Teparies as a Source of Useful Traits for Improving Common Beans

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The tepary bean (*Phaseolus acutifolius* A. Gray) is of interest for its intrinsic value as an under-exploited crop adapted to hot arid climates, and as a potential donor of desirable traits to the common bean (*P. vulgaris* L.) through interspecific hybridization. Teparies possess several traits that could be valuable if transferred to common beans. Teparies are more heat and drought resistant than common beans. They tolerate higher salt (Marcarian, 1981) and boron concentrations in the soil (C. J. Lovatt, personal communication; J. G. Waines, unpubl.). They are tolerant of damage by lesser cornstalk borer, *Elasmopalpus lignosellus* Zeller (Thomas, 1983). They show field resistance to charcoal rot, caused by *Macrophomina phaseolina* (Tassi) Goid (Thomas, 1983). All of these factors combine to produce a plant that performs well in hot, semiarid climates. In addition, they show high levels of resistance to *Xanthomonas phaseoli* (E.F. Sm.) Dows, the bacterium that causes common blight of beans (Coyne and Schuster, 1973).

Teparies are routinely grown during the summer in parts of the American Southwest and adjacent Mexico, where they set pods when temperatures are too high for pod formation in common beans. They are able to mature seed under conditions so dry that common beans die or yield poorly because of drought (Freeman, 1912; Nabhan and Felger, 1978). Our own experience with field-grown plants at the University of California Experiment Station at Riverside demonstrates these differences. Three tepary and three common bean varieties were planted May 14, 1980 and July 9, 1981 (Thomas, 1983). They were furrow irrigated for 48 hours after planting, but received no further irrigation or rain prior to maturity. All common beans gave zero yield in both years, but teparies gave yields of up to 420 kg/ha in 1980, and 1,000 kg/ha in 1981 based on 11.25 sq. meter plots of 100 plants each. Temperatures during flowering averaged a high of 35°C and a low of 17°C in both years. Teparies can give very high yields when grown with some irrigation and slightly cooler temperatures at the University of California South Coast Field Station, Irvine. Tepary lines there have yielded 3524 kg/ha and 3916 kg/ha (W. H. Isom, personal communication). Common bean cultivars in the same trial yielded only 1659 to 2059 kg/ha. This difference was attributed in part to a differential reaction to ozone smog damage.

Teparies are poorly adapted to cool and humid growing conditions. Wild teparies are unable to germinate with winter rains because soil temperatures are too low. Although domesticated teparies show a wider temperature tolerance than wild ones, they do not germinate rapidly unless soils are very warm. They are likely to rot in soils which are cool and wet. After germination, teparies grown at low temperatures remained stunted. The internodes fail to elongate, forming a rosette. The leaves are small and thick (Hendry, 1919; Thomas, 1983). Tepary plants that are not drought stressed remain green until killed by frost. This causes problems in humid areas because seeds may germinate on the plant (Duke, 1981) or rains may interfere with harvesting (Hendry, 1919). Even when hand-harvested, teparies grown in cool areas have depressed yields under irrigation. In Minnesota field trials, teparies yielded 1242 kg/ha when irrigated and 2230 kg/ha unirrigated, whereas commercial common bean cultivars in the same trial gave 1863 kg/ha when irrigated and 1421 kg/ha when not irrigated (Petersen and Davis, 1982). Teparies are also more subject to disease and insect attacks when grown in cool, humid areas (Duke, 1981; Kaiser, 1981). Production of common beans in hot

semi-arid tropical and subtropical regions could obviously be expanded by introduction of drought and heat resistance from teparies. Even in cooler climates, temporary hot and/or dry spells usually depress bean yields. Because many tepary varieties show day-length sensitivity and have optimum flower production at a day length of 12 hours or less (Pratt and Erickson, 1982), they may flower too late to mature seed before frost at high latitudes. It would be advisable to select tepary lines that flower well during long days for use in hybridization programs. Such lines are available (Garver, 1934; Pratt and Erickson, 1982).

The physiological and morphological components of the superior heat and drought adaptation in tepary beans are still under investigation. The heat resistance of teparies may be partly a result of their drought resistance and vice versa. In growth chamber studies, Parsons and Davis (1979) observed that teparies showed lower transpiration rates and suffered less chlorophyll loss and leaf senescence than common beans subjected to the same conditions (Parsons and Davis, 1978). This was probably because teparies have smaller, thinner leaves better able than common beans to dissipate heat (Nabhan, 1979). Both species orient their leaves to avoid the sun at midday (Parson, 1979), but water-stressed tepary plants orient their leaves perpendicular to the sun's rays in early morning and late afternoon when the stressed common beans avoid the sun by orienting leaves parallel to the rays, as we have observed at Riverside. This should allow teparies more hours of active photosynthesis than common beans when drought-stressed.

When grown outdoors at Riverside in 1.5 m tall pots on stored soil moisture and sampled at two-week intervals (Figure 4), teparies had longer roots than common beans at the same stage for every sampling period (Thomas, 1983). In the field, teparies may have more water available for growth than common beans due to a deeper root system. Studies at Riverside (Thomas, 1983) using a neutron depth moisture probe showed that tepary roots penetrated deeper than 2 m when grown on stored soil moisture, whereas common beans were not observed to extract water from much lower than 1 m.

At Riverside, under water-limited conditions in the field, teparies maintained better plant water status during flowering than common beans, showing an average of 0.2 megapascals higher plant water potential at midday and 0.1 megapascals higher at predawn. Parsons and Howe (1980) showed that teparies maintained higher turgor than common beans, partly by osmotic adjustment, and were able to maintain greater wall elasticity; both of which phenomena should allow continued growth. Coyne and Serrano (1963) documented that drought-stressed tepary leaves and petioles had higher sucrose and total soluble solids content than common beans. These results imply that teparies maintained higher rates of photosynthesis, although CO_2 uptake was not measured directly.

The only aspect of physiological heat resistance in teparies that has been examined is thermal stability of enzymes. Both malic dehydrogenase (Kinbacher et al., 1967) and fraction I protein (Sullivan and Kinbacher, 1967) showed much higher heat stability in extracts from heat-hardened teparies com-

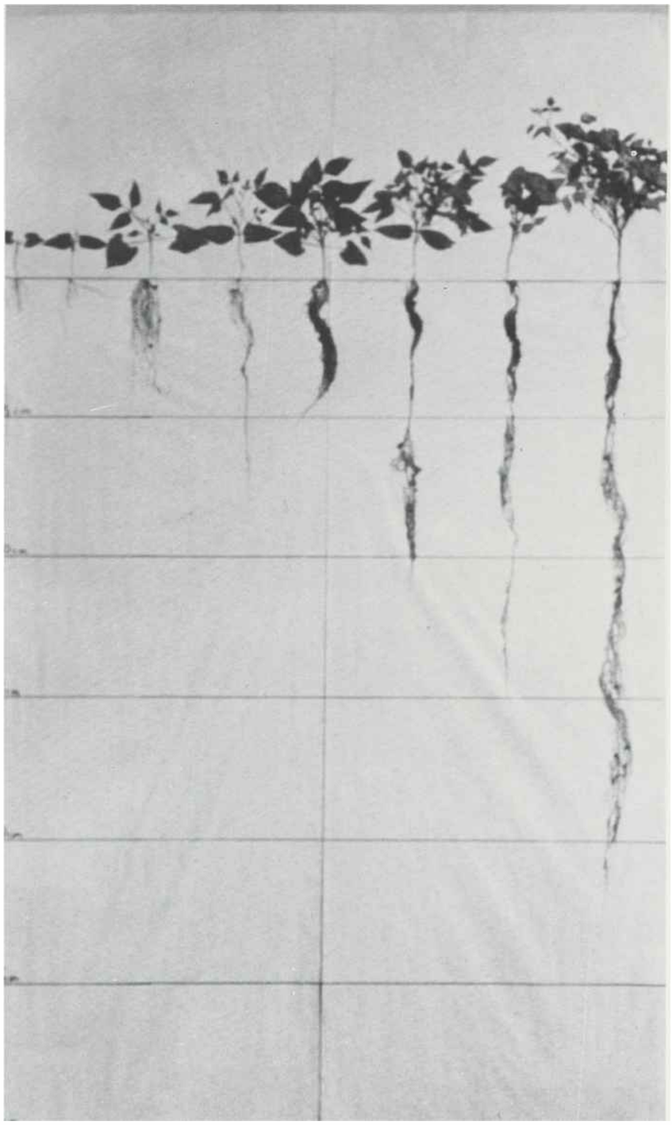

Figure 4. *Common bean (Small White 53) and tepary (PI 321638) plants grown in 1.5 m tall pots on stored soil moisture. Pairs were sampled 2, 4, 6, and 8 weeks after planting. The left plant in each pair is the common bean.*

(upper)

Figure 1. *Greenhouse grown plants 'Masterpiece' (left), F_1 hybrid 'Masterpiece' x L320 (middle), wild* P. acutifolius *ssp.* tenuifolius, *L320 (right).*

(lower left)

Figure 2. *Flowers and bracts from tepary PI 321638 (left), F_1 hybrid PI 321638 x 'Masterpiece' (middle), and the common bean, 'Masterpiece' (right).*

(lower right)

Figure 3. *Field trial of rooting depth of teparies and common beans when grown with stored soil moisture at Riverside, CA, 1981. Plants in foreground are teparies, dead plants at center were common beans.*

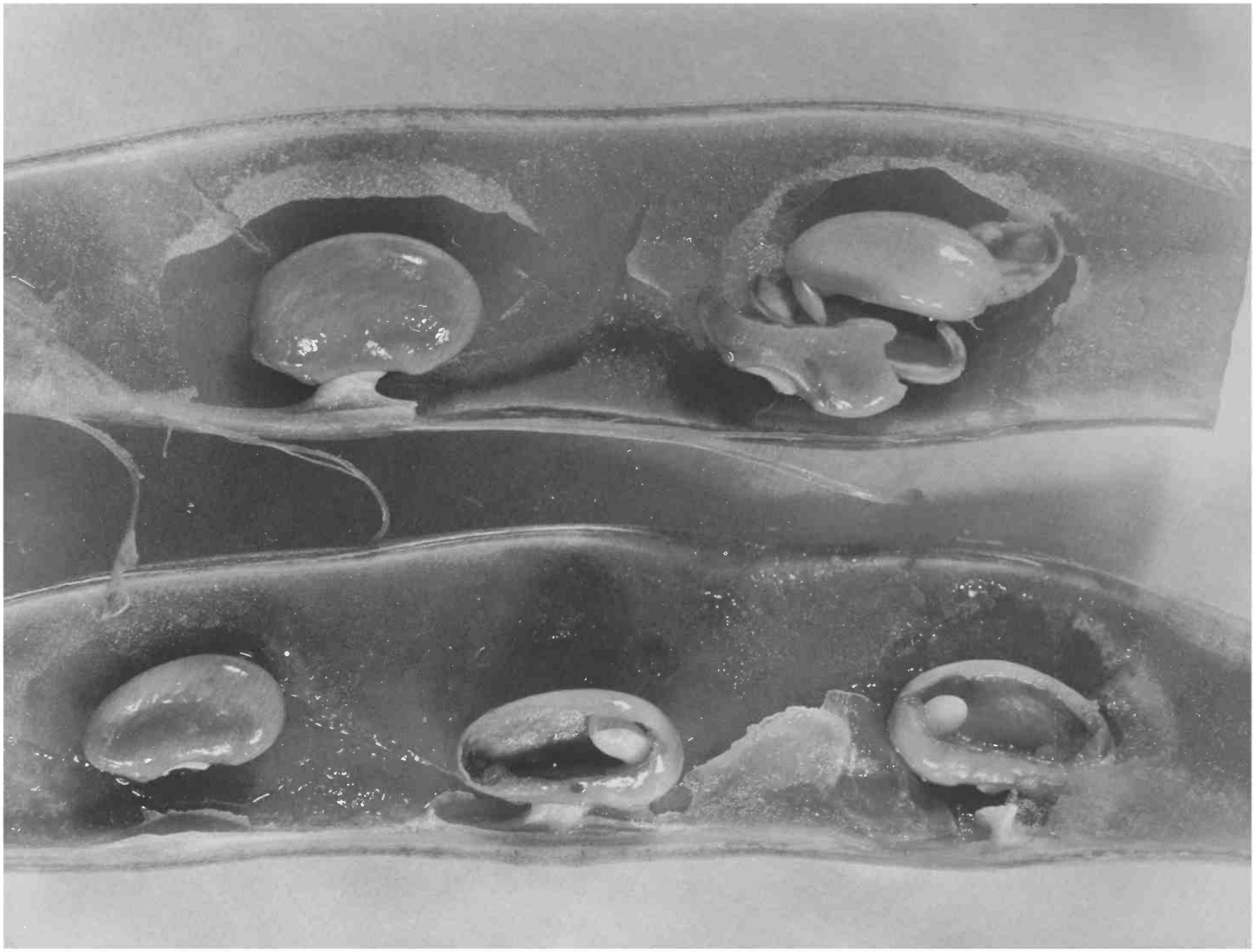

Figure 5. *Top: Common bean, self pollinated. Left ovule is intact and plump, right is dissected to show large embryo. Bottom: Common bean pollinated by tepary. Left ovule is intact but shrunken, center and right ovules are dissected to show small embryos, not filling ovules.*

pared to teparies that received no heat preconditioning. Such enzyme stability upon exposure to high temperatues is considered to contribute to heat tolerance in plants.

Field trials indicate that teparies tolerate much higher soil concentrations of salt (Marcarian, 1981) and boron (C.J. Lovatt, personal communication; J.G. Waines, unpubl.) than do common beans. These traits are important in water-limited conditions where soil concentrations of salts and boron may be high, especially in low areas with poor drainage or where irrigation water carries high concentrations of dissolved salts or boron.

Teparies are more tolerant of drought-related disease and insect damage than common beans. In the 1980 Riverside field trials referred to above common beans were killed not only by drought but also by charcoal rot caused by the fungus *Macrophomina phaseolina* (Tassi) Goid. In 1981 (Figure 3), common beans were decimated by a heavy infestation of the lesser cornstalk borer, *Elasmopalpus lignosellus* Zeller. Only a few tepary plants showed charcoal rot symptoms in 1980, and none died. Virtually all common bean plants showed symptoms, and all died. In 1981, the corn borer infestation was heavy. All but one common bean plant (out of 1200) died, but the three tepary varieties showed different levels of tolerance to the insect damage. Sixty-one percent of PI 321638, 55% of L 172, and 28% of PI 310801 plants survived. Corn borer damage could be seen at the soil line in many of the tepary plants that managed to mature pods and senesce normally. This indicates that teparies are tolerant of the damage caused by this insect, but not resistant to infection. Teparies have also been reported to show resistance to the leaf hopper, *Empoasca krameri* Ross and Moore (CIAT, 1979), an insect that is seldom a problem in hot, dry areas.

Some teparies also possess a higher degree of resistance to common bacterial blight caused by *Xanthomonas phaseoli* (E.F. Sm.) Dows, than is found in most common beans (Coyne and Schuster, 1973; Cafati and Saettler, 1980). This disease is not a problem in dry areas, but causes much damage to beans in warm, humid locations. Resistance to this bacterium has been reportedly transferred from teparies to common beans (Honma, 1956). Great Northern Nebraska #1, selection 27, which was derived from this cross, although tolerant of some strains of *X. phaseoli*, is susceptible to others (Schuster et al., 1973). Some

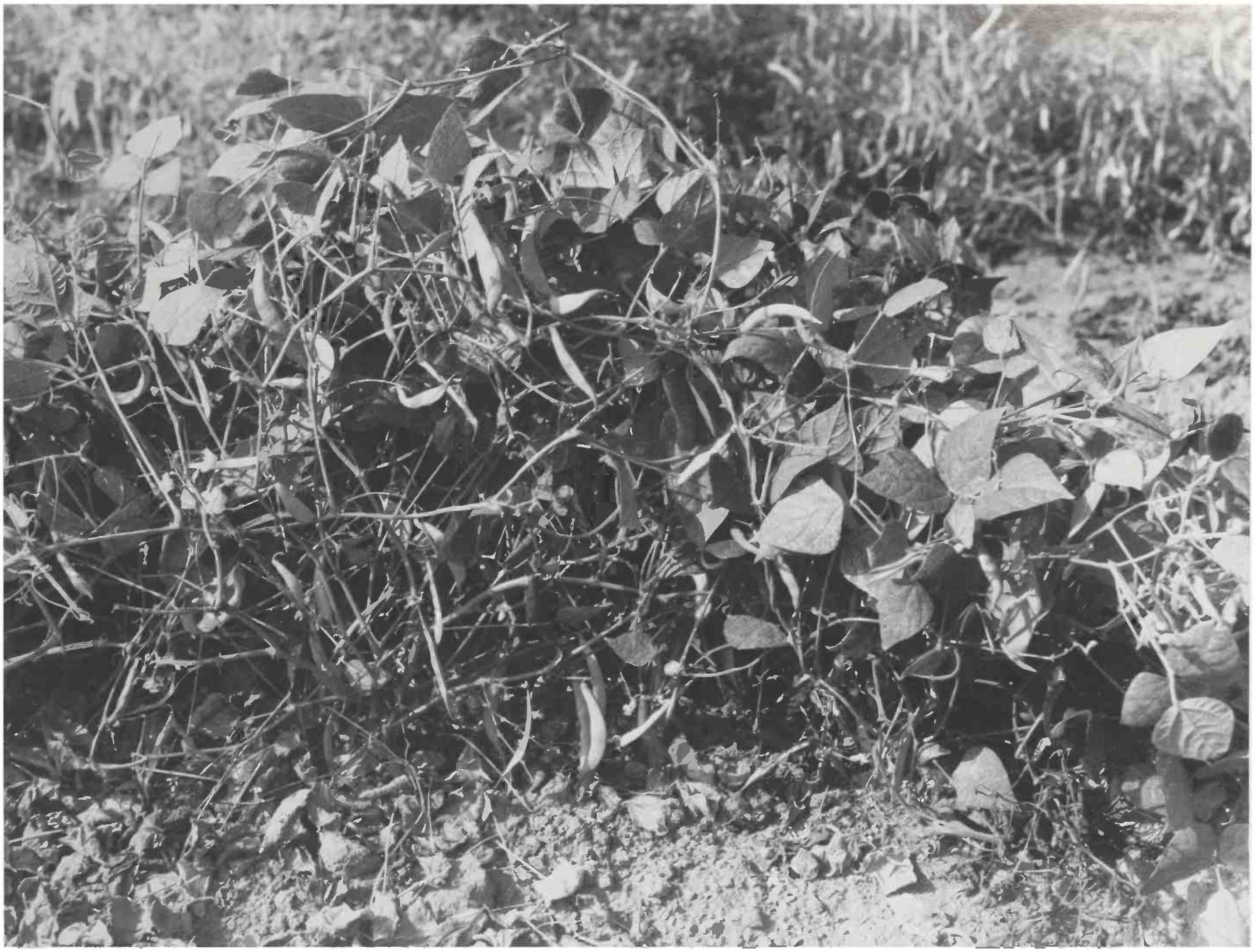

Figure 6. *Allotetraploid plants, PI 321638 x 'Masterpiece.'*

varieties of teparies have also been reported to show tolerance of rust caused by *Uromyces appendiculatus* (Pers.) Unger and bean golden mosaic virus (CIAT, 1977 and 1979).

A trait like drought resistance is certainly complex and has both morphological and physiological components. If all components of the system must work together to achieve a high degree of drought resistance, then this trait will probably be difficult to transfer completely. However, if one or two components can be shown to be of major importance, then success may be more easily realized. It seems possible that certain characters of teparies such as rooting depth may be sufficiently important to select for individually, but a high level of drought resistance probably depends on integration of several systems, and may be more difficult to transfer.

Certain desirable traits may be easier than others to transfer from teparies to common beans. The smaller the number of genes controlling a trait, the easier it should be to transfer from one species to another. Disease and insect resistance are sometimes under the control of a single gene, and can be easily transferred. Although the genetics of resistance to common bean blight or charcoal rot, and of tolerance to lesser cornstalk borer, have not been elucidated for teparies, it is quite possible that these traits may be simply inherited. The transfer of a complex trait controlled by many genes seems especially difficult when considered in light of the problems encountered in making the interspecific hybrids and obtaining progeny from them.

Because of doubts expressed by some workers (Smartt, 1970; Smartt, 1979; Pratt, 1983) regarding authenticity of some reported hybrids, it is important to confirm hybridity by the use of markers. Useful marker traits are growth habit, day-length sensitivity flower color, calyx bract size (Figure 2) and leaf shape in crosses utilizing var. *acutifolius* (including *tenuifolius)* (Figure 1).

There are two major problems that must be overcome in any interspecific hybridization program for teparies and common beans. The first is the difficulty of producing hybrid seed on the plant, since hybrid embryos typically abort before seed is fully developed unless embryo culture is used. One exception to this was seen in our crosses of a wild common bean, PI 325676, with several wild tepary lines. Pods from these crosses developed normally and eventually yielded dry mature seed which varied from plump to shrivelled. The seeds did not all germinate, but several hybrid plants were obtained. All other hybrid genotypes produced at Riverside required embryo culture to salvage abortive embryos, the techniques and results of which are described elsewhere.

For the interspecific crosses we made in October and November, 1981, the most important factor determining the success of F_1 hybrid production was the genotype of the female parent. Of the seven common bean cultivars used as female parents in crosses with five tepary lines, California Light Red Kidney-M (mosaic resistant) and Masterpiece were most efficient in F_1 hybrid production, yielding 0.92 and 0.87 mature F_1

plants per cross-pollination, respectively. Consequently, the majority of F_1 hybrids produced at Riverside involved these common bean cultivars. There was no relationship between the number of hybrid embryos produced by a common bean cultivar in crosses with teparies and the number of embryos that survived to maturity. Among tepary lines which we used as female parents in crosses with common beans, PI 321638 was the most efficient in the production of F_1 hybrid plants.

The second problem that must be overcome when attempting to transfer germplasm between these species is the sterility of the F_1 hybrid, which has been overcome only by backcrossing to the parental species, or by production of partially fertile allotetraploids through colchicine treatment.

Fertility of F_1 hybrids, as measured by pollen stainability in acetocarmine, was also influenced by the genotype of the female parent. In all cases, pollen stainability was low, ranging from 1% to 27%. However, pollen stainability of F_1 plants derived from California Light Red Kidney-M was significantly greater than that of F_1's derived from Masterpiece (17% vs. 6%).

In spite of the high degree of sterility, we have obtained a few backcross seeds using pollen from tepary and common bean parental types and a few allotetraploid plants from colchicine-treated F_1 cuttings (Figure 6). This seed was increased for several generations in the greenhouse, and fertility improved considerably.

Some of our backcross-derived common bean/tepary hybrid material was grown with irrigation at the South Coast Field Station, Irvine, in 1980. Fertility and seed set were very good. Seed derived from this planting was grown in summer 1981 at Riverside where day temperatures were in a range of 32-45^0 C (Thomas, 1983). The field was irrigated for 48 hours immediately after planting. Then one treatment received no more water, while the other was watered every other week. Low yields (165-826 kg/ha) in the irrigated treatments, plus a general late season pod-set, indicated that heat resistance probably was not inherited by these lines from the tepary parent. However, common bean backcross lines yielded on average twice as much as the common bean parents in one trial and three times as much in a second trial. Two backcross/second generation plots yielded approximately half the tepary mean yield, whereas the best common bean plot was only 20% of the tepary mean. We are currently increasing seed for additional replicated field trials.

Root length studies conducted in pots that were 1.5 m tall showed that the common bean backcross lines derived from interspecific hybrids had roots as long as the tepary parent and significantly longer than the common bean parent.

Field trials of the U.S. Department of Agriculture conducted by Dr. George Freytag at Isabella, Puerto Rico, using lines derived from our interspecific hybrids showed these lines to be more resistant to common blight than susceptible common bean varieties at indigenous field infection levels. Additional tests are being conducted by Dr. Steve Temple at CIAT, Cali, Colombia; preliminary results indicate the presence of resistance in the hybrids.

It is difficult to transfer genes between *P. vulgaris* and *P. acutifolius*. The barriers imposed by embryo culture, F_1 sterility, and genetic complexity of some desired traits can all be circumvented. However, the low rate of success at each stage ensures that gene transfer will be limited and subject to "bottlenecks," thereby making it unlikely that there will ever be a large amount of genetic exchange between these species. In spite of the difficulties, transfer of traits from one species to another is possible. Since teparies possess so many traits that could greatly increase the range of adaptation and resistance to natural enemies of common beans, transfer seems well worth the trouble.

References

Alvarez, M.N. 1980. *Effect of Interspecific Phaseolus Hybrids on Biological Nitrogen Fixation.* Ph.D. dissertation, University of Minnesota.

Cafati, C.R. and A.W. Saettler. 1980. Effect of host on multiplication and distribution of bean common blight bacteria. *Phytopath.* 70(7): 675-679.

Centro Internacional de Agricultura Tropical. 1977. Bean Program. *CIAT Annual Report, 1977.* Cali, Colombia. 85 pp.

Centro Internacional de Agricultura Tropical. 1979. Bean Program. *CIAT Annual Report, 1979.* Cali, Colombia. 111 pp.

Coyne, D.P. and M.L. Schuster. 1973. Phaseolus germplasm tolerant to common blight bacterium (*Xanthomonas phaseoli*). Plant Dis. Rep. 57 (2): 111-114.

Coyne, D.P. and J.L. Serrano. 1963. Diurnal variations of soluble solids, carbohydrates and respiration rate of drought tolerant and susceptible bean species and varieties. *Am. Soc. Hort. Sci.* 83: 453-460.

Duke, T.A. 1981. *Handbook of Legumes of World Economic Importance.* Plenum Press, New York, NY; London, England.

Freeman, G.F. 1912. *Southwestern Beans and Teparies.* University of Arizona Agric. Exp. Sta. Bull. 68: 573-619.

Garver, S. 1934. The Redfield tepary bean, an early maturing variety. *J. Amer. Soc. Agron.* 3: 397-403.

Hendry, G.W. 1919. Climatic adaptations of the white tepary bean. *J. Amer. Soc. Agron.* 11. 247-252.

Honma, S. 1956. A bean interspecific hybrid. *J. Heredity* 48: 217-220.

Kaiser, W. J. 1981. Diseases of chickpea, lentil, pigeon pea and tepary bean in Continental United States and Puerto Rico. *Econ. Bot.* 34(3): 300-320.

Kinbacher, E. J., C. Y. Sullivan, and H. R. Knull. 1967. Thermal stability of malic dehydrogenase from heat-hardened *Phaseolus acutifolius* 'Tepary Buff.' *Crop. Sci.* 7: 148-151.

Marcarian, V. 1981. Salt tolerance in *Phaseolus* spp. *Ann. Rep. Bean Improvement Coop.* 24: 80-81.

Mok, D. W. S., M. C. Mok, and A. Rabakoarihanta. 1978. Interspecific hybridization of *Phaseolus vulgaris* with *P. lunatus* and *P. acutifolius. Theor. Appl. Genet.* 52: 209-215.

Nabhan, G. 1979. Tepary beans: The effects of domestication on adaptations to arid environments. *Arid Lands Newsl.* (10): 11-16.

Nabhan, G. P. and R. S. Felger, 1978. Teparies in Southwestern North America. *Econ. Bot.* 32(1): 2-19.

Parsons, L. R. 1979. Breeding for drought resistance; What plant characteristics impart resistance? *Hort. Sci.* 14(5): 590-593.

Parsons, L. R. and D. W. Davis. 1978. Investigations on drought resistance of tepary and kidney beans. *Agron. Abstracts* 1978: 83.

Parsons, L. R. and T. K. Howe. 1980. Effects of water stress on osmotic and turgor changes in common beans and drought resistant tepary beans. *Plant Phys. (Supplement)* 65(6): 7.

Petersen, A. C. and D. D. Davis. 1982. Yield Response of *Phaseolus vulgaris* L. and *Phaseolus acutifolius* subjected to water stress. *Ann. Rep. Bean Improvement Coop.* 25: 53-54.

Pratt, R. C. 1983. Gene transfer between tepary and common beans. *Desert Plants*, this issue.

Pratt, R. C. and H. T. Erickson. 1982. Flowering response of *Phaseolus acutifolius* Gray and sub-species to photoperiod. *Ann. Rep. Bean Improvement Coop.* 25: 1-2.

Provvidenti, R. and E. D. Cobb. 1975. Seed transmission of bean common mosaic virus in tepary bean. *Plant Dis. Rep.* 59(12): 966-969.

Schuster, M. L., D. P. Coyne, and B. Hoff. 1973. Comparative virulence of *Xanthomonas phaseoli* strains from Uganda, Colombia, and Nebraska. *Plant Dis. Rep.* 57(1): 74-75.

Smartt, T. 1970. Interspecific hybridization between cultivated American species of the genus *Phaseolus. Euphytica* 19: 480-489.

Smartt, T. 1979. Authentication of interspecific hybrids in *Phaseolus. Ann. Rep. Bean Improvement Coop.* 22: 12-13.

Sullivan, C. Y. and E. J. Kinbacher. 1967. Thermal stability of fraction I protein from heat-hardened *Phaseolus acutifolius* Gray, 'Tepary Buff.' *Crop Sci.* 7: 241-244.

Thomas, Claire V. 1983. *Physiological and Genetic Studies of Drought Resistance in Phaseolus vulgaris L. and P. acutifolius A. Gray.* Ph.D. dissertation, Department of Botany and Plant Sciences. University of California, Riverside.