Coffee Breeding in Kenya: Achievements, Challenges and Current Focus

B. M. GICHIMU

Coffee Research Foundation, P.O. Box 4 – 00232, Ruiru, Kenya

SUMMARY

Coffee production in Kenya is seriously constrained by two fungal diseases namely Coffee Berry Disease (CBD) caused by *Colletotrichum kahawae* (Waller & Bridge) and Coffee Leaf Rust (CLR) caused by *Hemileia vastatrix* (Berk. and Br.). Growing resistant varieties is believed to be the most cost effective and sustainable means of managing plant diseases. In Kenya considerable success has been made in coffee breeding to improve yields, quality and to manage the two economically important diseases. However, emerging issues such as climate change have brought up new challenges which require to be addressed to ensure sustainability in coffee production. This paper reviews some of the achievements, challenges and future prospects/approaches to develop cost effective and sustainable coffee varieties that enhance yield and quality.

INTRODUCTION

Coffee belongs to the genus *Coffea* in the Rubiaceae family which contains some 640 genera and 10000 species (Bremer, 1996) and is mostly grown in tropical and sub-tropical regions (Berthaud and Charrier, 1988). The genus *Coffea* consist of approximately 105 taxa (Kumar *et al.*, 2008) and has been reorganized into two subgenera: *Coffea* and *Paracoffea* (Bridson, 1987). Particular attention has been paid to the subgenus *Coffea* which includes two cultivated species of economic importance, *Coffea arabica* L. and *Coffea canephora* Pierre (Anthony *et al*., 2002; Kumar *et al.*, 2008). *C. arabica* is tetraploid (2n = 4x = 44) and is self-fertile while other *Coffea* species are diploid 2n = 2x = 22) and generally self-incompatible (Masumbuko *et al.*, 2003). *C. arabica* has two distinct botanical varieties *C. arabica var. arabica* (usually called Typica) and *C. arabica var. bourbon* (usually called Bourbon) (Krug and Carvalho 1951 as cited in Hue, 2005). World production of arabica coffee is still largely based on cultivars developed long ago by line selection within the *typica* and *bourbon* varieties, or in offspring of crosses between these two (Van der Vossen, 2009).

In Kenya, coffee was introduced as a cash crop in 1900's by Europeans colonialists, and has remained one of the most important products of the country's agriculture. Over 90% of the total Kenya coffee acreage is under Arabica coffee, while the rest is occupied by Robusta coffee (Omondi *et al*., 2001; Gichimu *et al*., 2010). Production of *C. arabica* is seriously constrained by diseases (Omondi *et al*., 2001; Gichuru *et al*., 2008). The major diseases are Coffee Berry Disease (CBD) caused by *Colletotrichum kahawae*, Coffee Leaf Rust (CLR) caused by *Hemileia vastatrix* and Bacterial Blight of Coffee (BBC) caused by *Pseudomonas syringae* pv. garcae (Omondi *et al*., 2001). Introduction of resistance genes in *C. arabica* involves crossing with donor varieties, followed by backcrossing to restore desirable traits, especially yields and quality (Gichuru *et al*., 2008). However, breeding of Arabica coffee is largely constrained by its narrow genetic diversity resulting from its narrow geographic origin, its self-fertilising nature and the historical or selective bottlenecks in its agricultural adoption (Chaparro *et al.*, 2004). Over the years, coffee breeders have tried to widen the

genetic base of Arabica coffee by having more introductions and undertaking hybridisation programmes to create variability (Lashermes *et al*., 1999).

Coffee breeding in Kenya started in 1920s (Melville 1946; Thorold, 1947). Emphasis in selection was primarily for high yields, better bean size and liquor quality (Walyaro, 1983). This saw the selection and subsequent release of the first Kenyan coffee varieties (SL28, SL34 and K7) in 1930s. These cultivars produce high yields of fine quality coffee but are susceptible to CBD, CLR and BBC although K7 has resistance to some races of CLR as well as partial resistance to CBD. A breeding programme for disease resistance started in 1971 after the outbreak of CBD and CLR in the late 1960s. The main breeding goal has been to develop cultivars that combine resistance to diseases with improved yields and quality (Van der Vossen, 1973; Walyaro, 1983). In 1985, the first disease resistant hybrid cultivar, Ruiru 11, that is also high yielding, of fine quality and compact growth was released (Omondi *et al*., 2001). Further research and development culminated to the release of other disease resistant cultivars namely Batian 1, Batian2 and Batian 3. Their unique features include tall stature, true breeding and resistance CBD and CLR. They are also high yielding with good bean and liquor quality (Gichimu *et al*., 2010).

COFFEE BREEDING PROGRAMME IN KENYA

Initial coffee breeding mainly depended on the selection of elite varieties/cultivars from germplasm collections from Food Agricultural Organization (FAO) and ORSTOM (now IRD) French missions, along with accessions obtained through exchange with other coffee research institution across the world. Due to the nature of coffee tree, the qualities desirable for crop production were found to be mostly antagonistic (Van der vossen and Walyaro, 1981), for example, high yielding and good quality varieties were most of the time found to be highly susceptible to pests and diseases and vice versa. Although the original "French Mission" coffee plant in Kenya were observed to be generally less susceptible to CBD than later selections such as SL28 and SL34 (Van der Vossen and Walyaro, 1981), selection of true resistance within this material was considered unrewarding because of apparent lack of genetic variation. A number of accessions in the variety showed a high degree of field resistance to CBD and some certain CLR races. However, none of these possessed all desirable traits such as disease resistance, high yield, good quality and desirable growth habits. It therefore required a well planned breeding program to combine all or most of the desirable traits in a single variety.

The success of coffee breeding program depended on effective methods of early selection for disease resistance, the stability of disease resistance, full restoration of yield and quality and practical methods of large scale multiplication of the new disease resistant varieties. Initially, little knowledge was available on the above topics and it therefore necessitated ignition of a number of research projects on them to support the main breeding programme. Much of this research work resulted in the application of new and efficient methods of selection that led to an acceleration of the breeding programme. This resulted in the development of new disease resistant varieties of Arabica coffee much earlier than originally scheduled (Njoroge *et al*., 1981; Van der Vossen and Walyaro, 1981). Using this programme, it was possible to breed not only for resistance to CBD and CLR but also to select for high yields, good quality (both bean and cup) and desirable growth habit (either compact or tall).

The breeding programme was carried out along the following stages:

- Identification of genetic variability (e.g. resistance to diseases) from germplasm collections (parental genotypes).

- Selection within the parental genotypes followed by single crosses between disease resistant varieties and the best (high yielding and good quality) local cultivars.
- On the basis of information obtained, a number of F1 hybrids are selected for further improvement.
- Selected F1's representing different groups are involved in further crosses (with other elite cultivars or backcrossed to the elite parent) to incorporate other characters to improve the single hybrids
- Multiple crosses to assemble in one plant the desired traits of more than two varieties.
- Backcrosses of selected plants from the multiple crosses to the best local cultivars to improve on yields and quality.
- Selfing to fix the genes. For hybrid cultivars, steps 5 and 6 are omitted and selfed progenies are finally crossed for hybrid seed production.
- Field evaluation in different agro-ecological zones (adaptation trials).
- For true breeding cultivars, superior individual trees from superior lines are then selected for commercial seed production

The crossing was initiated right at the start of the programme which resulted in progenies of a large number of single crosses made between supposedly disease resistant varieties and susceptible commercial varieties. With this breeding programme, it is possible to develop hybrids as well as true breeding cultivars.

BREEDING FOR RESISTANCE TO CBD

CBD was first reported in Kenya in 1922 in newly established coffee plantations on the slope of Mt Elgon in Western Kenya (Mc'Donald, 1926). The effect of the disease then spread out in the succeeding years reaching east of Rift Valley by 1939. By 1951, it had spread through all the main coffee growing areas in the country (Rayner, 1952). From Kenya the disease spread to Angola in 1930, Zaire in 1937, Cameroon between 1955 and 1957, Uganda in 1959, Tanzania in 1964, Ethiopia in 1971 and Malawi in 1985 (Hindorf, 1975; Firman and Waller, 1977). Until now the disease has been restricted to East, Central and South African coffee-growing regions (Hindorf and Omondi, 2010) but strict precautions have always been taken to prevent the introduction of this disease to other parts of the world. In Kenya the effect of CBD was severely felt during the cropping years of 1962-1963 and 1967-1968 where coffee production loss rose to 80% (Griffiths *et al*., 1971). The disease infects all stages of the crop from flowers to ripe fruits and occasionally leaves, but maximum crop losses occur following infection of green berries with the formation of dark sunken lesions with sporulation, causing their premature dropping and mummification.

CBD resistance in Arabica coffee is believed to be horizontal/quantitative in nature (Robinson, 1974; Van der Graaf, 1981; 1985) and appears to be controlled by major genes on three different loci (Van der Vossen and Walyaro, 1980). The three genes have been identified in the varieties Rume Sudan *(R* and *k* genes), Hibrido de Timor *(T* gene) and K7 *(k* gene) (Van der Vossen & Walyaro, 1980). Similarly, the Catimor variety has also been shown to possess the *T* gene of resistance present in Hibrido de Timor (Agwanda et al., 1997). The moderately resistance variety K7 carries only the recessive k-gene (Vossen and Walyaro, 1980). The variety Pretoria also has *k*-genes (Omondi et al., 2001). The three genes of resistance have since been exploited in the Kenyan breeding programme either in pursuit of pure line varieties or for production of hybrid cultivars (Agwanda et al., 1997). The hybrid variety, Ruiru 11 and three pureline varieties, Batian 1, 2 and 3, are products of these strategies. Ruiru 11 was released to farmers in 1985 while the Batians were released in 2010.

The four varieties combines the superior quality attributes of the elite breeding lines as well as CBD and CLR resistance genes originating from Hibrido de Timor, Rume Sudan and K7.

Success in breeding for resistance to CBD was enhanced by availability of an efficient method for early screening for resistance through hypocotyl inoculation on 6-week old seedlings developed by Van der Vossen *et al*., 1976. For many years, selection for resistance to the disease has either been based solely on the seedling inoculation method or both on seedling inoculation and field expression of resistance on mature trees (Van der Graaff, 1981; Agwanda *et al*., 1997). The seedling inoculation method has contributed significantly by shortening the time required to identify resistant progenies from crosses involving resistant and susceptible donors. However, its efficiency becomes limited when a breeder is interested in accumulating a number of resistance genes into an improved cultivar, since this would require test crossing. Given the long generation cycle (five years) characteristic of Arabica coffee, the test cross approach is highly time-consuming and thus represents a real bottleneck to rapid development of varieties resistant to CBD. In view of this, Coffee Research Foundation embarked on the use of molecular markers which not only facilitate the pyramiding of resistance genes through marker-assisted selection, but are also useful in selecting against the genetic background of the donor varieties (Agwanda *et al*., 1997). This approach remains among the current focus at CRF and some candidate markers have been identified (Agwanda *et al*., 1997; Gichuru 2007) with search for more continuing.

BREEDING FOR RESISTANCE TO CLR

Coffee Leaf Rust (CLR) caused by the obligate parasitic fungus *Hemileia vastatrix* is a major disease which greatly limits Arabica coffee (*Coffea arabica* L) production in almost all growing countries around the world (Prakash *et al*., 2004, Hindorf and Omondi, 2010; Gichimu, 2012). Although it is rather difficult to estimate precisely the global impact of this disease, the economic damage to world Arabica coffee production has been estimated to be between 1 and 2 billion US Dollars per year (Van der Vossen, 2001) due to crop losses of 20–25% (Prakash *et al*., 2004). Chemical control of CLR by use of fungicides is expensive leading to high production costs and is not safe to humans and environment (Gichuru *et al*., 2008; Gichimu, 2012). In view of the economics and to minimise the chemical input for disease management, the development and cultivation of tolerant cultivars is the most effective and viable option (Gichimu, 2012). Therefore, the development of coffee varieties resistant to CLR has been one of the major breeding objectives in many countries including Kenya ((Prakash *et al*., 2004; Gichimu, 2012; Gichuru *et al*., In Press). The symptoms of the disease are characterized by a dusty or powdery coating of yellow uredosori covering the underside of the coffee leaves (Silva *et al*., 2006).

Breeding for resistance to CLR took into consideration the worldwide distribution of the disease and the multiple races of the pathogen. In 1955, the governments of the United States of America (USA) and Portugal established the Coffee Rust Research Centre (CIFC) in Oeiras, Portugal to coordinate CLR research without the risk of spreading new rust races to producing countries. Resistance to CLR is inferred from Flor's Gene-for-Gene concept, which states that for every major gene-conditioning resistance in the plant, there is a corresponding gene-conditioning virulence in the pathogen (Flor, 1971). The resistance genes in the host are designated 'SH' while the virulence genes in the pathogen are designated 'v' (Hindorf and Omondi, 2010). The CLR resistance is conditioned by at least 9 resistance genes designated as SH1–SH9 (and others not yet identified), either singly or in combination, while the corresponding virulence genes have been indicated as V1–V9 (Bettencourt and Rodrigues 1988; Hindorf and Omondi, 2010). Of the 9 resistance factors, SH1, SH2, SH4 and SH5 have been found in *C. arabica*. The other genes, SH6, SH7, SH8 and SH9, have been introgressed

from the diploid species *C. canephora*, while SH3 probably originates from another diploid species, *C. liberica* (Gichimu 2012). So far, there are 49 races of the pathogen that have been characterized the world over (Gichuru *et al*., In Press).

The resistance genes identified in *C. arabica*, used either singly or in combination, have not provided durable resistance to most of the races of rust fungus. In contrast, the SH3 gene from *C. liberica* as well as certain genes from *C. canephora* has provided long-lived protection under field conditions (Van der Vossen, 2005). In a collaborative effort between CIFC and Arabica coffee-producing countries around the world, several varieties resistant to rust were developed. The most notable variety that was introduced in most countries was the Colombian Catimor, combining CLR and CBD resistance and compact growth (Castillo and Moreno, 1988; Hindorf and Omondi, 2010). In Kenya breeding for rust resistance has been combined strategically with breeding for CBD and present effort is to simultaneously work on these two diseases so that all varieties developed will be resistant to the two fungal diseases. The breeding programme discussed earlier in this paper was effectively used to breed for resistance to both diseases. The release of Ruiru 11 hybrid variety and three pure line varieties, Batian 1, 2 and 3, all of which combines resistance to both diseases (Gichimu *et al*., 2010) is an output of this strategy. The adoption of these varieties by farmers has led to drastic reduction in use of fungicide sprays and eventual high returns to farmers.

SELECTION FOR HIGH YIELDS AND QUALITY

The duration of a breeding programme in arabica coffee *(Coffee arabica* L.) to produce new cultivars resistant to important diseases, largely depends upon the efficiency of selection for yield since methods of early selection for disease resistance are already available (Walyaro and Van der Vossen, 1979; Agwanda *et al.*, 1997). In the early past, higher productivity in Arabica coffee was achieved by straight selection for yield taken over considerable number of years (Carvalho and Monaco, 1969). Later studies demonstrated that there exists a high correlation between some growth characters and yield as well as plant vigour and yield (Walyaro and Van der Vossen, 1979). Indirect selection for yield potential is now possible when the first two years' data for growth, plant vigour and yield components are considered (Gichimu and Omondi, 2010). For quality, Van der Vossen (1973) observed that a minimum of 2 years of production is required to assess the bean size and cup quality factors in coffee.

The breeding programme in Kenya was strategically designed to enable development of varieties that combines resistance to the major diseases of economic importance with high yields and quality. Several varieties including Hibrido de Timor, Bourbon, K7, Rume Sudan, N39, SL4, SL34 and SL28 were used as progenitors to fully utilize the available genetic variability. A number of promising trees combining CBD and CLR resistance with plant vigour, high yield and good quality were selected from progenies of the multiple crosses. These were used in a programme of backcrosses to the best local cultivars (SL28 and SL34) and subsequent selfing to fix the genes. Currently, marker assisted backcrossing using available markers for diseases resistance efficiently enables rapid restoration of yield and quality after the target gene has been successfully transferred.

EMERGING CHALLENGES AND CURRENT FOCUS

The increase of greenhouse gas emissions (carbon dioxide and methane) in the atmosphere is causing wide changes in atmospheric events, influencing climate change and variability with critical impacts on coffee production. These include, shifting of optimal growing zones, changes in rainfall (amount and distribution), changes in dynamics of crop diseases and pests, changes in crop yields and quality, loss of agricultural land due to either rising sea levels

and/or desertification (Kimemia, 2010). Presently, coffee breeding in Kenya focuses on development of varieties with tolerance to abiotic stresses such as draught, salinity and high temperatures. Methods for early selection for tolerance to such stresses are already being explored targeting a variety that would combine this with other desirable traits such as disease resistance, yield and quality.

Apart from CBD and CLR, Bacterial Blight of Coffee (BBC) caused by *Pseudomonas syringae* pv *garcae* is another and the only bacterial disease of economic importance in Kenyan coffee. The spread of the disease is highly restricted, being present mainly in Brazil and Kenya (Silva *et al*., 2006). For a long time, BBC was restricted to the west of the Great Rift Valley in Kenya (Kairu 1985). The disease is however, gaining importance since it is endemic in areas with great potential for coffee expansion as land becomes scarce in the traditional coffee growing areas in Kenya. In addition, with the current shifts in weather pattern caused by climate change, the disease is becoming more widespread. Although copper based fungicides are recommended for BBC control, these sprays become less effective as infection pressure increases (Mugiira *et al*., 2011). Other challenges associated with chemical control approaches include high costs, phytotoxicity and residual effects of the fungicides (Abera *et al*., 2011). More so, as the hectareage of coffee covered by CBD resistant cultivars increases, BBC epidemiology may be expected to change as the use of fungicides drastically reduces. Previous studies have identified some Arabica coffee genotypes with resistance to *P. syringae* pv *garcae*. They include Catuaí x Icatu derivative IPR 102, Catucaí, Icatu and Hibrido de Timor (Ito *et al*., 2008). Breeding against the disease forms part of the current and future prospects of coffee breeding in Kenya and these introductions could therefore form the basis of this objective.

Efforts to improve the genetic base of resistance are applied during and after the development of disease resistant varieties but this is being challenged by the narrow genetic base of Arabica coffee and diverse variation within the pathogen. Isolates from the same or different geographic origins have been found to vary in aggressiveness and or pathogenicity (Firman and Waller, 1977; Masaba and Van der Vossen, 1978; Van der Vossen, 1985; Omondi *et al*. 2000). This shows the importance of re-evaluating existing varieties from time to time with an aim of identifying lines with broad based resistance. It has long been recognized that more durable forms of disease resistance can be devised if there is better knowledge of both the dynamics of the pathogen populations and the factors that determine host resistance or susceptibility. However, with climate change phenomenon, these factors are constantly and drastically changing and are becoming increasingly difficult to understand or to cope with.

When studying *C. kahawae* isolates from Kenyan cultivars, Omondi *et al*. 2000 observed some variation in aggressiveness among isolates but no differential pathogenicity was observed and hence no physiological races for *C. kahawae* were detected. The absence of races could be as a result of the pathogen co-evolving with genetically narrow based *C. arabica* species forming the bulk of the varieties grown in Kenya (Omondi *et al*. 2000). There are recent cases of CBD in infection on varieties hitherto considered resistant thus showing some weakened resistance probably caused by changes in climate, increased variation in pathogen virulence and/or pathogenicity. For *Hemileia vastatrix* recent work by Gichuru *et al*. (In Press) using Kenyan isolates have found that there are six (6) new races (III, XVII, XXIII, XXXVI, XLI and XLII) carrying three new virulence genes (v_1, v_7, $v_{8)}$ and possibly v_9. This represents a serious threat to CLR resistant varieties including Hibrido de Timor and as well as resistant commercial varieties in the country. This calls for identification of new sources of resistance and application of gene pyramiding to ensure durable resistance.

Apart from the challenges related to the actual breeding, other drawbacks are related to multiplication of new varieties for distribution to growers. Despite their wide acceptance by the farmers, full adoption of the new varieties has been limited by lack of sufficient planting materials to meet the national demand. This challenge is bigger in Ruiru 11 that in Batian because the former is an F1 hybrid hence the limitation of seed production which is the preferred method of propagation. Efforts to supplement seed production with vegetative propagation using clonal cuttings and mass propagation through tissue culture have not matched the high demand. The highest demand for planting materials was observed in 2010/2011 propelled by good coffee prices experienced during this period.

CONCLUSIONS

In Kenya considerable success has been made in coffee breeding to improve yields, quality and to manage the two economically important fungal diseases, CBD and CLR. However, emerging issues such as climate change have brought up new challenges which require to be addressed to ensure sustainability in coffee production. The challenges faced forms the basis for future prospects/approaches to develop cost effective and sustainable coffee varieties that enhance yield and quality.

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