Breeding for Lowland Tropics Adaptation in Potato

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Abstract

The results of heat tolerance trials on breeding lines, named varieties and true seed populations of potato are presented. The criterion of selection for heat tolerance was based upon their ability to produce marketable size tubers under hot, humid environment.

Introduction

Potato (*Solanum tuberosum* L.) is grown world-wide and ranks fourth among the world's major food crops. Nutritionally, it provides calories and nitrogen in proportion to the adult human requirement. Although somewhat deficient in amino acids methionine and cystine it ranks next to soybeans and is superior to the cereals in total protein production per hectare.

Todays potato production is greatest in the temperate zones where mean yields of 20 metric tons per hectare and above are reported. The high yields per unit area in these countries may be, to a large extent, caused by the influence of favorable climate on the growth of potatoes, i.e. moderate temperatures and long days with moderate light intensities.

In general, potato grows best at optimum air and soil temperatures of 15-18°C. However, this can be modified by daylength and light intensity. At temperatures above the optimum, potato plants show considerable stem elongation and greatly depressed tuber yields. The carbohydrates available for accumulation in the tubers diminishes progressively in temperature above 20°C and is practically nil above 34°C. Accordingly, the final tuber yield is determined by the combined interaction of climatological factors such as temperature, daylength, light intensity, etc. which altogether influence tuber initiation, leaf area, and assimilation rate.

Current Status and Future Prospects of Potato Production in the Tropics

Owing to its cool temperature requirement for growth and tuberization, potatoes are exclusively produced in the moderately cool highlands of the tropics. Such highland production zones in Southeast Asia, for example, are the Mountain Provinces in the Philippines, Cammeron Highlands in Malaysia, Cipanas in Indonesia, etc. Generally, mean temperatures in the lowland tropics, even during the coldest months, are not suitable for potato production. Fig. 1 shows some tropical lowland tropics locations in Asia and their mean monthly temperatures relative to the optimum range for potato growth.

The productivity of potatoes traditionally grown in the highland areas of the tropics is characteristically low. Apart from low average yields, these production areas are usually limited in acreage thereby accounting for the low total potato production in this part of the world (Table 1). The causes of low average yields are likely common to all tropical production regions – dearth of seed production technology, inavailability of well-adapted varieties, crop protection problems, cultural management problems, post-harvest losses, etc.

Conceivably, even with the eventual resolution of the major problems existing in its present area of production, the tropics may not really figure to be a principal potato producing and utilizing region mainly because of its limited acreage apart from a number of allied problems unique with the geographical features of its highland production zones.

The ecological constraints to potato production partly explains why this food crop has not attained the dominant role that major cereals have enjoyed in the tropics. In light of the burgeoning population in this region, crops with high yielding potential could become increasingly important as a supplement if not a complete substitute to the staple grains. Potato is a prime candidate for this subsidiary role as it is biologically a crop with yield potential much higher than cereal grains. Moreover, apart from being nutritionally better balanced, it is already considered a staple food in many parts of the world.

However, for potato to ostensibly create a significant impact on agriculture and industry in the tropics, its range of adaptation should be widened to cover the vast expense of the hot, humid lowland areas. Development of a truly tropical genotype could pave the way for the growth of the potato industry in this region. Cognizant of its potential importance, the Asian Vegetable Research Development Center (AVRDC) in Taiwan started a program in 1973 to search and/or develop clones adapted to the lowland tropics.

Based on theoretical and practical considerations, we define lowland tropics from an operational context as regions lying between 20^{o} north and south latitudes, with elevations no higher than 200 meters above sea level (Opena, 1978). Within this realm, seasons and/or locations with realtively moderate environmental stress may be chosen for eventual production of tropically adapted clones.

Lowland Tropics Adaptation: An overview of the AVRDC Program

The scope of potato research at AVRDC was initially limited to introduction and screening clones for adaptation to hot, humid environment typifying the lowland tropics of Southeast Asia. A continuing program was subsequently established to improve the levels of heat tolerance among promising genotypes isolated from initial tests.

Germplasm assembly. Major attention was devoted early to germplasm collection from around the world to provide a wide genetic base for the breeding program.

Immediate emphasis was concentrated on cultivated tetraploids because of the apparent ease with which any outstanding genotypes derived from there may be utilized.

Since the inception of the program, we have assembled a total of 1282 cultivated tetraploids (AVRDC, 1974). A major bulk of this was provided by the International Potato Program of the Rockefeller Foundation in Mexico. Rigid quarantine regulations on importation of clones have restricted collection of germplasm to botanical seeds for the most part. A total of 163 true seed populations from different sources have been collected since 1974 to provide one of our major genetic resources. Prime contributors of these populations were the International Potato Center, Cornell University, North Carolina State University, University of Guelph, and United States Department of Agriculture. The true seed materials solicited had varying genetic backgrounds – *Phureja/ Stenotomum* populations, *Neotuberosum* populations, *Tuberosum x Tuberosum* crosses. *Andigena* populations, *Andigena x Tuberosum* crosses, etc. True seed populations are usually converted into clones during the first year before they are entered in the heat tolerance nursery.

Screening for heat tolerance. Clones to be tested for heat tolerance are usually grown sometime between May and October at the experimental farm at AVRDC. AVRDC is situated at Shanhua, Tainan, Taiwan, 70 kilometers south of the Tropic of Cancer and 30 meters above sea level. Although our site is not encompassed within the latitudinal bounderies of what we define as lowland tropics belt, the summer monsoon season (May-October) is typically tropical. Table 2 summarizes the weather conditions in Tainan.

The monsoon season produces 91% of the 1,771 mm annual rainfall in Tainan area. The maximum temperature reaches a plateau in May that is sustained through October. During this period, an average of 25 days per month occurs during which the maximum exceeds 30°C. Daylength during this same period ranges from 11 hours and 30 minutes to 13 hours and 33 minutes.

Heat tolerance trials have been conducted on three kinds of materials – breeding lines and named varieties, true seed (segregation) populations, and wild species. Only the results from the first two groups will be presented here. The criterion of selection for heat tolerance among tetraploid materials was based mainly upon their ability to produce marketable size tubers under hot, humid environment. We have tentatively set the standard of marketability for Southeast Asia to include only tubers weighing at least 50 grams. While the minimum appears to be lower than those in temperate countries, this limit is still relatively larger than tubers we have seen in market places throughout the region.

Of 1,251 breeding lines and established cultivars screened in the 1973 summer, 1,065 clones (85%) survived until evaluation (AVRDC, 1974). Only 118 clones (11%) tuberized. However, none produced marketable tubers. In the 1974 summer, 594 clones (70%) out of 853 planted survived (AVRDC, 1975). Nine clones produced marketable tubers ranging from 150-390 g per plant. Although the proportion of tuberizing clones in the two-year tests of tetraploid accessions was generally low, the data suggested that tuber initiation was not a primary problem limiting potato adaptation in the hot, humid tropics.

Table 3. summarizes the horticultural traits of the top 3 to 5 selections from various segragatious screened in the 1974 summer. Selections from University of Guelph (UG) populations generally produced higher marketable yields than those from other populations. Selection 1282-4 gave the highest marketable yield of 400 g among UG derivatives.

Only three segregants from *Andigena/Tuberosum* crosses (population 1512) produced marketable tubers, Selection 1512-1 had the best marketable yield of 320 g. The other two selections, although twice as efficient in tuberization as 1512-1, gave lower yield probably as a result of their considerably reduced haulm development.

Among intervarietal crosses with Katahdin as common parent, segregants from populations 1486 and 1500 yielded more than those from other crosses. Like selections from UG populations, these clones tended to initiate a large number of tubers but only few enlarged to marketable size.

Figure 2 shows some representative initial selections from diverse materials evaluated for heat tolerance in 1974. All clones were lifted 105 days after planting before the onset of the cool season.

Breeding scheme to improve heat tolerance. The development of a truly tropical potato will likely entail a gradual, stepwise approach. Our terse experience in evaluating breeding lines, established cultivars and segregating populations of diverse genetic background suggests that genotypes with exceptionally high levels of heat tolerance are difficult, if not impossible, to recover. However, the few selected clones appear to be near if not at the threshold of physiological adaptation to high thermoperiod. These clones produced marketable tubers under relatively short days and high temperatures of the lowland tropics although only seemingly modest yields.

Recurrent selection appears to be the most logical breeding scheme to adopt in improving the current level of heat tolerance among initially selected clones. Component parents to create new base populations for continuing selection cycles may be selected on the basis of their phenotypes or on performance of their progenies. A recurrent selection scheme based on phenotype is preferred as an initial step in developing clones with progressively better adaptation to the warm lowland areas (Fig. 3). The method, while not as effective in identifying genetically superior clones as that based on progeny performance, has the decisive advantage of allowing rapid generation turnover. Within limits of genetic variability, stepwise improvement of populations may be expected through the gradual accumulation of favorable genes as selection cycles proceed.

A notable feature of the proposed scheme is the linkage with a highland program. This tie-up should enable year-round transformation of true seeds into clones and should aid in speeding-up the program.

The provision of an alternative environment for heat tolerance test should also be helpful in accelerating the program. Under Taiwan conditions, heat tolerance screening can be done only once a year. By establishing an alternative selection environment, preferably during the drier part of the year in other tropical areas of Southeast Asia, an opportunity for year-round screening is available.

The most promising clones utilized from the 1974 heat tolerance nursery at AVRDC were immediately utilized as parents in crosses to develop new populations for phenotypic recurrent selection. A number of these cycle 2 populations were successfully synthesized in early 1975, transformed into clones in the 1975 summer at Taichung Mountain in central Taiwan, and immediately evaluated under lowland tropics conditions of southern Philippines during the early part of 1976 (Fig. 4). Thus, we were able to complete 2 selection cycles in 20 months time.

Results from 2 selection cycles among 4 populations evaluated appear extremely promising as far as increase in marketable yield is concerned (Table 4). While the relative comparisons between cycles are aptly biased since 2nd cycle means were derived only from single-hill data of selected clones, the substantial differences in yield still attest to the significant gains achieved in different populations with only 2 cycles of selection.

Moreover, yields per plant as high as those observed in 2nd cycle populations were never noted from observational plots of 1st cycle clones. Compelling evidence is further provided by the performance of the same 2nd cycle populations when evaluated at AVRDC in 1976 summer. Second cycle clones with yields twice as much as their lst cycle parents were recovered within the same growth duration of 105 days (AVRDC, 1977). Fig. 5 shows some of these 2nd cycle clones selected at AVRDC. Compared to 1st cycle selections (Table 3 and Fig. 2), 2nd cycle clones produced larger tubers and consequently higher marketable yields.

Preliminary indications from the foregoing 2-selection-cycle data imply that a lengthy selection program may not be all that necessary to develop clones with high levels of heat tolerance. As a matter of fact, clones already possessing acceptable yield potentials under lowland tropics conditions were possible to isolate from even among 1st cycle selections as detailed in the following section.

Yield potential of selections in the lowland tropics. We conducted small plot lowland tropics trials of initial selections to further isolate promising parents for the recurrent selection program. the first field trial was carried out in 1975 in Davao, Philippines. Preliminary results were very encouraging that we continued the testing program as adequate tubers of other selections became available. Trials at AVRDC were also conducted for an additional location. The performance of the best clones in these two sites in different years is summarized in Table 5.

The yielding ability of outstanding heat tolerant clones varied from 14-27 metric tons of marketable tubers per hectare in growth duration of 80-120 days. By comparison, check varieties yielded 0-2 tons per hectare in the same duration.

Generally, clones survived longer in Taiwan than in the more tropical, short daylength location of Davao, Philippines. While no unequivocal proof is offered, the comparatively longer daylength during the summer months of May to October in Taiwan (see Table 2) is suspected to delay the maturation of clones to some degree. Moreover, excessively wet growing conditions combined with high temperatures and long daylength could have had synergestic interactions delaying time to initiation and extent of tuberization of clones. The 1978 trial in Taiwan was harvested earlier than the 1976 trial due to the onset of the cool season.

Figures 6 and 7 show some typical result from the above trials. The 1978 photographs were taken from a summer transplanting experiment using clone 1282-19 and a heat sensitive check cultivar (WIS-BR 69-68). Better haulm development and much larger tubers of 1282-19 compared to that of the check are evident.

Although selection 1282-19 was not entered in the 1975 Davao trial, its good yielding ability in the lowland tropics is evident in later tests at both locations. Thus far, this is the only clone which has performed consistently well in repeated tests in Taiwan. In the Philippines, this clone is among those selected by the national potato program for further trials based on its performance in 2 lowland tropics locations in 1978 (personal communication with Mr. E.T. Rasco, Jr., potato breeder, Institute of Plant Breeding).

The need for more exhaustive tests of promising clones in several lowland tropics locations is obvious and only just now underway. Nonetheless, results from the initial two-location tests suggest that the yield potential of the best selections may be already acceptable especially when respective national averages in tropical countries are considered. For instance, the average for the Philippines is only 6.4 tons per hectare (see Table 1) which is less than half of that obtained from outstanding clones in the lowland tropics tests.

Challenges Beyond Physiological Adaptation

Clearly, the program at AVRDC to adapt potato to the lowland tropics is at present greatly simplified. Our program basically emphasizes the isolation and/or development of genotypes that can yield well under hot, humid climate. To a great extent, this immediate objective has been pursued with conscious disregard for other important attributes of the potato.

It is a foregone conclusion, however, that the adaptation of potato to the lowland tropics will entail more than mere alteration of the physiological architecture of the plant relative to high thermoperiods. Certainly, other major constraints exist which render the entire problem vastly formidable. Considered generally of extreme importance are problems related to major diseases, cultural and management practices seed production aspects, storage, etc.

The results obtained from two cycles of recurrent selection of AVRDC have been extremely encouraging in terms of improved yielding ability under tropical climate. A stage appears to have now been reached whereby other components of adaptation may be given important attention. The major pathological resistance needed by the best heat tolerant selections is considered the next essential target. Bacterial wilt, caused by *Pseudomonas solanacearum* E.F.S., poses among others the most serious disease threat as it is a well-known destructive disease of many solanaceous relatives of potato in the tropics. Therefore, greater importance should be initially devoted to this disease. We have already noted from past studies at AVRDC that selection 1282-19, apart from being heat tolerant, also carries useful level of resistance to bacterial wilt (AVRDC, 1979). This clone should be of prime interest in future multilocation trials in the lowland tropics. Its value as a parent in further breeding work is also indubitably obvious.

Concomitant efforts should likewise be expended towards the development of improved cultural and management techniques for potato production in the lowland tropics. This phase is immediately important as far as further maximization of the yield potential of selected heat tolerant clones is concerned.

While other constraints do not currently merit attention, they are equally immense problems that will likely be resolved only through well-concerted, intensified research and development. However, they are limitations that logically follow after the development of a truly tropical potato is considered an overwhelming success.

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Table 1. Potato acreage, production, and yield in selected temperate and tropical countries, 1975[a]

Country	Acreage (1,000 ha)	Production (1,000 metric tons)	Average Yield (metric tons per ha)
United States	509	14,323	28.1
United Kingdom	205	4,536	22.1
West Germany	415	10,853	26.2
Japan	140	3,000	21.4
Philippines	4	26	6.4
Indonesia	39	149	3.8
Thailand	1	10	8.6
Sri Lanka	3	27	8.4

[a] Adapted from the 1975 FAO Production Yearbook, Vol, 29.

Table 2 Summary of weather conditions* in Tainan, Taiwan

Month	Temperature[a] Max (°C)	Min	Precipitation[a] (mm)	Observed Solar Radiation (cal/cm/day)	Daylength[c] hours	minutes
January	23.7	12.6	17.3	301	10	57
Feburuary	24.1	12.9	30.9	353	11	31
March	26.3	15.5	44.9	402	12	08
April	29.4	19.2	66.8	464	12	48
May	31.7	22.7	175.1	493	13	20
June	31.9	24.2	380.6	483	13	33
July	32.5	24.7	402.8	466	13	21
August	32.2	23.7	416.7	442	12	49
September	32.3	23.7	169.9	405	12	09
October	31.0	20.7	32.4	372	11	30
November	28.2	17.5	17.7	311	10	57
December	25.0	14.3	16.2	274	10	43

a Mean 1987 – 1970

b Data provided by Taiwan Sugar Research Institute

c Measured at 23°N latitude (Tropic of Cancer)

* General Reference: Central Weather 1974. Summary of Meteorological Data-Taiwan. Volume III. 1961-1970.

Table 3 **Horticultural characteristics of the top 3-5 potato selections derived from various segragating populations, 1974 heat tolerance nursery**

Selection No.	Haulm Growth (gm)	Total Yield (gm)	Marketable Yield (gm)	Total Tuber (no.)	Marketable Tuber (no.)	Tuberization Efficiency[a]
I. University of Guelp populations						
1282-1	–	500	335	15	6	–
1282-3	690	460	355	12	6	0.7
1282-4	250	650	400	31	8	2.6
1284-5	–	500	360	13	6	–
1284-18	680	430	335	11	5	0.6
II/ *Andigena/Tuberosum* Crosses						
1512-1	380	400	320	9	5	1.1
1512-2	110	240	180	6	2	2.2
1512-3	140	330	200	10	4	2.4
III. Intervarietal Crosses (Katahdin as common parent)						
1487-3	–	500	300	16	6	–
1487-5	–	540	400	14	7	–
1500-1	210	600	300	17	4	2.9

a
Ratio of total yield to haulm growth.

Table 4 Results of 2 cycles of pheotypic recurrent selection to improve potato yield under hot, humid tropical environment[a]

Population	Selection Cycle	Number of Selections	Mean Marketable Yield (g/plant)	Yield of Best Clone (g/plant)
RS 009	1st	4	368	–
	2nd	4	1,200	1,500
RS 021	1st	3	462	–
	2nd	5	880	1,148
RS 023	1st	3[b]	487	–
	2nd	7	813	950
RS 033	1st	6[c]	405	–
	2nd	7	857	1,300

a Test were conducted in 1976 at Twin Rivers Research Center, Davao, Philippines (about 7°N latitude, 5m above sea level; min temperature >20°C, max. temperature >30°C).

b Data available only for 3 of the original 5 parental clones of RS 023.

c Data available only for 6 of the original 13 parental clones of RS 033.

Table 5 Performance of the best potato selection in lowland tropics trials[a] at 2 locations in different years

Location[b]	U Year	Clone	Marketable Yield (metric tons/ha)	Growth Duration (days)
Davao, Philippines	1975	1282-1	22	83
		1284-5	20	83
	1977	1282-19	21	80
		Local (check)	2	80
Tainan, Taiwan	1976	1282-17	27[d]	120
		1282-19	18[d]	120
		Norin (check)	0	120
	1978	1282-19	14	97
		WIS-BR 69-68 (check)	0	97

[a] Plot size in all tests was 4.5 m^2, 20 plants per plot, and replicated twice.

[b] Trials in the Philippines were conducted at Twin Rivers Research Center. In Taiwan, trials were conducted at the AVRDC Farm strictly during the summer season (May to October) only.

[c] Uncorrected for stand unless superscripted as d.

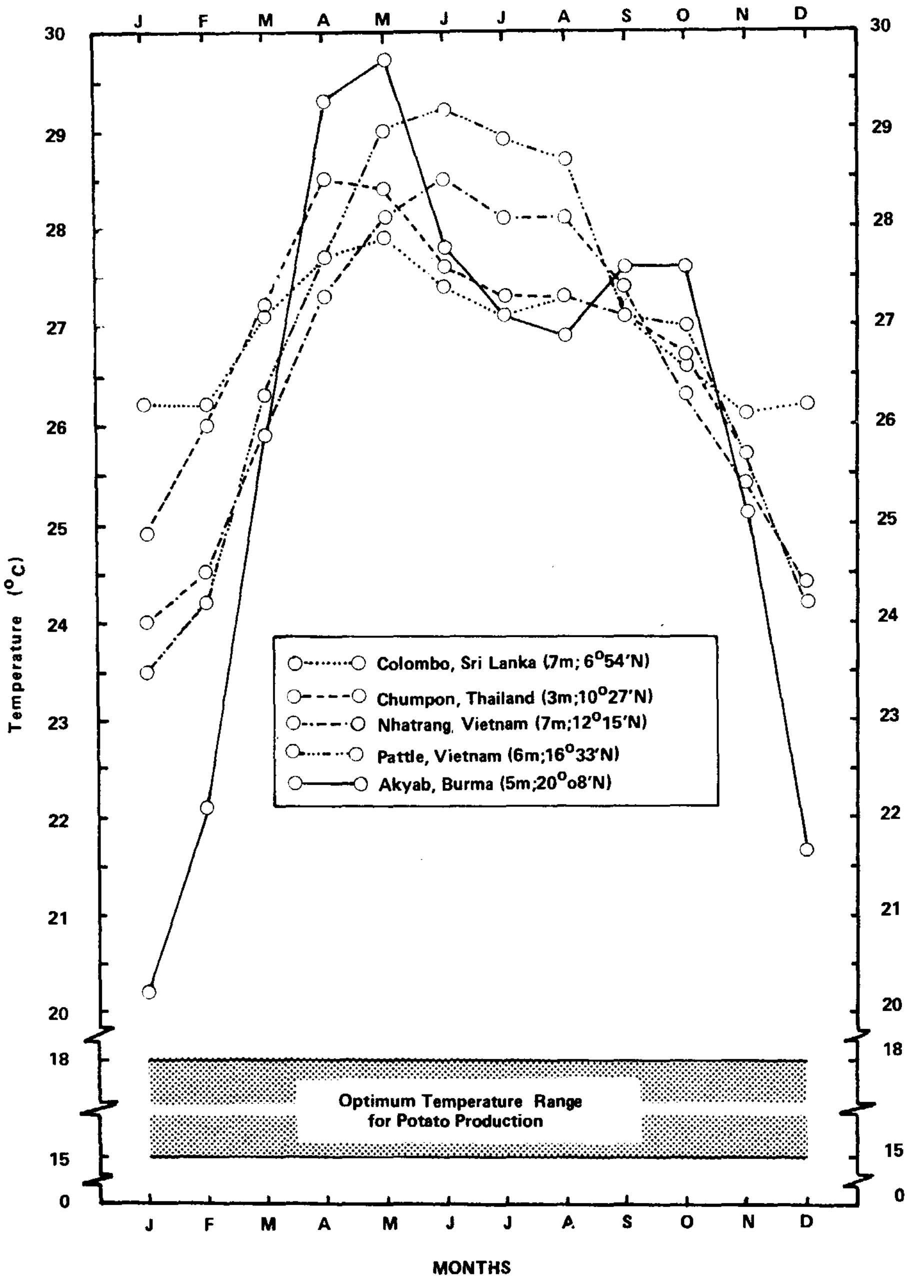

Figure 1. Mean monthly temperature in some typical lowland tropics locations of Asia relative to the optimum range for potato growth. Note elevation (meters above sea level) and latitude in parentheses after each location. Source: World Weather Records, 1951-1960. Vol. 4. Asia. 1967. U.S. Department of Commerce. Washington, D.C.

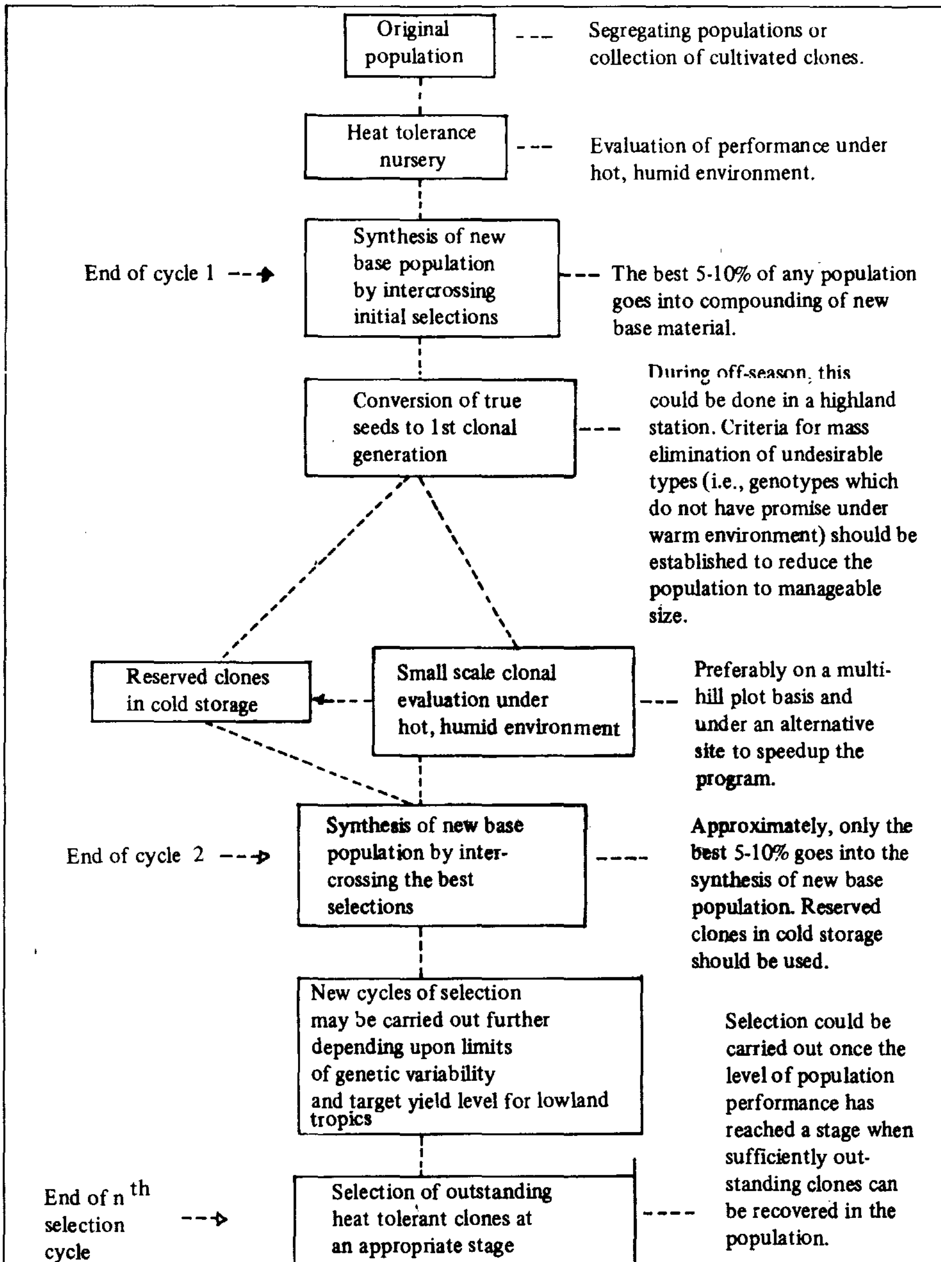

Figure 2. A simple phenotypic recurrent selection scheme to improve physiological adaptation of cultivated potato to lowland tropics.