ADVANCES IN RESEARCH AND DEVELOPMENT OF MANGO INDUSTRY[1]

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ABSTRACT - World mango production is spread over 100 countries that produce over 34.3 million tons of fruit annually. Eighty percent of this production is based in the top nine producing nations that also consume upward of 90% of their production domestically. One to 2 percent of fruit is traded internationally in to markets in the European Community, USA, Arabian Peninsula and Asia. This paper outlines some of the recent research and development advances in mango breeding and genomics, rootstock development, disease management and harvest technologies that are influencing the production and quality of mango fruit traded domestically and internationally.
Index terms: Australia, breeding, molecular markers, rootstocks, anthracnose, harvesting, sap-burn.

AVANÇOS NA PESQUISA E DESENVOLVIMENTO DA INDUSTRIA DE MANGA

RESUMO - A produção mundial de manga está em cerca de 100 países que produzem 34,3 milhões de t ao ano. Oito porcento da produção é baseada em nove principais países, os quais consomem cerca de 90 % de sua produção. Apenas 2 % da fruta é vendida no mercado internacional, sendo consumida na Comunidade Européia, n os EUA,n a Península Arábica e na Ásia. Esse artigo aborda algumas pesquisas recentes e os avanços recentes no melhoramento da manga,sua genômica, porta-enxertos, manejo de doenças e tecnologias de colheita que tem influenciado a produção e qualidade da manga comercializada tanto no mercado interno, como externo.
Termos para indexação: Austrália,criação, marcadores moleculares, porta-enxertos, antracnose, colheita.

WORLD MANGO STATISTICS

Globally the mango industry is the 5th largest tropical fruit industry with production of over 34.3 million tons (FAO 2008 Statistics- check 2009 stats). Production is based across approximately 100 countries in tropical and subtropical regions of the world, with Asia the largest production region with 25,955×10³ tons followed by Africa with 3,389×10³ tons, North and Central America with 2,929×10³ tons and South America 2,008×10³ tons (GALÁN SAÚCO, 2010). Production has been increasing with a doubling of production over the past 18 years, a trend that is expected to continue with current expansion in Brazil, Ecuador, Peru, China West Africa and Spain. Although about 100 countries grow mangoes, about 80% of production comes from the top nine countries in order of production, India, China, Indonesia, Mexico, Thailand, Pakistan Brazil, Philippines and Nigeria (GALÁN SAÚCO, 2010). Approximately 1% to 2% of the world production is traded internationally the rest is traded and consumed within the countries of production.

The main exporting producing nations include Mexico (23% of production), Brazil (14.3%), Pakistan (3.2%), Peru (10.3%) and India (9.71%). The largest importing destinations are the European community (34%), USA (20%), Arabian Peninsula (14%) and Asia (27%) (GERBAUD, 2009). A key factor in international mango trade is fruit quality at the consumer end of the chain. Factors such as a fruit shelf life, ripening and controlled temperature storage facilities available at the export destination and good agricultural practice certification are significant limitations to this trade.

BREEDING AND GENETIC IMPROVEMENT

Some of the most significant advances in mango research and development that have the capacity to improve the industry and consumer

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acceptance of mangoes are occurring in the discipline of breeding and genetic improvement. Many of the mango industries in the larger producing nations are based on traditional mango cultivars that have been grown for hundreds of years. Often these cultivars are not up to the challenges of modern international trade, supply chain and consumer demands. As a result, most of the repeat international trade is confined to a few cultivars, often those developed in Florida in the first half of the 20th centaury such as 'Tommy Atkins', 'Kent', 'Keitt'. Although widely adapted these cultivars have a narrow genetic base (SCHNELL; BROWN et al., 2006) and fruit lower fruit quality than the traditional cultivars. With these limitations recognised by many growing and exporting nations several breeding programs have been established to develop new cultivars to improve their export fruit.

Breeding tropical tree fruits such as mango is a long term endeavour taking up to 20 years from crossing to commercial uptake of a new cultivar. Some of the new cultivars coming out of these breeding programs that are beginning to gain market share include: 'Calypso'(™), 'Honey Gold'[A], R2R2, from Australia, 'Maha Chanok' from Thailand, and 'Alpha" among others from Brazil. These and others are listed in Table 1.

It will be these new genetics that drive world trade in mango in the future due to their superior adaption to production conditions, improved consumer appeal and legal proprietary protection through plant variety rights and associated patents and trademarks. One example of this success is the 'Calypso'(™) where the value of the benefit derived from the investment in breeding the cultivar has a benefit cost ratio of 9.5:1, ten years after its release and marketing on the Australian domestic market (StrahAN; PRATT, 2011).

MARKER BASED DIVERSITY AND SELECTION

Molecular genomics technologies are being used to assist our understanding of mango genetics and the diversity of the world mango genepoole. In recent years many studies using molecular marker to discover the diversity and phylogenetic relationships between mango varieties and related *Mangifera* species have been undertaken.The genetic relationships and origins of individual mangoes and groups of varieties is providing a good understanding of how mangoes have spread around the tropical and subtropical regions of the world. Some of these early analyses used protein or isozyme markers that are influenced by environment and have low polymorphism (SMITH; SMITH, 1992). More recently the more reliable DNA markers generated by PCR-based methods that are reproducible and fast (Varshney, Graner *et al.*, 2005) have been used. Markers such as restriction fragment length polymorphisms (RFLPs), random amplification of polymorphic DNAs (RAPDs), amplified fragment length polymorphisms (AFLPs), inter simple sequence repeat (ISSR) markers and microsatellites or SSRs have been used in mango. SSRs have become the preferred marker for plant analysis because of their reproducibility, multiallelic nature, co-dominant inheritance, relative abundance and good genome coverage (Phillips e Vasil, 2001). In mango SSR marker analyses has revealed genetic relationship over a wide cross-section of the mango and *Mangifera* genepoole through a series of studies undertaken by (EIADTHONG; YONEMORI et al., 1999; DUVAL; BUNEL et al., 2005; HONSHO; NISHIYAMA et al., 2005; SCHNELL; OLANO et al., 2005; VIRUEL; ESCRIBANO et al., 2005; UKOSKIT, 2007; GÁLVEZ-LÓPEZ; HERNÁNDEZ-DELGADO et al., 2009). Studies on the Phylogenetic relationships among *Mangifera* L. species (EIADTHONG; YONEMORI et al., 2000; YONEMORI; HONSHO et al., 2002; HIDAYAT; PANCORO et al., 2011) are revealing some large diversity within species and new and unrecognised relationships between species previously not revealed in traditional taxonomic models of the genus.

Molecular markers have also been used to identify of fingerprint individual mango varieties by unique patterns of marker alleles. Fingerprinting data has been used in support of plant breeders rights and patients (IP AUSTRALIA, 2008) and in maker assisted selection (MAS). MAS is being used routinely in the Australian and Japanese mango breeding programs to identify unknown pollen parents in hybrid progeny lines (Dillon, N., Bally, I. S. E. *et al.*, 2010) and to determine the self- and cross pollination origins of progeny (Kanzaki, Honsho *et al.*, 2005). Fingerprinting of some of the major mango collections around the world has identified duplicated, misnamed and otherwise mislabelled individuals within the collections (SCHNELL, 2006; DILLON, N. L., BALLY, I. S. E. et al., 2010).

The improved understanding of mango genetics and adoption of molecular genetics in breeding programs is enabling breeders to greatly improve their breeding efficiency through improved selection of parents and progeny. This along with research in mango genomics and gene discovery will identify genes and markers associated with traits of interest and advance the quality of the next generation of cultivars released from breeding programs.

ROOTSTOCKS

In mango both polyembryonic and monoembryonic rootstocks are used with only a few rootstock cultivars identified as conferring beneficial effects on scions. In recent times more of an effort has been put in to discovering and evaluation rootstocks for mango that deliver environmental adaptability, uniformity, vigour control or yield enhancement to scions. Some of the specific rootstock cultivars that have been shown to advantage certain scions include, the three root-rot resistant rootstocks IAC 101, IAC104, and IAC106 (ROSSETTO, BORTOLETTO et al., 2006). Rootstocks 'Brodie' and 'MYP' that increased the yield efficiency of 'Kensington Pride' Smith et al (2003). Rootstock evaluation and selection is ongoing in many countries and is likely to provide specific rootstock/ scion combination that will enhance the production and quality performance of specific scions and help to even out annual fluctuations in production and quality.

MANGO DISEASES

Mangoes are susceptible to a range of pest and diseases that can significantly reduce commercial production and fruit quality. One of the most significant diseases of mango is anthracnose caused by the fungal pathogen *Colletotrichum gloeosporioides*. Anthracnose affects the flowers, leaves and fruit at various stages of growth and is a major cause of fruit rots in the postharvest supply chain. Despite the development of chemical and cultural control measures for this disease, significant losses to production during harvest are still a reality, especially in years where wet wether is experienced. Over recent years several areas of pathogen / host interactions have been studied that may lead to new management options for the disease. These include: investigations of natural defence mechanisms with in the mango and identification genotypes with high levels of natural resistance to the disease. In many plants pre-formed natural anti-fungal compounds act as protective chemical barriers against a range of pathogen infections when found in high concentrations.

In mango high concentrations of the anti-fungal compounds (alk(en)ylresorcinols) are found the in the peel and in resin ducts of developing fruit. The decline in concentration of alk(en)ylresorcinols during fruit ripening have been significantly correlated with the development of anthracnose symptoms (Hassan, Dann *et al.*, 2007; Hassan, Irving *et al.*, 2009). Alk(en)ylresorcinols concentrations have been shown to vary between mango cultivars (HASSAN; DANN *et al.*, 2007) and can be influenced by tree nitrogen nutrition (BALLY, 2006; BALLY; HOFMAN et al., 2009). Reduced incidence and severity of postharvest anthracnose has been demonstrated in the cultivar 'Kensington Pride' when anti-fungal compounds are retained in the fruit skin during ripening (HASSAN; DANN et al., 2011). This was achieved by leaving long (2 – 3 cm) peduncles attached to the fruit during harvest which prevents sap loss and maintains anti-fungal concentrations in the peel and in resin ducts.

In Australia a screening program to identify mango cultivars with natural resistance to anthracnose has identified several accessions with superior disease resistance. The strongest being in one accession of the wild mango species *Mangifera laurina* (Akem, Grice *et al.*, 2007; Grice e Bally, 2007). This is ongoing work with ongoing screening of germplasm and research in to the mechanisms of resistance. Breeders in the Australian Mango Breeding Program have also begun to develop hybrid breeding populations segregating for disease resistance and to integrate natural resistance in to commercially acceptable cultivars (BALLY, AKEM et al., 2010).

HARVESTING AND HANDLING MANGO SAP

Harvesting fruit at optimum maturity to maximise the eating quality when ripe has traditionally been done using visual signals from fruit shape internal flesh colour and skin colour. In some cultivars these visual signals are week making maturity determination in unripe fruit difficult. Over recent years several instruments have been developed to non-destructively measure fruit maturity. Near infrared (SWNIR) (400-1100 nm) spectroscopy to non-destructively determine fruit maturity at harvest and link it to eating quality in ripe fruit (SUBEDI; WALSH et al., 2007; SUBEDI;WALSH, 2009). Leuchaudel et al (2010) have also used chlorophyll fluorescence to measure fruit maturity in developing fruits. A near infrared hand held instrument (Nirvana) supplied by Integrated Spectronics Pty. Ltd. Sydney (www.intspec.com/products) is being routinely used to determine fruit maturity of Calypso™ mangoes by larger growers to schedule harvesting to maximise fruit eating quality for consumers.

Lactiferous sap from the resin canals in the mango peel contains several caustic compounds that will burn the skin of people harvesting the fruit and the skin of the fruit being harvested if not managed appropriately. The causticity of the sap varies between cultivars and with fruit maturity and environmental conditions (HESSE; BOWDEN, 1995; HASSAN; IRVING et al., 2009). Sap is responsible for several fruit blemishes that detract from the fruit aesthetically and reduce the market value of affected fruit. The blemishes commonly referred to as 'sap-burn' and 'skin-browning' have lactiferous sap as their primary causal agent. In the cultivar 'Kensington Pride', the sap is particularly caustic and the Australian industry has developed methods of managing the harvesting process to minimise sap contamination of fruit. Fruit are essentially harvested in one of two ways, with long stems and de-sapped in the packing shed or with stem removal in the field with the use of harvest aids. Shed de-sapping to remove the caustic sap generally involves harvesting fruit with the peduncle attached and pre-dipping fruit in a detergent solution to protect the fruit before hand de-stemming in a manner that directs the sap flow away from the fruit. Field harvest-aids have been developed to de-sap fruit as it is picked in the field and avoid the de-sapping bottlenecks in the packing shed. Harvest-aid design has progressed over the past decade with a wide range of designs being used to day. Two popular designs are elevated platform cherry picker styles where fruit is hand picked into an elevated bin that is constantly being sprayed with a de-sapping agent and mobile ground models that use a detergent covered tarpaulin to catch fruit picked from the tree by hand or by harvest hocks with peduncles removed (figure 1 and 2).

The examples above of some of the advanced in mango production and quality derived through research and development, demonstrate the health of world mango industries and its adaptability for current and future challenges.

TABLE 1 - Some of the new recently breed mango cultivars that are being adopted by growers and traded nationally and internationally.

Cultivar name	Country of origin	Plant Variety Protection	Comments
Delta R_2E_2	Australia	Public Domain	Large fruit popular in Asia as a gift fruit
B74[A] (Calypso™)	Australia	PBR[A] Australia & Internationally	High blush, fibreless pulp with excellent shipping qualities
Honey Gold[A]	Australia	PBR[A] Australia	Rich and sweet 'Kensington' style flavour with a firm, fibre-free flesh
NMBP1201[A]	Australia	PBR[A] Australia	Early production with sweet 'Kensington' style flavour
NMBP1243[A]	Australia	PBR[A] Australia	Firm high yielding fruit with firm flesh and strong red blush
NMBP4069[A]	Australia	PBR[A] Australia	Firm fruit with sweet juicy flesh and pink blush
Joa	South Africa	PBR[A] South Africa	Mid season cropping, tolerant to bacterial black spot disease
Chené	South Africa	PBR[A] South Africa	Resistant to sun scorch, tolerant to bacterial black spot disease and mid season cropping
Alfa	Brazil		Semi Dwarf, high yielding with some resistance to fruit flies, postharvest rots and powdery mildew.
Roxa	Brazil		High yield, fibreless very sweet
Lita	Brazil		Late season, regular cropping, excellent fruit quality.
Maha Chanok	Thailand	Public Domain	Long shape fruit with orange-red blush, thick blemish resistant skin
Summer Snow	Taiwan		'Irwin' style fragrance with, low fibre, red blush

FIGURE 1 - Australian mango harvest-aid used in field uses a detergent covered tarpaulin to catch fruit and cover them in a protective layer of detergent to prevent sap-burn.

FIGURE 2 - Australian mango harvest-aid chery--picker model.

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