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Conceptual Changes in Cuban Plant Breeding in Response to a National Socio-economic Crisis: the Example of Pumpkins

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Abstract

Major changes in the economy of Cuba since 1989 have led to reduced inputs in agricultural production resulting in changes in some of the goals of Cuban plant breeding and a search for new, more appropriate methods of plant breeding for pumpkin, including consideration of participatory plant breeding (PPB). This chapter reports the results of a pumpkin breeding project that explored the benefits of plant breeders' collaboration with farmers in Habana province. The research focused on two issues: (i) the use of landraces as sources of genetic diversity under low-input conditions; and (ii) farmers' and plant breeders' methods of seed production. In this chapter we describe why these issues are important for cross-pollinated crops in the Cuban context, and why PPB might be a useful response in terms of the biological results, energy efficiency and economic returns achieved.

Cuban Agriculture, 1959–1989

Objectives and development of Cuban agriculture after 1959

The three most important objectives for the transformation of Cuban agriculture after the Cuban revolution in 1959 were to: (i) meet the growing food requirements of the Cuban population; (ii) create export

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funds in order to obtain raw materials and empower the food industry; and (iii) eradicate poverty from the countryside (Funes, 1997). An industrialized or conventional agricultural model, typified by the 'green revolution' approach to agricultural development was pursued in order to achieve these objectives.

In Cuba the conventional approach to agricultural modernization in the style of the green revolution was possible because of the strong relations that had been built with the Socialist countries of Eastern Europe and, in particular, with the former Soviet Union (USSR) (Enríquez, 2000). This relationship permitted pursuit of high-input agriculture, focused on labour efficiency and productivity. As such, this reflected an industrialized world trend of progressive substitution of labour with capital as a method for increasing land productivity (Funes, 1997). The management of agricultural processes through high use of external inputs, large-scale production, specialization, monoculture and mechanization, was adopted in Cuba at a national level, with the intention of producing sufficient food for all. Indeed, this model, supported by high input levels, was successful in achieving the prescribed objectives over its 25-year duration (Table 9.1).

However, throughout the 1980s, 87% of Cuba's export trade was carried out at preferential prices with socialist countries, and only 13% at world 'market' prices with Western countries (Enríquez, 2000). This meant that national goods were sold at high prices, and imports were purchased at low prices. Principal export cash crops, primarily sugar, tobacco and citrus, covered 50% of the agricultural land (Pérez Marín and Muñoz Baños, 1992; Rosset and Benjamin, 1993). The high level of importation of energy (petroleum), fertilizer, herbicides and livestock concentrates was favourable for Cuban food production, but not for Cuban self-sufficiency (Table 9.2). The success of this model was based on a strong dependency on external inputs.

The plant breeding model

A centralized plant breeding model was a component of the high-input agriculture being used particularly for the country's cash crops (Begemman *et al.*, 2000). Introduction of foreign varieties, hybridization, landraces and mutation breeding were the principal sources of genetic variation used for varietal development in Cuban plant breeding programmes (Ríos, 1999). At the end of the 10–12 years typically spent in varietal development for a specific crop, the breeding programmes usually released only one or two varieties for the entire country, emphasizing geographically wide adaptation. Wide geographical adaptation was encouraged by policy makers, with most Cuban

Table 9.1. Successes obtained with the conventional agricultural model in Cuba. (Sources: Deere, 1992; Funes, 1997; Oficina Nacional de Estadísticas, June 1997.)

	Year	
Indicators of success	1965	1988–89
Calorie consumption (kcal per person day^{-1})	2500	2834
Protein consumption (g per person day^{-1})	66	76
Life expectancy (years)	55	75

Table 9.2. Principal agricultural imports in Cuba in relation to total national requirements at the end of the 1980s. (Sources: Deere, 1992; Pastor, 1992; Funes, 1997.)

Agricultural import	Percentage of Cuba's national needs met by imports
Edible oils and grains	94
Wheat	100
Rice	50
Beans	99
Meat	21
Milk and derivatives	38
Fish	44
Sugar	0
Root and tuber crops	0
Fruits and vegetables	1–2
Fertilizers	94
Herbicides	96
Livestock concentrates	97

governmental organizations providing incentives to scientists involved in releasing a variety for use over a large area (Ríos, 1999).

Ambitious plant breeding programmes were developed in sugarcane, roots and tubers, rice, tobacco, coffee, horticultural crops, pastures, grains, fibres and some fruit trees, undertaken by 15 research institutes and an experimental station network that spread over the island in the 1980s (Begemman *et al.*, 2000).

As a part of the varietal release process, each new variety had to pass through a hierarchical series of steps:

> When a research institute has a significant result they send this to the Scientific Forum (Consejo Cientifico) at the national level. This Forum checks its scientific validity and, if it is approved, they send it to an Expert Group (Grupo expertos) consisting of researchers, teachers and

> production directors. If this Group approves the result it is then sent to the Vice-Minister of Diverse Crops (Vice-Ministro Cultivos Varios). This Minister will send the results to the provincial delegations, who implement them into their production plans, and this means that producers have to adopt them as an order. This procedure takes a top-down approach without consulting the producers. Some researchers do visit farms, but still the research areas and problems come from the decisions of the researchers. Further, the Scientific Forum only evaluates the scientific content and not its applicability, and therefore they may reject good techniques and accept those that are unsuitable for producers.
>
> (Trinks and Miedema, 1999: 116)

Landraces and plant breeding

Since professional plant breeding in Cuba was officially established in April 1904 through the Estación Experimental Agronómica in Santiago de las Vegas, landraces have been widely used in crop improvement programmes for different species. Some landraces of food crops such as garlic, maize, pepper, cowpea, groundnut, tomato, common beans and pumpkin were released as commercial varieties after roguing the population of undesirable off types. In others, plant breeders selected favourable off types within landrace accessions (Esquivel *et al.*, 1994). Both procedures produced important varieties with good qualities and acceptable yields throughout the history of professional plant breeding in Cuba. For tomato, hybridization of Cuban landraces with materials of temperate origin had a good impact in Cuba (Moya, 1987). Some of the materials of diverse crop species collected in Cuba with characteristics such as disease resistance, short growing cycles and good food qualities were not used by the formal plant breeding sector due to their low yields under high-input conditions (e.g. for beans see Castiñeiras, 1992).

In the 1980s, the peak of industrial agriculture in Cuba, an investigation of plant genetic resources in Cuba was undertaken as a collaboration between the Cuban Fundamental Research Institute in Tropical Agriculture (the former Estación Experimental Agronómica) and the Gene Bank of Gatersleben, Germany. This study documented the diversity of plant genetic resources within the country and found that the majority of this diversity was being maintained and managed by farmers and in non-industrial systems (Hammer *et al.*, 1992). Esquivel and Hammer (1992) describe the ‘conucos’, traditional home gardens characteristic of subsistence agriculture in Cuba, as the central ecosystems for maintaining plant genetic resources in the country, and for maintaining materials to satisfy farmers’ needs (medicinal, religious, economic, food) that were not met by industrial agriculture.

Cuban Agriculture After the Collapse of the Socialist Block: 'The Special Period'

The collapse of the socialist countries of Eastern Europe and the USSR highlighted the vulnerabilities of the agricultural model being followed by Cuba. Cuba lost its principal export markets and guarantees, which had been provided by these countries. Foreign purchase capacity was dramatically reduced from US$8100 million in 1989 to US$1700 million by 1993, a decrease of almost 80% (Rosset and Benjamin, 1993). Of this new figure, US$750 million was required solely for the purchase of fuel, and US$440 million for basic foods. The ability to purchase agrochemicals was also greatly affected (Table 9.3).

As a result of this situation, agricultural production was immediately and severely reduced. All Cuban farmers suffered in these difficult circumstances; however it was most acutely felt in the large, high-input enterprises; small- and medium-scale farmers were less affected (Funes, 1997). The lack of financial resources also had a severe effect on the seed industry in Cuba. For example, before 1989, seed production capacity for maize and beans had reached over 3180 t year^{-1} but in 1998 only approximately 50% of that amount was produced (Ríos and Wright, 1999).

Strategic changes and popular responses to the crisis in agricultural production

To address the crisis, the Cuban government implemented changes in all sectors to reduce the negative impact on the national economy. During the early 1990s, severe social and economic changes were made in order to maintain the social guarantees of the government while simultaneously reconstructing the Cuban economy (Rosset and Benjamin, 1993; Enríquez, 2000).

Since the beginning of the crisis, the government attempted to reduce the negative impact of the lack of inputs for agriculture. Accordingly, national strategies were implemented to accelerate research and

Table 9.3. Comparison of agrochemical imports pre and post collapse of the socialist block. (Source: Rosset and Benjamin, 1993.)

Agrochemical	1989 imports	1992 imports	Reduction (%)
Petroleum (Mt)	13,000,000	6,100,000	53
Fertilizers (Mt)	1,300,000	300,000	77
Chemicals (US$ millions)	80	30	62

application in areas including biological control (Estrada and López, 1997; Fernández-Larrea, 1997), crop rotations and polycultures. Legumes as green manure, biofertilizers and other organic fertilizers were also considered crucial themes for researchers and national institutions (Funes, 1997). A dramatic change in mechanization was quickly implemented; the total number of tractors in the country was reduced to less than 30,000, while the number of ox teams rose to 300,000 (Trinks and Miedema, 1999).

There were also spontaneous responses among both urban and rural populations to the crisis in agricultural production and food availability. For example, urban and peri-urban agriculture reached unanticipated levels of production. In 1994, it was reported that 4200 t of vegetables were produced by urban and peri-urban agriculture, increasing to 480,000 t by 1998, with further increases predicted (Grupo Nacional de Agricultura Urbana, 1999). Similarly, between 1992 and 1993 small-scale production of rice also became significant. The National Rice Research Institute (Instituto de Investigaciones del Arroz, 1999) reported production of more than 150,000 t of rice on smallholdings disseminated over 100,000 ha nation-wide, estimated to contribute more than 53% of the nation's production of that crop.

It became apparent that a substantial amount of the food that people were consuming was not being accounted for in the official agricultural statistics. Plant breeders and policy makers recognized that small-scale producers, using their own knowledge and genetic resources from the informal system, were filling important gaps in agricultural productivity (J.R. Martin Triana, San José de las Lajas, 2001, personal communication). This realization was one of the factors that laid the foundation for some changes in Cuban plant breeding that were to occur over the coming years.

Refocusing plant breeding efforts during the agricultural input crisis in Cuba

Pumpkin (*Cucurbita moschata*. Duch. ex Lam; hereafter 'pumpkin' always refers to this species) in Cuba is very popular for culinary and medicinal properties, taste, β carotene content as well as use in ceremonies in African religions. A prostrate growing habit with numerous, large lateral branches is a characteristic feature of pumpkin, with branches sometimes reaching lengths of more than 10–12 m (Lira, 1992; Wessel-Beaver, 1995). This growth pattern, as well as being a monoecious plant (separate female and male flowers borne on the same plant) favours cross-pollination (Guenkov, 1969). Pollination is carried out primarily by insects, especially honey bees (*Apis melifera*) since pumpkin pollen grains are too heavy to be transported by the wind (Withaker, 1962).

As a result of the input crisis, no chemical products were applied to Cuban pumpkin fields and artificial irrigation was greatly reduced. At the beginning of the special period the government planned to satisfy the demand for pumpkin by increasing the areas sown to this crop, more than 40,000 ha in 1993. However, yields dropped from 2–3 t ha^{-1} in 1987, to 0.2–0.4 in 1993 (Ministerio de la Agricultura, 1987, 1988, 1989, 1992, 1993) along with decreasing input levels. The abrupt reduction in productivity resulted in pumpkins disappearing from every market and becoming an exotic vegetable in Cuba (Ríos *et al.*, 1994, 1996). The circumstances of the economic crisis made it evident that the conventional breeding model had assumed that varieties should be highly responsive to external inputs (agrochemicals and irrigation). When such inputs were no longer available, the yields of those varieties dropped substantially.

To address this situation a governmental committee composed of researchers and representatives of the Ministry of Agriculture analysed the causes of the decreased yield in pumpkin. Two reasons for the low yields were identified: (i) a lack of chemical inputs including pesticides and fuel for irrigation; and (ii) the degeneration of the commercial variety RG (a crookneck fruit shape), potentially capable of yielding 18–20 t ha^{-1} with intensive application of external inputs (Ministerio de la Agricultura, n.d.). Because of its culinary quality and high yield potential under the conditions before the special period, RG was sown on more than 70% of the area planted with pumpkin across the whole island (Ríos, 1999).

In response to the conclusions of the governmental committee, a plant breeding programme was established in the National Institute of Agricultural Sciences (INCA) in collaboration with the Higher Pedagogical Institute for Professional and Technical Education. The principal goal was to provide seed of new varieties of pumpkin to the national seed company. Initially many efforts were made by the first author's multidisciplinary team to provide fertilizer, pesticides and artificial irrigation to their research plots on the experimental station. However those inputs were simply not available and pumpkins on research stations and in farmers' fields had to grow under abiotic and biotic stresses reflecting the reality of the new Cuban condition.

Plant breeding for abiotic and biotic stresses is common, but these stresses have usually been studied in isolation (Ríos, 1997) with plant breeders typically selecting the best genotypes on the basis of one type of stress with all other factors controlled. However, low-input growing conditions, such as those brought about by the economic crisis in Cuba, result in multiple stress interactions (Ríos, 1997, 1999). Therefore, a central research question was: Is it possible to select pumpkin varieties capable of good yields under the multiple stresses present in the growing environments of the special period in Cuba?

Pumpkin Landraces: Breeding Material for the New Cuban Agriculture

Two approaches were taken to seeking appropriate pumpkin genetic material for the new Cuban conditions. The first was to explore the possibility of purchasing modern variety (MV) seed from international seed companies. Policy makers acquired different varieties from such companies for testing under Cuba's new, low-input conditions. The second approach was to test, under low-input conditions, a sample of landraces from the collaborative collecting mission of the Gene Bank of Gatersleben, Germany, and the Cuban Fundamental Research Institute in Tropical Agriculture. While evidence suggests that landraces of pumpkin and other species were important as sources of variability with adaptation to high-input Cuban agriculture in the 1980s (Moya, 1987; Hammer *et al.*, 1992), it was rare to find reference to landrace utility for plant breeding for low-input conditions.

Overall, the 20 MVs tested had very low yields, high pest and disease infestations and poor culinary quality (Ríos *et al.*, 1996). In contrast, within the pool of 33 landraces evaluated, favourable variation was found for some characteristics important to the new breeding programme.

Landrace variability analysis

Materials and methods

Thirty-three pumpkin landraces from diverse sources collected during the 1980s (Table 9.4) were sown in the Fundamental Research Institute in Tropical Agriculture research plots in San Jose de Las Lajas, La Habana, Cuba, in 1988. The variety RG was included as a control because it was widely sown and well known (Ríos *et al.*, 1994). Growing conditions were in most ways typical of the special period with no agrochemical use and farmers' labour and their traditional management practices. Organic fertilizer in the form of readily available sugarcane processing by-product was applied, at the rate of 3 kg per plant. To avoid any confusion when harvesting the fruit, landrace plots were sown 8 m apart, all having a within-plot sowing distance of

Table 9.4. Thirty-three pumpkin landraces[a] and one control variety evaluated in the INCA breeding programme during the special period.

Landrace	Collection site
H-909, H-900, H-1411, H-1345, H-1188, H-1388, H-1291, H-1377	Holguin
IJ-1523	Isla de la Juventud
LH-21, LH-1175, LH-30, Crisostomo	La Habana
SS-1130, SS-550	Sancti Spíritus
PR-1189, PR-130, PR-40, PR-39	Pinar del Río
C-1027, C-1029, C-1043	Cienfuegos
G-1442	Guantánamo
CA-711	Ciego de Avila
VC-1118	Villa Clara
LT-826, LT-828	Las Tunas
U-1974, U-357, U-1461, U-2002, U-278, U-1665, RG (control)	Unknown

[a]Collected as part of the collaborative programme between the Fundamental Research Institute in Tropical Agriculture and Gatersleben Gene Bank (Hammer *et al*., 1992).

1 m between hills. For this evaluation each landrace was represented by 21 plants all located in one unreplicated plot.

In order to cluster the landraces' phenotypic variability, different characters such as percentage dry matter, placental zone diameter, leaf shape, leaf lobules, number of fruits per plant, and fruit characteristics including weight, calculated yield ha^{-1}, length, diameter, flesh diameter, shape, skin colour, flesh colour and skin texture were evaluated according to Esquinas and Gulick (1983). A matrix of landraces based on average values for quantitative and qualitative characteristics was analysed using factorial analysis.

Findings

Among the landraces, 23 were capable of producing fruits in 80–110 days. The rest fruited after 120 days, and were therefore eliminated from further testing. Earliness is desirable because it allows farmers to produce two crops per year from the same piece of land instead of just one as is the case with longer cycle material. The materials producing ripe fruits in less than 120 days were seen as an important genetic source for earliness because some genotypes can take longer than 160 days to mature in the tropics (Lira, 1992).

Among the quantitative and qualitative characters evaluated in the pumpkin collection, fruit yield and fruit skin colour were predominant in classifying these materials under low-input conditions according to the factorial analysis. The contributions of these two traits allowed formation of six ranked clusters ranging from light to dark fruit skin colour and with fruit yields of less than 1.5 t ha^{-1} to 15 t ha^{-1} (Table 9.5).

Based on the morphological variability observed, the landrace collection seemed to have potential as a starting point for pumpkin breeding for the new Cuban conditions. However, there remained the question of whether landraces in and of themselves could contribute to increasing yields (e.g. Ceccarelli *et al.*, 1998). Our next research question addressed this, asking: Is it possible to increase pumpkin yields under the new Cuban conditions by developing new varieties based solely on landraces?

Yield as a Selection Criterion

The economic crisis and its impact on research funds and facilities forced one Cuban plant breeder (HRL) to take promising pumpkin landrace families identified in the evaluation trial at the Fundamental Research Institute in Tropical Agriculture experimental station to farmers' fields much earlier than had originally been intended. Once there, he decided to enlist farmers' help in doing family selection within those landraces. Thus, to test the potential for increased fruit production by selecting families originating from landraces, some

Table 9.5. Pumpkin landrace clusters produced by a factorial analysis of the 1988 evaluation trials in the Fundamental Research Institute, Santiago de la Vegas, Cuba. (Source: Ríos, 1999.)

Cluster description	Landraces
Very high yielding (15.7–7.0 t ha^{-1}) genotypes and fruits with green skin colour	H-1388 and LT-828
High yielding genotypes (6.4–6.5 t ha^{-1}) and fruits with green skin colour	SS-550 and PR-130
Medium yielding genotypes (3.4–1.6 t ha^{-1}) and fruits with brown, yellow or grey skin colour	U-1461, LH-30 and VC-1118
Medium yielding genotypes (3.4–1.6 t ha^{-1}) and fruits with green skin colour	H-1411, IJ-1523, C-1043 and C-1029
Low yielding genotypes (less than 1.5 t ha^{-1}) and fruits with brown, yellow or grey skin colour	LH-1175, H-909, H-900, H-1377 and LT-826
Low yielding genotypes (less than 1.5 t ha^{-1}) and fruits with green skin colour	H-1188, CA-711, U-1974, C-1027, PR-1189, G-1442, PR-39, RG

experiments, including farmers' participation in selection on farm, were carried out in the middle of the most difficult period of Cuba's input crisis.

Materials and methods

In the summer of 1989 an experiment that developed into a collaboration between farmers and plant breeders was sown at the 28 de Septiembre Cooperative in Batabanó Municipality, Habana province. Plant breeders brought 13 half-sib families, each one representing a landrace that had been chosen for overall yield under low-input conditions at the experimental station as described above, and planted the experiment at the cooperative. The variety RG was again included as a control. The families were distributed in a randomized complete block design with three replications permitting free cross-pollination aided by the presence of a beehive 100 m from the experimental field. Each half-sib family plot was sown 8 m distant from the other plots, and all had a within-plot sowing distance between hills of 1 m, with 21 plants per half-sib plot as in the original landrace evaluation described above.

During the summer season characterized by heat stress, two farmers from Batabanó (males 58 and 70 years old) chose among the 13 half-sib families according to yield and fruit shape and selected individual fruits within those chosen families. Afterwards the chosen families, represented by the selected individuals, were sown at the same cooperative and at the INCA experimental station under low-input conditions during the cool, dry season (winter) and again in the hot, rainy season (summer).

Components of variation for half-sib progenies were calculated, including additive genetic variance. This permitted estimation of heritability and predictions of genetic response to selection for fruit weight, yield and number per plant, determined according to Galvez (1985), assuming a selected proportion of 40%.

Findings

Among the 13 half-sib families presented, the farmers chose nine families under the low-input conditions in Batabanó in the summer season. Average estimations of predicted genetic response across families for yield and its components (fruit weight and number) tended to be superior in the winter season (Table 9.6), probably because the relatively low temperatures favourably influence fruit set (Guenkov,

Table 9.6. Average predicted genetic response of nine half-sib pumpkin families to two cycles of selection estimated under low-input conditions. (Source: Ríos, 1999.)

Selection environment (season and average fruit yield, t ha^{-1})	Predicted genetic response for		
	Fruit yield (t ha^{-1})	Number of fruit per plant	Fruit weight (kg per fruit)
Hot (summer, 6.1)	0.6	0.3	0.7
Dry (winter, 3.2)	1.5	1.5	1.1

1969). The response of number of fruits per plant tended to be low in the summer season, presumably due to the effects of high temperature on flowering and early fruit abortion (J. Casanova, La Habana, 1998, personal communication).

The genetic response to selection predicted in this experiment was inversely associated with environmental yield, so high genetic response occurred in the low-yielding environment of the winter season and vice versa. In both growing environments, fruit yield had a genetic response superior or similar to its components, indicating that in half-sib families, some genetic advance could be obtained by direct selection for yield under low-input conditions.

Working on farm, with farmers and Cuban pumpkin landraces provided two important insights to pumpkin breeding for the input crisis: (i) wide phenotypic variability of useful traits exists and has been documented among Cuban landraces grown under low-input conditions; and (ii) it is possible to increase production by selecting directly for fruit yield under low-input conditions (see Ceccarelli and Grando, Chapter 12, this volume).

Participatory Plant Breeding for Multiple Stress Tolerance

To specifically evaluate the pumpkin material selected by farmers in terms of response to the multiple stresses of the agricultural conditions in Cuba during the special period, a further experiment was conducted.

Materials and methods

The performance of the nine half-sib families chosen by the two farmers and the control variety (RG) were evaluated by the same two farmers and two breeders in the summer and winter seasons as described above. The farmers' selection criteria were obtained through informal interviews at the end of each harvesting period (Ríos, 1999). For each of the nine half-sib families, breeders measured variation in fruit yield in relation to drought and heat stress (Fig. 9.1, Table 9.7). These data permitted estimation of a stress tolerance index (STI) according to Fernández (1992): STI = [(highest yield under stress A) × (highest yield under stress B)]/[yield average under stress most limiting yields (either A or B)]^2.

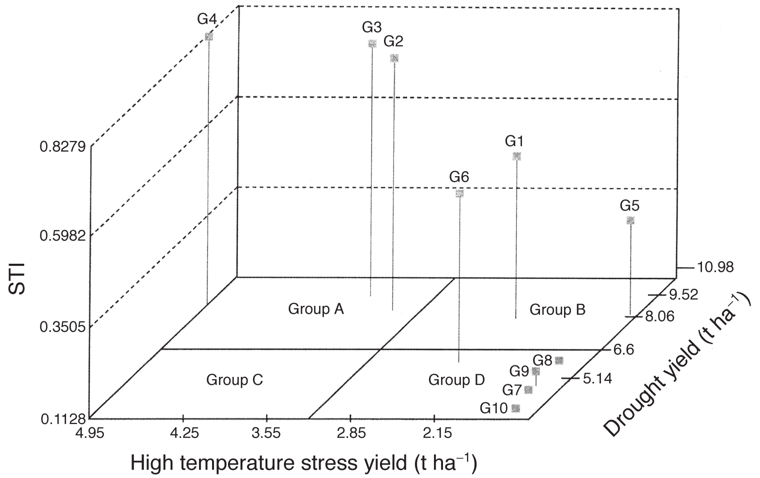

Fig. 9.1. Response to abiotic stresses (high temperature and drought) of lines selected from landraces as measured by their stress tolerance index (STI) (Fernández, 1992). (Source: Ríos *et al.*, 1998a.)

Table 9.7. Codes used in Figs 9.1 and 9.2 for selected lines and their landrace source. (Source: Ríos, 1999.)

Code	Landrace source of lines selected from half-sib family
G1	IJ-1523
G2	IJ-1523
G3	PR-130
G4	PR-130
G5	LT-828
G6	PR-1029
G7	LT-828
G8	SS-550
G9	SS-550
G10	RG (control, commercial variety)

Findings

Based on their STIs, the nine half-sib families were classified into the following groups:

- Group A: perform favourably under both high temperature and drought stresses.
- Group B: perform favourably under high temperature stress and poorly under drought stress.
- Group C: perform poorly in high temperature stress and favourably under drought stress.
- Group D: perform poorly under both stresses.

During the drought stress trial in the winter season when diseases are most limiting in pumpkin, the infection indices of silvering leaves (Paris *et al.*, 1987) and downy mildew (*Pseudoperonospora cubensis* Ber.Cur) (CIBA-GEIGY, 1984) under highly infectious natural conditions were plotted against half-sib family average yield, to identify any variation in their responses. Based on this criterion families were classified as follows (Fig. 9.2):

- Group A: half-sib families having high infection index for both downy mildew and silvering leaves.
- Group B: half-sib families having high infection index for downy mildew and low for silvering leaves.

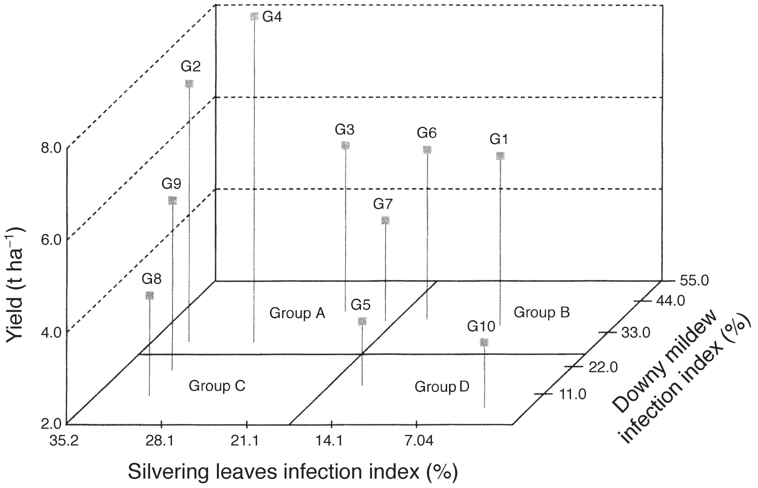

Fig. 9.2. Response to biotic stresses (silvering leaves and downy mildew) of lines selected from landraces as measured by yield under infection. (Source: Ríos *et al.*, 1998a.)

- Group C: half-sib families having low infection index for downy mildew and high for silvering leaves.
- Group D: half-sib families having a low index for both diseases.

Farmer-chosen families included the response group A or B (Fig. 9.1), except for one half-sib from PR-130 (see Table 9.4) that had high yield under high abiotic stress conditions but its shape and quality did not satisfy farmers' criteria. The farmers were particularly interested in materials with a good response under summer conditions because production is more economical when summer rainfall eliminates the need for irrigation.

The inclusion of a control variety recommended by breeders was an important component of this experiment. Because of this, farmers were able to compare the new material chosen by them with the material that they usually sow in the area. Sometimes extension workers complain about the difficulties of convincing farmers to adopt new materials; however, providing a clear comparison between what they are currently using and potential new materials provided a valuable discussion point for farmers and extension workers.

A superior performance under biotic stress was shown by another PR-130 half-sib and one from IJ-1523, giving higher fruit yield, despite presenting the highest leaf infection index for powdery mildew and silvering leaf (Fig. 9.2). Indeed, the farmers did not pay attention to leaf infection, because their selection criteria focused on fruit yield and shape, stating that neither disease is important in terms of the quality and yield of fruit.

Formal researchers have two possible explanations for the performance of these two half-sib families. First, it may be that the yield potential of these genotypes is so high that they produce superior phenotypes despite the presence of adverse conditions (Blum, 1988; M. Hernandez, San Jose de las Lajas, 1998, personal communication). Second, these genotypes may be using alternative physiological strategies that allow them to tolerate disease infestation and still produce desirable harvests (Seidel, 1996). As of yet the actual mechanism(s) for the success of these genotypes has not been identified. Still, in response to the new circumstances in Cuban agriculture, Cuban breeders and other scientists accepted both genotypes for release through the formal system, representing an agreement between farmers and scientists on the most desirable pumpkin material.

Evaluation in the target growing environment made it possible to make use of both farmers' and scientists' capacity to identify families tolerant to drought, powdery mildew and silvering leaf interaction. It was also observed that the two participating farmers recognized the possibility of identifying materials with long necks and satisfactory yield under conditions of low external inputs.

The research described above indicated ways in which to improve the breeding process for pumpkin varieties more appropriate for the new conditions of Cuban agriculture. However, the limitations of typical seed production methods developed under the high-input conditions of the 1980s suggested another area that might require rethinking in order to be better adapted to the current realities of Cuban agriculture. An investigation concerning this is the subject of the following section.

Seed Production and its Relationship to Plant Breeding

One of the fundamental distinctions between formal and informal or traditionally based systems of ‘conservation’ and plant breeding in terms of their biological consequences is the organization of these processes (de Boef and Almekinders, 2000). As noted by Smale *et al.* (1998) and Soleri *et al.* (Chapter 2, this volume), in formal systems genetic resource conservation, plant improvement and seed production are physically and temporally isolated from one another, while in traditionally based systems these tasks are accomplished simultaneously within the same populations and growing environments. The differences between these two systems could potentially lead to different genetic effects. A similar contrast exists between formal and informal pumpkin breeding and seed production in Cuba. Another part of this research has been testing the hypothesis that one aspect of the organization of seed production (varietal isolation and selfing) has negative biological consequences in comparison with the process of seed production used by the informal system.

A central focus of the formal seed production system in Cuba is maintaining the principal varietal characteristics on release of the variety. The formal sector attempts to maintain the varietal characteristics developed by breeding through continued roguing of off types and complete isolation to maintain trueness to type during seed production (Ministerio de la Agricultura, n.d.). Indeed, early in the special period it was believed that pumpkin yield depression was caused by carelessness in maintaining seed purity during the multiplication phase due to pollen contamination, which resulted in negative deviations from the expected variety response trend. To achieve the desired ‘purity’ and to ensure high seed production, large amounts of seed are multiplied in optimum conditions outside the target environment made possible through high rates of application of external inputs.

To test the hypothesis that isolation and selfing might in fact have a negative impact on varietal productivity compared with the seed production methods used by the informal system, the two models were examined. The formal model, typically used by the formal seed system in Cuba, separates recombination and selection temporally and spatially from seed production, and the informal model, used by farmers in Cuba, combines recombination, selection and seed production into one simultaneous process (Ríos *et al.*, 1998b).

Methods

To represent the formal model, seeds from two half-sib families, Marucha and Fifí (the commercial names of the half-sib families G3 and G4, respectively, see Table 9.7), were each multiplied in isolation without any other pumpkin genotypes within 1000 m. Seeds obtained from individuals within each variety characterized by favourable yield and fruit quality were sown separately, avoiding any mixing with extraneous pollen, for two multiplication cycles, one in winter and the other in the summer, with a population size of 2500–2700 plants for each variety in both seasons per cycle. Typical fruits of each variety were selected as seed sources in each cycle.

The informal model was represented by a common approach among Cuban farmers (e.g. Ríos *et al.*, 1998b, for pumpkins; Ríos and Almekinders, 1999, for maize) in which different varieties are grown in close proximity and their seeds saved. In this experiment, Marucha and Fifí half-sibs were grown among eight other pumpkin half-sibs selected from landraces (three half-sibs from the same landrace that Marucha and Fifí originally came from, PR-130, the other five were derived from different landraces). Again, typical fruits of each of the two varieties were selected as seed sources for two multiplication cycles, one in winter and the other in summer, with a population size of 50 plants for each variety in both seasons in each cycle.

The seeds of Marucha and Fifí obtained by simulating the two models of seed production were compared in a randomized complete block design under low-input growing conditions during the summer and winter, with a population size of 100 plants for each model in each season.

Findings

The pumpkin seed multiplied using the informal model showed higher yields than those produced using the formal model across summer and winter seasons (Table 9.8). As was found in the earlier selection experiment (see Table 9.6), the yield averages are lower during the

Table 9.8. Comparison of yields of two pumpkin varieties when seeds are produced using the formal vs. informal seed production models. (Source: Ríos *et al.*, 1998b.)

	Varietal yield (t ha^{-1})	
Seed production model	Marucha	Fifí
Summer sowing period (heat stress)		
Formal model	5.2	3.1
Informal model	7.9	4.1
Yield gain using informal model[a]	35%	26%
Winter sowing period (drought stress)		
Formal model	3.2	1.1
Informal model	5.9	2.6
Yield gain using informal model[a]	46%	58%

[a] Yield gain = [1-(yield from formal model/yield from informal model)] × 100.

winter; however, response to selection for increased yield is higher compared with the summer.

A lineal scheme of varietal development and seed production and dissemination for cross-pollinated crops has been followed in Cuba. This scheme divides the process into two parts: in the first part breeders play a key role in selection and recombination at the experimental station, the second part is accomplished by the Cuban Seed Company – through its seed growers' network – which promotes strict isolation in seed production.

Initially, according to the formal model, recombination is encouraged through cross-pollination between families at the experimental station. However, at the end of the varietal development process on the experimental station, isolation is rigorously enforced with cross-pollination only permitted within families. Once a variety has been released from the research institute the Cuban Seed Company conducts a first multiplication and evaluation, receiving feedback from the seed growers.

In contrast, in Jalisco, Mexico, the informal system for another cross-pollinated crop species (maize) has been able to maintain the population characteristics of greatest interest to farmers by selection while still tolerating continual recombination of populations in the field (Louette and Smale, 2000). Similarly, farmers in a community in central Chiapas, Mexico, were reported to manage more than nine races of maize using the informal system (Bellon and Brush, 1994). Indeed there are some communities in Cuba where maize varietal maintenance and seed production are integrated as described above, and the populations produced have shown promise in terms of yield under low-input conditions (Ríos and Wright, 1999).

It will be important to investigate more carefully the potential for the informal system to improve, as opposed to maintain, their crop varieties. Still, it seems likely that continual recombination in the informal system has played an important role in genetic resource conservation on farm for some cross-pollinating species, and as such may have maintained the genetic potential to respond to ongoing or novel stresses.

Population improvement as a plant breeding approach attempts to improve the mean performance of the population while maintaining genetic variability in the population to facilitate long-term selection (Simmonds, 1979). The informal system may represent population maintenance or perhaps improvement that in itself could offer a more viable alternative for pumpkin improvement in Cuba than the current strategy.

Conclusions

As emphasized throughout this chapter, the economic crisis in Cuba after the socialist countries collapsed has been the key factor favouring low consumption of conventional agrochemicals. This change has stimulated discussion of the efficiency, advantages and weaknesses of chemical compared with organic inputs (Altieri, 1998). This discussion has also been applied to approaches to plant breeding in the country. For example, Table 9.9 shows a comparison of plant breeding practices under high-input agriculture and those described here, carried out under low-input conditions. The comparison is made in terms of energy consumption, inputs used on farm and farmers' participation.

The collaborative effort towards crop improvement under low-input conditions was more efficient in terms of energy use. And, notably, the yield obtained under the low-input system was comparable to yields under the conventional, high-input technological package.

The economic impact of varieties selected under high- compared with low-input conditions was evaluated by growing the most popular variety disseminated in Cuba (RG) under low-input conditions, as well as two varieties selected collaboratively with farmers under those low-input conditions (Table 9.10).

The situation that occurred in Cuban pumpkin breeding seems to be an example of the possible negative economic effects when varieties are selected in an environment not representative of the target area. The occurrence of a cross-over response (Ceccarelli, 1994; see Ceccarelli

Table 9.9. Comparison of input use and results of pumpkin breeding strategies in Habana Province. (Source: Ríos, 1999.)

Indicators	Before the special period (1980s)	Under conditions of the special period (1990s)
Mineral fertilization (kg ha^{-1})	Nitrogen: 42 Phosphorus: 39 Potassium: 62	0
Organic soil amendments	Rarely applied	Typically 6–7 t ha^{-1}
Frequency and amount of artificial irrigation (summer season)	9–11 times per season, 2000 m^3 ha^{-1}	2–4 times per season, 200 m^3 ha^{-1}
Number of varieties released in 10 years	1	2
Varietal maintenance and seed multiplication	Isolation	Cross-pollination
Pest and disease control	Agrochemical intensive	Biological
Use of honey bees	Sporadic	Frequent
Yield	6–8 t ha^{-1}	6–8 t ha^{-1}
Farmer participation	Contracted seed production	On-farm selection of half-sib families
Researcher participation	Screening germplasm and varietal evaluation and selection. Cross-pollination control	Screening germplasm, facilitating availability of new germplasm, evaluation of variety with farmers
Energy requirements (kcal ha^{-1})[a]	Fertilization: 679,000 Irrigation: 10,160,000 Pesticides: 6,160,000 Total: 16,999,000	Fertilization: 42,000 Irrigation: 3,697,200 Pesticides: 88,000 Total: 3,827,200

[a] Pimentel, 1984; Masera and Astier, 1993.

and Grando, Chapter 12, this volume) suggests the importance of having a realistic view about who will be using the products of plant breeding. In the case of pumpkins, the effect of sowing in low-input conditions varieties selected under high-input conditions, with the genetic consequences of that selection strategy perhaps reinforced by restrictions on recombination early in the breeding cycle, has meant an inefficient use of energy as well as an economic loss.

During the collaborative pumpkin breeding described here, the farmers and the informal sector they are a part of offered: (i) pumpkin landraces that showed wide phenotypic variability for useful traits under low-input conditions; and (ii) selection skills and a real

Table 9.10. Economic impact of pumpkin breeding under low-input conditions. (Source: Ríos, 1999.)

Indicators (calculated as averages)	Varieties bred under high-input conditions sown in low-input conditions	Varieties bred and sown under low-input conditions
Cost ha^{-1} under low-input conditions (Cuban pesos)	702.3	708.3
Fruit yield (t ha^{-1})	1.5	6.7
Total income ha^{-1} (0.16 Cuban pesos kg^{-1})	240	1080
Net income ha^{-1}(Cuban pesos)	–462[a]	372
Benefit/cost ratio	0.34 : 1	1.5 : 1

[a] Average net loss.

low-input situation including interacting biotic and abiotic stresses and socio-economic constraints and thus the possibility of obtaining advances in characters with complex inheritance such as yield.

In the pumpkin experiences described here, plant breeders offered: (i) a bridge between the plant genetic resources conserved in gene banks and farmers, and the opportunity to screen those resources; and (ii) experimental design, an estimation of plant genetic variability, and estimations of potential genetic advance in a complex character (yield), monitoring variability in time and space.

The advent of low-input agriculture in Cuba, necessitated by the collapse of the Soviet Union, led to some new initiatives in Cuban plant breeding. Clearly, farmers' agricultural knowledge and skills, including those relating to seed management under the pressure of adverse environmental conditions, were an inspiration to develop a new, collaborative approach towards a more efficient use of inputs such as energy, more profitable crop production and maintenance of greater genetic diversity *in situ*.

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