INTERNAL HEAT NECROSIS IN THE MIDATLANTIC REGION - INFLUENCE OF ENVIRONMENT AND CULTURAL MANAGEMENT*

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Commercial potato chip processors in southern and eastern U.S. refer to necrosis of the parenchyma tissue internal to the vascular ring of potato tubers as internal heat necrosis (IHN). Symptoms of IHN include round-to-irregular, tan-to-reddish brown spots or blotches that appear first toward the apical end of the tuber. Necrotic tissue appears at or near harvest and generally in the largest tubers (76.3 cm) first. Both the color intensity and the tuber area affected increase over time (Sterrett *et al.*, 1991a).

The presence of nonpathogenic necrotic parenchyma tissue in tubers has been reported using a variety of descriptive names in potato production areas worldwide. Necrotic tissue in potato tubers of various cultivars has been described as internal rust spot (Davies and Talbot, 1989); internal browning (Ellison and Jacob, 1952; Wolcott and Ellis, 1959); physiological internal necrosis (Larson and Albert, 1945, 1949); internal brown fleck (Novak *et al.*, 1986), or chocolate spot (Kamal and Marroush, 1971). Larson and Albert (1945) reported economic loss in various varieties because of necrotic tuber tissue (physiological internal necrosis) in the commercial potato crop as early as 1937. In the 1950s, Wolcott and Ellis (1959) reported varietal differences in the development of necrotic tuber tissue (internal browning). Since the release of Atlantic (Webb *et al.*, 1979), IHN has become a serious concern for growers in most areas when Atlantic is processed into chips directly from the field. The potential for high yield and high specific gravity of Atlantic is combined with desirable tuber characteristics for chip processing. Nevertheless, Atlantic is notably more susceptible to IHN than other varieties in the same trials (Henninger *et al.*, 1979; Sterrett and Henninger, 1991). From a survey of commercial growers in Virginia (VA) and North Carolina (NC), Sterrett and Wilson (1990) reported that the acreage left unharvested because tubers were out of USDA no. 1 grade as a result of IHN ranged from 3.2 to 11.2% over a three-year period (1986-1988).

The necrotic symptoms found in Atlantic are similar to some symptoms reported for internal brown spot (IBS) or physiological internal necrosis and to some symptoms of IHN. Like IBS, necrosis in Atlantic occurs in tubers

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throughout the soil profile (Hiller *et al.*, 1985; Larson and Albert, 1945) while IHN has been associated with tubers within the top 5 cm of the soil surface (Hooker, 1981). However, necrosis in Atlantic appears mid to late in the bulking period, like that reported for IHN (O'Brien and Rich, 1976). IBS reportedly can occur at various times throughout the growing season (Hiller *et al.*, 1985; Hooker, 1981; Larson and Albert, 1945). As in IBS, Atlantic tubers with IHN exhibit no external symptoms at harvest.

Differences in symptom expression may be cultivar related but attempts to verify this have been frustrated by lack of regional adaptation and seasonal influences on IHN incidence and severity (personal communication, L.K. Hiller). However, IHN symptoms have been reported for Katahdin (New Jersey (NJ), VA), Russet Burbank (NJ, VA), and BelRus (NJ) in germplasm trials using a common seed source (Morrow, 1992; 1993; 1994). Research efforts by the authors have focused on 1) examination of the environmental influence on development of IHN, 2) evaluation of cultural management strategies to delay expression of IHN and most recently, 3) estimation of genetic heritability of IHN.

Environmental Influence

The seasonal influence on development of necrotic tuber tissue has been well documented (Ellison and Jacob, 1952; Larson and Albert, 1949; Sterrett, *et al.*, 1991a; Wolcott and Ellis, 1959). However, in most of the early studies, tuber necrosis was evaluated as the percentage of affected tubers at a single harvest. Sterrett *et al.* (1991a) developed a rating scale (Fig. 1) to document severity (color intensity) and area of tuber necrosis. Commercially, potatoes would be considered off-grade when given an average rating ≤7.0. Both the percentage of tubers with necrosis and the rating in succeeding harvests were used to examine the progression of IHN over the commercial harvest period (Sterrett *et al.*, 1991a). In the mid-Atlantic region, IHN occurs annually. However, the time from the first appearance of necrotic tissue (first trace) to off-grade (IHN rating ≤7) varies with year, location, and date of planting (Sterrett *et al.*, 1991b).

Lee *et al.* (1992) developed the Atlantic heat-sum model based upon four conditional algorithms.

1) If Tmin > 21C HU = 21 - (2(Tmax-25)) - 10 + (21 - Tmin)
2) If Tmax > 25C HU = 21 - (2(Tmax - 25)) - 10
3) If Tave < 10C HU = 0
4) Then all else HU = Tave - 10

When the minimum or night temperature (Tmin) is elevated above 21C, then the daily heat units (HU) would be calculated by the first algorithm (1). When (Tmin) is less than 21C but the maximum or day temperature (Tmax) is above 25C, HU is calculated by the second algorithm (2) which is identical to that of Dean *et al.* (1981). If the average daily temperature (Tave) is less than 10C, then the HU equal zero (3). The last conditional algorithm allows for the traditional HU accumulation with a base temperature of 10C.

The heat sum model developed by Dean *et al.* (Algorithm 2) was used to

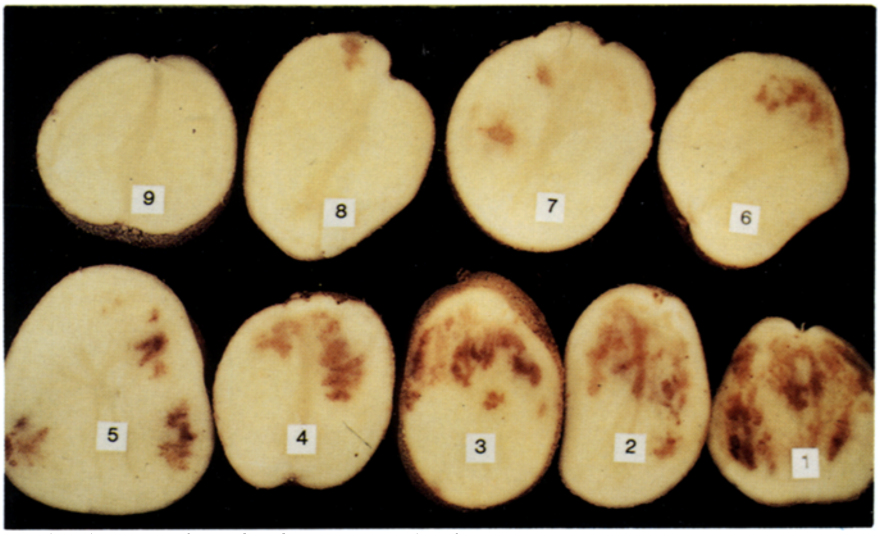

FIG. 1. Subjective scale used to document severity of IHN. Tubers were cut longitudinally. Necrotic tissue often diffuse without distinct boundaries (Sterrett *et al.*, 1991a).

predict yield of Russet Burbank potato grown in the Northwest. Lee *et al.* (1992) used these two models to predict yield of Atlantic grown in the mid-Atlantic region and found that the multiple coefficients of determination for yield were similar using variables generated by either heat sum model with or without the elevated night algorithm, R^2=0.83 and 0.82, respectively). However, in the initial development of a predictive model for IHN, a stronger relationship was found for the number of days from first trace to offgrade by including variables generated by the Atlantic heat-sum model (R^2=0.50) than those generated by the Dean model (R^2=0.27) (Lee, *et al.*, 1992).

The variables to describe environmental differences between growing seasons were generated by plotting the accumulated heat-sum calculated by the Atlantic model against the days after planting (DAP). As seen in Fig. 2, Slope60 is the slope of the regression equation of accumulated heat units 0-60 days after planting (DAP). Penalty is associated with DAP to first occurrence of three consecutive days of negative heat unit accumulation. Maximum heat sum reflects the greatest accumulated heat units for a specific planting.

Sterrett *et al.* (1991a) noted that the development of IHN was not necessarily a simple response to high temperature, but a response to a combination of several environmental stimuli. Sterrett, *et al.* (1991b) developed a two-stage forecasting model (Table 1) using variables generated by the Atlantic heat-sum model (Lee *et al.*, 1992) to assist growers in scheduling harvest to reduce risk of economic loss from IHN. The first stage estimated DAP to first trace by using stepwise regression analyses that included variables reflecting the environmental conditions to which plants were exposed during the first 60 DAP (Slope60, Penalty, and the number of rain events (Nrain60) but not the total

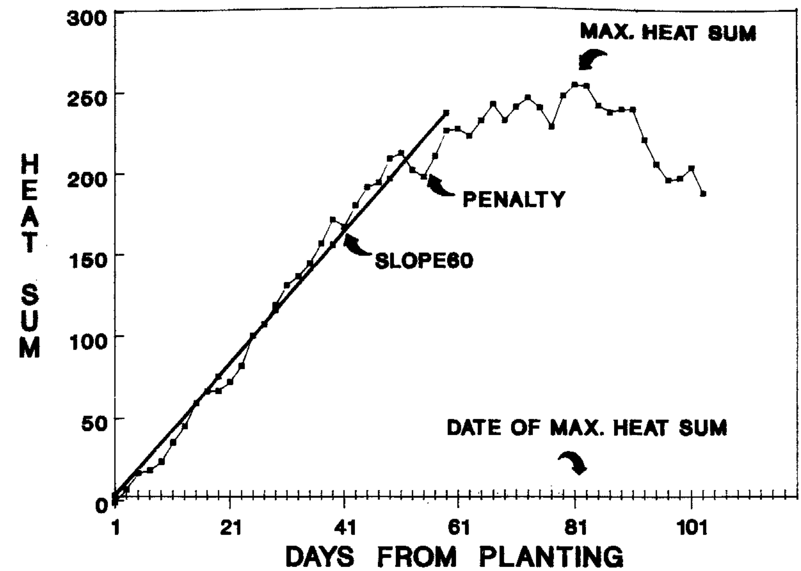

FIG. 2. Accumulated heat units calculated by Atlantic heat-sum model (Lee, *et al.*, 1992), showing variables considered for two-stage forecasting model.

amount of rainfall (Table 1)). A rain event consisted of rainfall ≥ 2.54 mm.

Variables that reflected environmental conditions during the first 60 DAP and those associated with first trace were included in the stepwise regression analyses to estimate off-grade, the second stage of the forecasting model (Table 1). Fields must be scouted to determine the actual occurrence of first trace so that the percentage of tubers greater than 64 mm at first trace (%Large) and the number of rain events in the ten days after first trace (NrainFT) can be determined. Since IHN in Atlantic generally appears first in the largest tubers in the hill (Henninger *et al.*, 1979) and rarely before the diameter of at least one tuber exceeds 83 mm. Growers, when scouting, should examine hills with either single stems or those next to a skipped hill first as these are more likely to have a greater percentage of large tubers and thus exhibit IHN symptoms first.

This model suggests that the development of first trace would be promoted by warm weather before 60 DAP, particularly with day and night temperature exceeding 25C and 21C, respectively, and reduced rainfall. Off-grade may be hastened in those plantings having a higher percentage of tubers ≥ 64cm at first trace and no rain events within 10 days after first trace is determined (Sterrett *et al.*, 1991b). Growers in the mid-Atlantic region supplement rainfall with irrigation as needed. With the high relative humidity that is frequently encountered in the eastern U.S., rainfall or irrigation is not necessarily associated with substantial evaporative cooling. However, rain events in the mid-Atlantic states are often associated with colder ambient air temperature, higher relative humidity, and lower light intensity. Hence, the plants may experience

TABLE 1.—*Two-stage forecast model for IHN.*

Phase	Model[1]	R^2	P>F	C(p)[2]
Days to First Trace=	$90.62 - 11.00X_{slope60} + 1.08X_{Nrain60} + 0.43X_{penalty}$	0.86	.01	4.33
Days to Offgrade=	$113.31 + 0.51X_{Penalty} - 38.29X_{\%\ large} + 3.75_{NrainFT}$	0.98	.01	2.97

[1]Variables: Slope60 = slope of regression equation for accumulated heat units over 60 DAP.
Penalty = DAP to first three consecutive days of negative accumulated heat units.
Nrain60 = Number of rain events 60 DAP.
% large = percentage of tubers > 64 mm at first trace.
NrainFT = Number of rain events during 10 days after occurrence of first trace.
[2]Mallows criterion, a measure of total squared error (SAS, 1995).

a temporary amelioration in environmental stress as suggested by inclusion of the rain event variables in the model. In years when environmental conditions are not conducive to development of IHN, this two-phase forecasting model predicts off-grade to occur after the usual harvest period. This model has been used by researchers to assess the potential risk for a given growing season but one of the limiting factors for commercial plantings has been associated with the finite flow of raw product to the processing plant.

Cultural Management Strategies

Various management strategies have been evaluated for effectiveness in delaying the onset of reducing severity of IHN.

Date of Planting

Iritani *et al.* (1984) noted that the incidence of IBS in Russet Burbank was delayed as planting date was delayed by six weeks. Increased incidence of IBS in early plantings of round-white varieties was noted by Ellison and Jacob (1952). Sterrett *et al.* (1991b) also found a delay in calendar days with delayed planting. However, the interval from planting to first trace and off-grade shortened with each successive harvest in 1989 in New Jersey (Table 2) and Virginia (data not shown). Marketable yield was also reduced with the late planting, thus limiting the economic potential of managing IHN by delayed planting in the mid-Atlantic region.

Preplant Stress

O'Brien, *et al.* (1983) noted a reduced final yield in some varieties with increased physiological age of the seed pieces. They calculated accumulated day degrees as a measure of physiological age and related this to the length of the longest sprout. IHN in commercial fields in NC was observed to be more severe in 1989 than in those farther north. Rainy weather at planting resulted in prolonged storage of seedpieces at ambient temperature in NC; seed shipments were held in cold storage by the seed growers for VA and NJ until weather conditions permitted planting. To examine the influence of preplant storage temperature on

TABLE 2.—*Delayed planting shortens length of time to off-grade and reduces yield (t/ha) in New Jersey, 1986, 1989.*

Planting Date	First Trace[1] DAP	First Trace[1] Date	Off-Grade[2] DAP	Off-Grade[2] Date	Marketable Yield
			1986		
2 April	98	9 July	133	13 Aug	58.0
23 April	75	7 July	111	13 Aug	54.1
P>F	.05	–	.05	–	.05
			1989		
29 March	111	17 July	136	12 Aug	46.1
11 April	98	18 July	130	19 Aug	46.1
21 April	88	11 July	125	24 Aug	40.4
P>F	.01	–	.01	–	.01

[1]First Trace = observation of visible necrotic tissue. DAP = Days after planting.
[2]Off-grade = severity rating ≤7.0.

yield and development of IHN, seed potatoes from a common source were planted in eastern North Carolina, Virginia, and New Jersey. At each location, seed tubers were taken from 4C and held at ambient room temperature for 21, 14, 7, or 1 day before planting. Sprout length increased with increased warming period in all locations. Tuber yield was increased in North Carolina with increased warming but was unaffected in the other locations. Preplant treatments did not affect either incidence or severity of IHN in 1990 or 1991 (Henninger *et al.* 1992).

Vine Killing

Preharvest vine killing is a widely used practice in growing areas where potatoes are stored for an extended time for the purposes of preventing oversized tuber development, maintaining tuber quality, and reducing the spread of disease (Halderson *et al.*, 1985, Murphy, 1968). Ellison and Jacob (1952) reported a greater incidence of IHN in hills with green vines than those with dead vines. To evaluate the potential of vine killing as a management tool for slowing the progression of IHN, studies were completed in Virginia in 1986 and 1987 and in New Jersey in 1986, 1987, and 1988. Mechanical removal and chemical desiccation (dinoseb at 1.12 kg ai/ha - Virginia or diquat at 0.28 kg/ha - New Jersey) were compared with intact vines. Vine removal/desiccation occurred after first trace in each planting. In Virginia, chemical desiccation was more detrimental to yield than mechanical removal or the control in 1987 while yield was not affected by treatment in Virginia in 1986 (data not shown). However, mechanical removal was consistently more detrimental to yield than the control in New Jersey in 1986, in two of the four harvests in 1987, and in the first two of 3 harvests in 1988 (Fig. 3, 1988 data not shown). IHN was less severe in New Jersey in 1986 than 1987, with both vine kill treatments improving the rating over the control in 1986. However, treatment effect on severity was less consistent in 1987 when risk of economic loss from IHN was greater (Fig. 3). Because

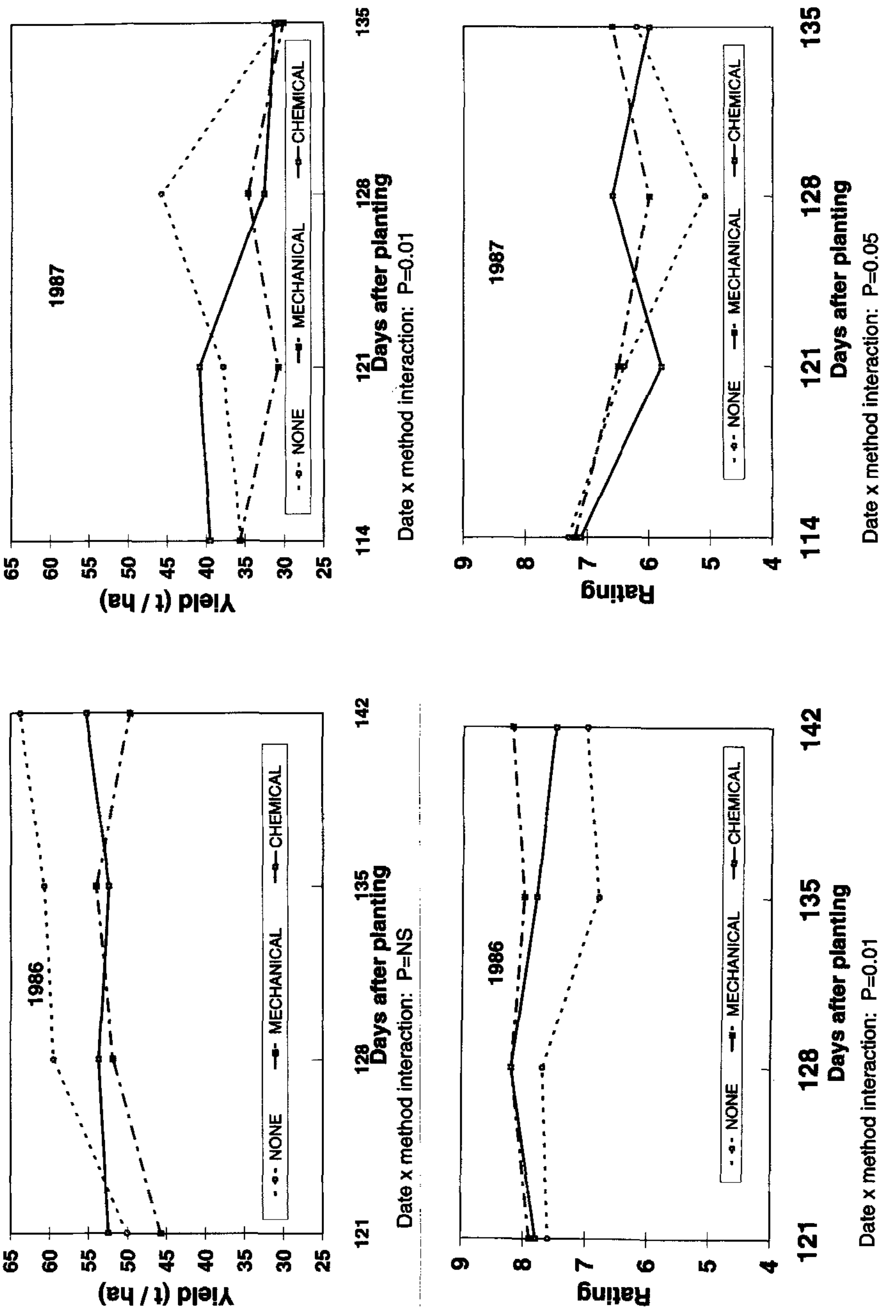

FIG. 3. Influence of vinekill treatments on marketable yield and severity of IHN in New Jersey.

of the reduced effectiveness of vinekill treatments in years of increased incidence and severity of IHN combined with similar or reduced yields, vinekilling does not appear to be a reliable management strategy for IHN management of Atlantic in this area. When soil conditions exist late in the harvest season that are conducive to tuber rot, tubers with IHN may be more susceptible to decay. As seen in Figure 3 for 1987, yield for the control treatment exceeded 45 m ton/ha at 128 DAP but dropped to 30.5 m ton/ha at 135 DAP. Severity rating of IHN improved from 5.1 to 6.2 for this time. Occasionally, commercial plantings have been abandoned because of quality problems with IHN and harvested later after tuber decay of the affected tubers resulted in sufficient quality improvement to make grade.

Antitranspirant

Wiersum (1966) suggested that physiological disorders of various vegetables associated with localized calcium (Ca) deficiency are caused by unfavorable internal water potential gradients. Non-senescing leaves with high transpiration rates (low water potentials) act as strong sinks for Ca movement through the xylem, restricting Ca flow to slowly transpiring organs such as roots and tubers (Wiersum, 1966). By applying an antitranspirant formulation containing a wax emulsion with a spreader-sticker surfactant during a drought episode, Win *et al.* (1991) found that tuber calcium was significantly increased with increasing antitranspirant rate. The percentage of small (50-100 g) tubers with necrosis were reduced by nearly 40% with increasing antitransparent while the reduction in large tubers (>200 g) was 20-25%. They reported a similar reduction in the extent of necrotic tissue (Win *et al.*, 1991). Whether the reduction in IHN was sufficient for tubers to be salable, particularly in years with severe symptoms is unclear; additional study in antitranspirants may be warranted.

Population Density

A more narrow in-row spacing is recommended for varieties that tend to set few tubers or develop oversized tubers (Sieczka and Thornton, 1992). The most effective management strategy employed by commercial growers to reduce losses from IHN has been to increase the population density, reducing the percentage of tubers greater than 83 mm in diameter. White and Sanderson (1983) noted a reduction in yield and an increased percentage of large tubers with wider (38 cm) within-row spacing; lower N (67 vs. 134 kg N/ha) fertilizer application also reduced yield.

Calcium and Nitrogen

The influence of Ca on internal disorders is addressed in detail by Palta *et al.* (1996). However, Sterrett and Henninger (1991) found that neither lime nor gypsum were as effective in reducing incidences of IHN in Atlantic in the mid-Atlantic region as in Wisconsin where the native soil calcium concentration is low. Clough (1994) found improved internal tuber quality with supplemental Ca fertilization but expressed concern that amelioration of IBS may not be adequate in years when IBS was more severe. Progression of IHN was hastened in Virginia with reduced nitrogen (68 or 84 vs. 168 kg N/ha) but not necessarily delayed by additional N (252 kg N/ha) (Sterrett and Henninger, 1991). Lynch and Rowberry (1977) reported that tuber survival was improved with increased rates of fertilizer resulting in increased marketable yield. Improved tuber survival would effectively increase tuber set and reduce overall tuber size, reducing severity of IHN by changing the size distribution.

Foliar Fertilization

Boron (B) deficiency symptoms in potato tubers have been described as brown discoloration near the vascular ring, especially at the naval end (Bradford, 1973). Since the Atlantic coastal plain is one of four broad regions where B deficiency is likely to occur (Wetstone *et al.*, 1942), a 4-year (1990-1993) factorial study was established in VA to examine the influence of foliar applications of commercial formulations of boron, micronutrients, and N-P-K on potato yield and development of IHN. Foliar B had no significant effect on crop yield or size distribution (data not shown). The influence of foliar N-P-K and/or micronutrients on yield was inconsistent from year to year suggesting the combination of foliar N-P-K and micronutrients may have delayed tuber bulking under some environmental conditions. Foliar application of B with N-P-K improved the severity rating in early harvest but not in the late harvest (Sterrett and Savage, 1993). The inconsistencies in yield and expression of IHN suggest that foliar applications of N-P-K, B alone, or B in combination with other micronutrients are of limited commercial value.

Summary of Cultural Management Strategies

In the mid-Atlantic region, attempts to delay expression or slow progression of IHN by cultural management have not been consistently successful. Management of either calcium, nitrogen, or an antitranspirant has reduced severity of IHN in some years, particularly when IHN was not severe. However, no cultural management strategy tested to date has consistently delayed progression of IHN beyond the usual harvest period or adequately lessened the severity to avoid off-grade. Thus, growers remain vulnerable to economic loss in years with environmental conditions conducive to expression of severe symptoms of IHN. Replacement of Atlantic may be the most acceptable long-range solution to IHN in the mid-Atlantic region.

Genetic Heritability

Development of new varieties with high tuber yield potential, high dry matter content, acceptable chip color, and reduced susceptibility to IHN has been a long-term objective of several Northeastern breeding programs. Haynes and Wilson (1991) noted a significant negative correlation between yield and specific gravity in a potato tuberling population selected for either horticultural characteristics or for specific gravity. The relationship between yield, specific gravity, and susceptibility to IHN is not yet well understood. In a three-year study of 19 genotypes at two locations, Henninger *et al.* (1994) found that broad-sense heritability (additive + dominance components) was 86% for incidence and 88% for severity of IHN with most of the remaining variation in this population due to genotype x environment interaction. Narrow-sense heritability (additive component) will be determined using progeny of selected crosses of these same 19 genotypes. The expected outcomes of these heritability studies include more efficient breeding strategies based upon heritability of these traits and greater understanding of the genetic mechanisms controlling expression of IHN.

Literature Cited

Bradford, G.R. 1973. Boron. *In:* H. Chapman (ed.). Diagnostic criteria for plants and soil. Second edtion. Chapman Publishing, Riverside, CA.

Clough, G.H. 1994. Potato tuber yield, mineral concentration and quality after calcium fertilization. J Am Soc Hort Sci 119:175-179.

Davies, H.V. and L.S. Talbot. 1989. Studies on the physiological basis for genotypic variation in susceptibility of tubers to internal rust spot (IRS)—A calcium related disorder. Am Potato J 66:514. (Abstr.)

Ellison, J.H. and W.C. Jacob. 1952. Internal browning of potatoes as affected by date of planting and storage. Am Potato J 29:241-252.

Halderson, J.L., L.C. Haderli, and D.L. Corsini. 1985. Potato vine kill: pulling, chemical killing, and rolling effects on yield and quality of Russet Burbank. Am Potato J 62:281-288.

Haynes, K.G. and D.R. Wilson. 1991. Correlation of yield and specific gravity in a tetraploid potato tuberling population. Am Potato J 68:355-362.

Henninger, M.R., J.W. Patterson, and R.E. Webb. 1979. Tuber necrosis in 'Atlantic'. Am Potato J 56:464. (Abstr.)

Henninger, M.R., S.B. Sterrett, and M.J. Wannamaker. 1992. Evaluation of preplant conditioning on yield and development of internal heat necrosis. Am Potato J 69:587. (Abstr.)

Henninger, M.R., K.G. Haynes, and S.B. Sterrett. 1994. Genetic components of variance for internal heat necrosis in clonally propagated potatoes. Am Potato J 71:677-678. (Abstr.)

Hiller, L.K., D.C. Koller, and R.E. Thornton. 1985. Physiological disorders of potato tubers. *In:* P.H. Li (ed.). Potato Physiology. Academic Press, Orlando, Fla.

Hooker, W.J. 1981. Internal heat necrosis. *In:* Compendium of potato diseases, W.J. Hooker (ed.), pp. 11-12. Am Phytopathol Soc, St. Paul, Minn.

Iritani, W.M., L.D. Weller, and N.R. Knowles. 1984. Factors influencing incidence of internal brown spot in Russet Burbank potatoes. Am Potato J 61:335-343.

Kamal, A.L. and M. Marroush. 1971. Control of chocolate spot in potato tubers by foliar spray with 2-chlorethylphosphonic acid. HortScience 6:42.

Larson, R.H. and A.R. Albert. 1945. Physiological internal necrosis of potato tubers in Wisconsin. J Agr Res 71:487-505.

Larson, R.H. and A.R. Albert. 1949. Relation of potato varieties to incidence of physiological internal tuber necrosis. Am Potato J 26:427-431.

Lee, G.S., S.B. Sterrett, and M.R. Henninger. 1992. A heat-sum model to determine yield and onset of internal heat necrosis for 'Atlantic' potato. Am Potato J 69:353-362.

Lynch, D.R. and R.G. Rowberry. 1977. Population density studies with Russet Burbank II. The effect of fertilization and plant density on growth, development and yield. Am Potato J 54:57-71.

Murphy, H.J. 1968. Potato vine killing. Am Potato J 45:472-478.

Novak, V.J., G.D. Mann, and G.N. Schrodter. 1986. Effects of age at harvest and irrigation near maturity on the incidence of internal brown fleck in potato tubers. Austral J Exp Agr 26:129-132.

O'Brien, M.J. and A.E. Rich. 1976. Potato diseases. U.S. Dept. Agr., Agr Hdbk 474.

O'Brien, P.J., E.J. Allen, J.N. Bean, R.L. Griffith, S.A. Jones, and J.L. Jones. 1983. Accumulated day-degrees as a measure of physiological age and the relationships with growth and yield in early potato varieties. J Agric Sci 101:613-631.

Palta, J. 1996. Improving potato tuber quality with calcium nutrition. Am Potato J. (In press)

SAS Institute, Inc. 1985. SAS Users' guide: Statistics. SAS Institute, Inc., Cary, NC.

Sieczka, J.B. and R.E. Thornton (eds.). 1993. Commercial Potato Production in North America. Revision of Am Potato J Vol. 57 Supplement: USDA Handbook 267.

Sterrett, S.B. and M.R. Henninger. 1991. Influence of calcium on internal heat necrosis of Atlantic potato. Am Potato J 68:467-477.

Sterrett, S.B., M.R. Henninger, and G.S. Lee. 1991a. Relationship of internal heat necrosis of potato to time and temperature after planting. J Am Soc Hort Sci 116:697-700.

Sterrett, S.B., G.S. Lee, M.R. Henninger, and M. Lentner. 1991b. Predictive model for onset and development of internal heat necrosis of 'Atlantic' potato. J Am Soc Hort Sci 116(4):701-705.

Sterrett, S.B. and C.P. Savage. 1993. Yield and development of internal heat necrosis affected by foliar fertilization. Am Potato J 70:844. (Abstr.)

Webb, R.E., D.R. Wilson, J.R. Shumaker, B. Graves, M.R. Henninger, J. Watts, J.A. Frank, and H.J. Murphy. 1978. Atlantic: A new potato variety with high solids, good processing quality and resistance to pests. Am Potato J 55:141-145.

Whetstone, R.R., W.O. Robinson, and H.G. Byers. 1942. Boron distribution in soils and related data. U.S. Dept. Agr Tech Bull 797.

White, R.P. and J.B. Sanderson. 1983. Effect of planting date, nitrogen rate, and plant spacing on potatoes grown for processing in Prince Edward Island. Am Potato J 60:115-126.

Wiersum, L.K. 1966. Ca-content of fruits and storage tissues in relation to the mode of water supply. Acta Bot Neerl 15:406-418.

Win, K., G.A. Berkowitz, and M. Henninger. 1991. Antitranspirant-induced increases in leaf water potential increase tuber calcium and decrease tuber necrosis in water-stressed potato plants. Plant Physiol 96:116-120.

Wolcott, A.R. and N.K. Ellis. 1959. Internal browning of potato tubers: Varietal susceptibility as related to weather and cultural practices. Am Potato J 36:394-403.