computed from the no. of emerging plants per line from the *Pythium* test or from the mean damage rating for *Rhizoctonia* estimates. The uniformity of the tests is reflected in the variance of the homogyous parents.

Previous studies of *Pythium* and *Fusarium* resistance have been made with pure cultures (2, 7, 17). However in the field both organisms are present and interact synergistically. This study was made with both organisms acting together since the information gained would be more relative to the conditions encountered in the field.

The *Pythium* and *Fusarium* tests were conducted at the same time. Ten F_3 seed from each F_2 plant or BC-1 seed from each BC plant were tested. The seed from each plant is referred to as a family. Twelve entries were tested per flat (60 × 30 cm). Each flat also included a row of each parent. All seed planted appeared viable and undamaged and it was assumed potential germination was 100% but seed from each plant was not tested for germination. The planting medium was 3 sand:1 peat which had been flame pastuerized. The *Pythium* and *Fusarium* cultures were each separately grown for 5 days on Armstrong's liquid medium with constant shaking. The suspension was blended for 30 sec in a Waring blender after which the *Fusarium* was diluted to 2.2×10^5 macroconidia per ml while the *Pythium* was adjusted to 2.0×10^5 fragments per ml. For each flat 50 ml of the *Pythium* solution was diluted to 120 ml and 10 ml pipeted directly over each row of seeds. The seeds were then covered with 5 cm of the soil mixture and the flat was watered lightly. Finally 100 ml of the *Fusarium* solution and 50 ml of the *Pythium* solution were combined and diluted to 550 ml and sprinkled evenly over the surface of the soil. The greenhouse was maintained at 15°C (night)/20° (day) for 5 days, after which the soil medium was raised to 25° using heating cables buried in sand beneath the flats. Stand counts and damage ratings were made 21 days after inoculation.

Pythium ratings were based on the no. of live plants at 21 days. The *Fusarium* damage was rated at 21 days and based on a scale of 1 (white stem with no sign of *Fusarium*) to 10 (dead). Each plant was given a *Fusarium* rating and the mean for the family or parent became its damage class rating.

The measure of *Fusarium* resistance reflected *Pythium* resistance: if all plants were killed by *Pythium* then the *Fusarium* damage rating was automatically 10.

The *Fusarium* resistant white seeded (green hypocotyl) segregates were transplanted from the test flats to 12 cm pots and allowed to grow to maturity in the same infested soil used for the test. At maturity the roots were rated poor, fair, and good for resistance. Progenies of those rated fair or better were grown in a field which was inoculated in the same way as the greenhouse test.

A special bench was constructed for the *Rhizoctonia* test. The bench was filled with a mixture of 3 sand:1 peat and infested with Race 2 (obtained from Dr. G. Abawi who isolated it from beets, Orleans Co., N.Y.). This race is lethal to standard white-seeded cultivars but it is generally not as virulent as R5 (Dr. G. A. Papavizas, USDA, ARS, Washington, DC). In comparable tests of R5 compared to R2, PI 165426B survival was 40 and 60%, 2114-12 20 and 70%, and B4096 50 and 40% respectively. Several plantings of a susceptible cultivar were then made to build up the inoculam level uniformly throughout the bench. Ten seeds of each family (identical families to those used for the *Pythium-Fusarium* test) were planted 5 cm deep in rows 5 cm apart with each parent planted every 12th row. Emergence and damage ratings were made after 14 days. *Rhizoctonia* was scored for damage on a basis 1 (no damage) to 5 (complete girdling of the hypocotyl). The plants were dug, scored individually, and means calculated (Table 3).

Rhizoctonia resistant segregates were saved and allowed to produce seed and the F_4 were retested in the greenhouse along with susceptible checks. In this test 30 wheat grains infested with *Rhizoctonia* were placed among 10 seed of each entry 4 cm below the soil surface in a 12 cm plastic pot.

Results and Discussion

A definite seed color and *Pythium* resistance association was noted (Table 1), confirming findings of York et al (17), with colored seed being generally more resistant than white seed. However, in the F_2 susceptible G4 × resistant 2114-12 the colored segregates were scattered across all resistance classes and were not as concentrated towards the high resistance classes as found by York (17). Some scores of 6 and above indicated considerable opportunity to select for *Pythium* resistance in white-seeded segregates. G959 had fair tolerance to *Pythium*, and this resulted in a higher mean rating for both the colored and especially white segregates in the F_2 than for the crosses using G4 and G924.

Heritability estimates (10, 16) for *Pythium* resistance were affected by the seed color but less so for the cross involving G924 which had a low level of resistance in the susceptible parent, resulting in a near expected narrow sense heritability (NSH). The seed color did not appear to influence the heritability values for *Fusarium* or *Rhizoctonia* resistance.

Pythium susceptibility influenced the *Fusarium* ratings (Table 2). A considerable number of families had a *Fusarium* rating of 10 because all plants had been killed by the *Pythium*. Other families with a *Fusarium* rating of 10 had been killed by the *Fusarium* or a combination of diseases. This occurred for both white and colored seeded segregates. G959 had both moderate *Pythium* resistance and some *Fusarium* resistance and the ratings were much better than for the 2 crosses involving highly susceptible parents, G4 and G924. Because of the *Pythium-Fusarium* interaction heritability was not estimated. The correlation between *Fusarium* ratings for F_3 and F_4 generations was 0.557**. The field rating was made when the beans were at market stage. The field mean rating for the 75 lines studied being 5.8 vs. 5.4 in the greenhouse. This contrasted to the rating of 7.5 to 8.5 for susceptible checks grown in the field and indicated our greenhouse selection technique was successful.

In contrast to previous literautre reports (6, 11, 12), resistance to *Rhizoctonia* appeared in pure white seeded segregates (Table 3). The white seeded parents 924 and 959 had some *Rhizoctonia* race 2 resistance and there was little if any association of seed color with segregation for resistance in any of the three crosses.

The test of the progeny of the resistant segregates was more severe (very few susceptible check plants germinated and all those which did died shortly following emergence) than the test used on the segregating populations but the correlation between the two tests (between the F_3 parents and their F_4 progeny) was r=0.527** (n=50) which is in line with the NSH values of 32 and 29%. There was a better correlation (r=0.90**) where the selection saved was from a line with a very low mean rating (below two) than those rated 2-3 (r=0.21) which were segregating or intermediate for resistance. A regression of F_4 on F_3 was not used to estimate heritability as only resistant plants

Table 1. Distribution of resistance to *Pythium ultimum*.

Pedigree[x]	Generation	Seed color[z]	No. of plants per emergence class[y]											No.	Mean[w]
			0	1	2	3	4	5	6	7	8	9	10		
1	P_1	C							4	4	4	4	3	19	7.79 ± .32
2	P_2	W	14	4	1									19	0.32 ± .13
1×2	F_2	C	3	1	7	14	9	17	15	18	14	19	14	131	6.23 ± .22
1×2	F_2	W	10	12	5	2	6	4	1		2	1		43	2.39 ± .40
1×2	F_2	C+W	13	13	12	16	15	21	16	18	16	20	14	174	5.29 ± .23
(1×2)×1	BC	C					1		3	4	5	6	2	21	7.81 ± .33
(1×2)×2	BC	C			2	1		1		1		2		7	5.28 ± .94
(1×2)×2	BC	W	3	1	1	3								8	1.50 ± .45
(1×2)×2	BC	C+W	3	1	3	4		1		1		2		15	3.27 ± .77
Narrow sense heritability = .77			Broad sense heritability = .91												
3	P_2	W	3	6	4	2	2							17	1.65 ± .31
1×3	F_2	C		1			5	2	7	5	9	14	19	62	8.13 ± .27
1×3	F_2	W	4	4	3	5	2	3	1					22	2.45 ± .39
1×3	F_2	C+W	4	5	3	5	7	5	8	5	9	14	19	84	6.55 ± .34
(1×3)×1	BC	C					1		1		1	3	5	11	8.64 ± .59
(1×3)×3	BC	C										1	1	2	9.50 ± .50
(1×3)×3	BC	W		1	1	1	2	1						6	3.16 ± .60
(1×3)×3	BC	C+W		1	1	1	2	1				1	1	8	4.75 ± 1.27
Narrow sense heritability = .33			Broad sense heritability = .82												
4	P_2	W			2	1	2	3	1	2	1			12	4.83 ± .56
1×4	F_2	C			1	1	1	1	1	4	7	12	10	38	8.21 ± .32
1×4	F_2	W		1		1	2	2	1	1				8	4.37 ± .65
1×4	F_2	C+W		1	1	2	3	3	2	5	7	12	10	46	7.54 ± .38
			Broad sense heritability = .58												

[z]C = colored; W = white. Ten seed of the indicated color were tested from each plant for the families 1×2, 1×3, and 1 ×4.

[y]No. of seedlings which emerged per 10 seeds planted.

[x]1, Cornell 2114-12; 2 G4; 3, G924; 4, G959.

[w]± SE.

were saved for progeny testing which would have resulted in a biased estimate.

Correlations between the 2114 × G4 and 2114 × 924 F_2 populations were made for all 3 diseases. For *Pythium* vs. *Fusarium* they were r=–0.366** and –0.692**, for *Rhizoctonia* and *Fusarium* r=–.008 and 0.027, while for *Rhizoctonia* and *Pythium* r=–0.073 and 0.161. The low correlation indicates that resistances to *Rhizoctonia, Fusarium,* and *Pythium*

Table 2. Distribution of resistance to *Fusarium solani*.

Pedigree[y]	Generation	Seed color	No. of plants per damage class[z]										No.	Mean[x]
			1	2	3	4	5	6	7	8	9	10		
1	P_1	C			10	8		1					19	4.04 ± .17
2	P_2	W					1			4		16	19	9.40 ± .27
1×2	F_2	C			9	29	29	20	17	16	7	5	132	6.21 ± .13
1×2	F_2	W				2	7	11	7	2	2	11	42	7.32 ± .28
1×2	F_2	C+W			9	31	36	31	24	18	9	16	174	6.48 ± .14
(1×2)×1	BC	C			2	10	3	4	1	1			21	5.11 ± .26
(1×2)×2	BC	C				1	1		1	3	1		7	7.16 ± .65
(1×2)×2	BC	W					1		2	2		3	8	8.16 ± .64
(1×2)×2	BC	C+W				1	2		3	5	1	3	15	7.69 ± .48
3	P_2	W					1		3	3	7	3	17	8.54 ± .28
1×3	F_2	C			8	27	15	5	1	1			57	4.80 ± .13
1×3	F_2	W			2	2	1	4	4	5		4	22	7.01 ± .44
1×3	F_2	C+W			10	29	16	9	5	6		4	79	5.42 ± .19
(1×3)×1	BC	C			2	5	2						9	4.42 ± .23
(1×3)×3	BC	C				2							2	4.25 ± .05
(1×3)×3	BC	W					2	3					6	7.47 ± .48
(1×3)×3	BC	C+W				2	2	3				1	8	6.66 ± .67
4	P_2	W				3	4	2	2	1			12	5.93 ± .37
1×4	F_2	C			8	17	9	3	3				40	4.72 ± .18
1×4	F_2	W				1	3	1	1	2			8	6.36 ± .48
1×4	F_2	C+W			8	18	12	4	4	2			48	4.99 ± .18

[z]Damage class ratings: 1 = white stem; 10 = dead plant. Ten seed of the indicated color were tested from each plant and the mean of the individual seedling damage ratings were used to assign a plant a damage class for the families 1×2, 1×3, and 1×4.

[y]1, Cornell 2114-12; 2, G4; 3, G924; and 4, G959.

[x]± SE.

Table 3. Distribution of resistance to *Rhizoctonia solani*.

Pedigree[y]	Generation	Seed color	Number of plants per damage class[z] 0.5	1.5	2.5	3.5	4.5	No.	Mean[x]
1	P_1	C	16	5				21	1.35 ± .06
2	P_2	W			3	16	4	23	4.10 ± .12
1x2	F_2	C	35	66	21	4	1	127	2.06 ± .07
1x2	F_2	W	12	18	6	3	0	39	2.14 ± .14
1x2	F_2	C+W	47	84	27	7	1	166	2.08 ± .06
(1x2)x1	BC	C	5	13	2			20	1.86 ± .12
(1x2)x2	BC	C		4	2	1		7	2.78 ± .37
(1x2)x2	BC	W				6		6	3.64 ± .25
(1x2)x2	BC	C+W		4	2	7		13	3.24 ± .25
Narrow sense heritability = 0.32			Broad sense heritability = 0.75						
3	P_2	W	1	10	9			20	2.46 ± .12
1x3	F_2	C	24	26	5	1		56	1.71 ± .10
1x3	F_2	W	6	15				21	1.68 ± .10
1x3	F_2	C+W	30	41	5	1		77	1.70 ± .07
(1x3)x1	BC	C	8	1				9	1.32 ± .12
(1x3)x3	BC	C			2			2	2.70 ± .54
(1x3)x3	BC	W		4	2			6	2.63 ± .40
(1x3)x3	BC	C+W		4	6			10	2.66 ± .25
Narrow sense heritability = 0.29			Broad sense heritability = 0.65						
4	P_2	W	5	8	3			16	1.86 ± .14
1x4	F_2	C	19	18	1			38	1.54 ± .08
1x4	F_2	W	5	4				9	1.55 ± .16
1x4	F_2	C+W	24	22	1			77	1.54 ± .06

[z]Damage class ratings: 1 = white stem; 5 = girdled stem and dead plant. Ten seed of the indicated color were tested from each plant and the mean of the individual seedling damage ratings were used to assign a plant a damage class for the families 1x2, 1x3, and 1x4.

[y]1, Cornell 2114-12; 2, G4; 3, G924; and 4, G959.

[x]± SE.

are independent. The *Pythium* vs. *Fusarium* correlations were highly significant as would be expected since the tests were interrelated.

Independent resistance to each of the 3 pathogens is quantitatively inherited and multiple resistance can be recombined with white seed. In contrast to the conclusions of others, except that economic levels of *Pythium* resistance in white seed has been reported previously (5, 17).

For maximum efficiency, screening should be made simultaneously for 2 or 3 diseases. In nature usually more than one pathogen is a problem and selecting resistance only to one pathogen in the greenhouse does not appear to greatly help solve the root rot problem in the field. Screening for *Pythium* and *Rhizoctonia* tolerance results in rapid elimination of susceptibles (since it is a lethal test) and reduction in population being screened for *Fusarium*. Large F_3 or F_4 bulked populations can be screened with relative ease if those susceptible to two diseases can be eliminated prior to emergence.

Screening in the F_3 or later generations is essential if progress is to be made following crosses of susceptible bush beans with good horticultural type with resistant lines without any desirable horticultural characteristics. This will permit selection for seed coat color and for bush types as well as increase in the no. of recessive genes for higher level resistance in a homozygous state. In contrast we have found testing and selection in the F_2 worthwhile, following intercrosses among snap bean selections with good horticultural type and with some tolerance in both parents. However, Wallace (15) in breeding dry beans, found intercrossing and selection did not lead to selections with resistance and desired seed type. This may have been because of the linkage of *Fusarium* resistance with small seed, which was undesirable when selecting for 'Red Kidney' type beans with large seed, but does not present a problem when breeding for snap beans.

In other self pollinated crops the single seed descent approach (3) has been effective and efficient and is recommended for snap beans. It allows for selection of quantitatively inherited traits with minimum effort in advanced generations while maintaining genetic variation between lines, along with some opportunity for selection of qualitative traits such as seed color and bush habit in early generations.

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Azide as a Broadspectrum Soil Treatment for Vegetable Crops[1]

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Additional index words. soil fumigation, weed control, nematode control, nutsedge, *Cyperus esculentus*

Abstract. **Azide as NaN_3 or KN_3 impregnated on clay granules gave excellent control of yellow nutsedge (*Cyperus esculentus* L.) compared to methyl isothiocyanate combined with chlorinated C_3 hydrocarbons (Vorlex) or a non-hand weeded control. Nematode control was obtained with all treatments. Significant yield responses from the use of azide were obtained with all crops.**

Salts of azide have been known for about 75 years. Azide has been investigated as a nitrogen source, an explosive, and a biologically active agent. In the ealy 1950's, Hill, Klingman, and Woltz (6) reported that azide was potentially useful as a nematicide, fungicide, and herbicide for tobacco plant beds.

In 1957 Bradbury et al. (3) obtained excellent control of late season infestations of nematodes with sodium azide (NaN_3) placed in the planting zone. They also observed that the nematicidal activity of azides increased progressively with decreasing pH. Adams et al. (1) conducted studies *in vitro* which demonstrated that hydrazoic acid (HN_3) is biologically active below pH 5.5 to 6.0 and inactive at values above 6.0 to 6.5 for reducing growth of *Sclerotinia sclerotiorum* and *Rhizoctonia solani*. When Adams adjusted pH in soil, pH had little or no effect on quantities of potassium azide (KN_3) required to obtain 50% reduction of *S. sclerotiorum* or *R. solani*.

Weaver (13) reported control of *Cylindrocladium floridanum* in artificially infested soils with KN_3. He suggested KN_3 is potentially useful for control of many soil borne pathogens.

Soil pH is one of the most important factors in determining the movement and biological activity of azide (2). Hydrolysis of azide salts to HN_3 (hydrazoic acid), the form of azide which volatilizes and moves within the soil as a vapor, occurs rapidly in an acid environment and is inhibited by alkaline conditions, thus giving greater biocidal activity and movement in acid soils. Likewise, soil moisture influences movement of azide vapors and consequently its biological activity. NaN_3 is water soluble to 40 g/100 ml in water; therefore, high soil moisture greatly restricts azide vapor movement, even in an acid environment, however, both HN_3 and NaN_3 are readily leached. Thus, the importance of thorough mixing of azide with soil for optimum biological activity is apparent (6, 8). Soil moisture content optimum for seed germination is also considered optimum for azide fumigation. Parochetti and Warren (8) showed that 30% of the azide was lost from air dry soil surfaces at pH 6.0 in 4 hr, whereas, only 5% was lost during the same period at pH 8.3. At field capacity losses from soil surface at pH 6.0 and 8.3 were 20 and 3% respectively. Additional studies by Ketchersid and Merkle (7) confirmed that dissipation from alkaline soil was much slower than from acid soil and that dissipation was reduced by higher moisture conditions.

In 1953, Hill et al. (6) reported that sodium azide killed bermudagrass (*Cynodon dactylon* (L.) Pers.) and many germinating weed seeds in tobacco plant beds. Danielson (5), working with soils having a pH of 6.2, controlled mugwort (*Artemisia vulgaris* L.) with potassium and sodium azide at 56 kg/ha rates of azide ion. He also showed that azide vapors released from the soil surface were toxic to exposed mugwort plants.

Parochetti and Warren (8) reported control of various weeds with KN_3 at rates of 112, 224 and 448 kg/ha when soil incorporated and covered with polyethylene film in a silt loam soil having a pH of 5.9. They reported a half life of 2 to 3 days for non-covered plots and 6 to 7 days in polyethylene covered plots. When soil pH was adjusted to 7.3, no diffusion of azide in the soil occurred, but diffusion was demonstrated at pH 5.4 and 6.0.

In 1969, Skroch and Monaco (9) reported control of some annual grasses, some broadleaves, and yellow nutsedge (*Cyperus esculentus* L.) with 84 kg/ha azide ion on the soil surface under plastic in a Norfolk sandy loam. Skroch et al. (10, 11) found that weed control with azide 84 kg/ha soil incorporated 5 cm (2 inches) and tarped under plastic was equivalent to that obtained from treatment with 269 kg/ha methyl bromide soil injected and tarped. Increases in tomato yield were associated with azide treatment.

This study was initiated to test the relative effectiveness of KN_3, NaN_3, and Vorlex (methyl isothiocyanate combined with chlorinated C_3 hydrocarbons) as preplant soil treatments to control weeds, nematodes, and soil-borne pathogens in long-season vegetable production.

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