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Mango value chain improvement through postharvest research and development: a developing country case study

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Abstract

Pakistan is one of the major mango-producing and -exporting countries in the world. During 2007-15, significant postharvest research and development (R&D) work was conducted under the Australian-funded ASLP mango supply chain management/value chain improvement projects (two phases). The project started by laying a postharvest foundation R&D infrastructure in 2007. Fruit quality losses in supply chains were documented. Protocols were developed for maturity testing, de-sapping, storage/sea-freighting, and ripening and postharvest disease management of major mango cultivars. Quantity loss (unmarketable fruit) was around 20% while quality loss (affecting price) was 65 and 70% in Sindhri and Samar Bahisht Chaunsa mango, respectively. Sap burn and postharvest diseases were the most important fruit quality issues at retail. Cultivars differed in terms of fruit harvest maturity indicators, postharvest treatment response, controlled atmosphere conditions and temperatures for storage and ripening. Besides physical de-sapping (on racks), lime wash (de-stemming and dipping fruit in 0.5% lime solution for 2-3 min) was also found to be effective, with morning being the best time for fruit picking. Significant relationships of production locality, orchard management, nutrition (Ca, B and K) and pre-cooling were found with postharvest disease incidence. Postharvest hot-water fungicidal dip of Scholar (active ingredient (a.i.) fludioxonil), Amistar (a.i. azoxystrobin) and Sportak (a.i. procholaz) gave significant fruit disease control. An integrated approach of good production practices, right maturity, correct postharvest fungicidal treatments and pre-cooling was an effective strategy for reducing disease incidence and maintaining better shelf-life at retail. On the basis of R&D and interventions, significant improvement was brought to the local mango industry and export. Sindhri mangoes were sea-freighted commercially to the EU and UK with good fruit quality outturn and overall postharvest life of 40-45 days.

Keywords: *Mangifera indica*, export, marketability, storability, supply chain

INTRODUCTION

Mango is the second largest fruit crop of Pakistan, which ranks sixth among the top mango producing countries of the world (FAO, 2013). Mango harvest starts in Sindh province, with relatively less popular cultivars (e.g. 'Malda') from end of April to early May (Rajwana et al., 2011). However, mango export usually starts during the 3rd to 4th week of May commencing with the cultivar 'Sindhri' and lasts until late September to early October with a promising late cultivar ('Sufaid Chaunsa') in Punjab province. Another promising mango cultivar with high export potential is 'Samar Bahisht Chaunsa' ('S.B. Chaunsa'), mainly produced in Punjab province.

Although Pakistan has always remained amongst the top ten exporters of mango in the world, Pakistani mangoes have not had any access to the high-end supermarkets of Europe and the UK. Exported fruit is usually sold in traditional retail markets, mainly in ethnic community areas, where it fetches low prices. Importers of Pakistani mangoes often complain about fruit quality issues (mainly sap burn), disease infestation, collapsed packaging and short shelf-life (Collins et al., 2006). A decade ago (2006), the mango industry in Pakistan was struggling to compete globally. At that time, after comprehensive consultation with public and private sector stakeholders, the Australian Centre for International Agricultural Research (ACIAR) included the mango industry in its priority research and development areas under a large Australia and Pakistan Agriculture Sector Linkages Program (ASLP) (ACIAR, 2011). The ASLP program included two phases (phase I: 2007-10; phase II: 2011-15). Both phases comprised two integrated projects with focus on improving production and postharvest supply chain, respectively. ASLP production projects conducted research and development (R&D) and demonstrated the benefits of good agricultural practices, i.e. clean nurseries, orchard canopy and floor management (pruning, training, hygiene, etc.) and enhancing quality yield. While the postharvest projects focused on managing supply chains (phase I) and improving value chains (phase II), the overall goal was to address the key factors limiting the profitability of mango value chains in Pakistan. The key objectives included conducting postharvest R&D for product quality improvement; exploring the issues and demands of domestic and export markets; demonstrating better supply chains; and capacity building of the stakeholders (ACIAR, 2007). Phase I dealt with the key players of existing mango supply chains in order to develop their capacity for producing premium-quality mangoes and accessing the high-end export markets. While during phase II, along with continued work and support to the lead supply chain partners, the major focus was directed towards the smallholder rural communities, growers and women for capacity development in ASLP best practices and promoting small-scale mango industry based entrepreneurships.

MATERIALS AND METHODS

Preliminary studies

The project started with a workshop of key stakeholders to discuss the main issues of mango supply chains and prioritize the researchable ones. Initially, a baseline industry survey was done to benchmark existing domestic and export supply chain practices and the nature and extent of postharvest losses in mango. The project then conducted a "walking the chain" case study of Australian mangoes as an example of a developed mango industry. Under this activity, 17 mango industry stakeholders from Pakistan (including growers, contractors, exporters, service providers, commission agents, researchers, government personnel, etc.) walked through the Australian mango industry export supply chain (Singapore market all the way back to mango farm). Moreover, the project team also held meetings with the industry stakeholders to identify the key R&D gaps. On the basis of these initial activities, the project line of work and goals were set. Moreover, a well-equipped postharvest lab was established at the Institute of Horticultural Sciences (IHS), University of Agriculture, Faisalabad (UAF), Pakistan, to provide a R&D base for addressing the R&D issues associated with fruit quality and to develop the human resource capacity for managing fresh produce supply chains (ACIAR, 2007).

Strategic cycle (approach)

The strategic objectives of the two project phases are given in Figure 1. A holistic participatory approach was adopted in implementing the project. The general activities included (A) workshops of stakeholders; (B) annual planning and review meetings; (C) conducting R&D and capacity-building activities; (D) sharing new R&D information with industry in annual workshops; and (E) demonstrating improvements in mango value chains by working with stakeholders for mango export shipments and distribution in domestic markets.

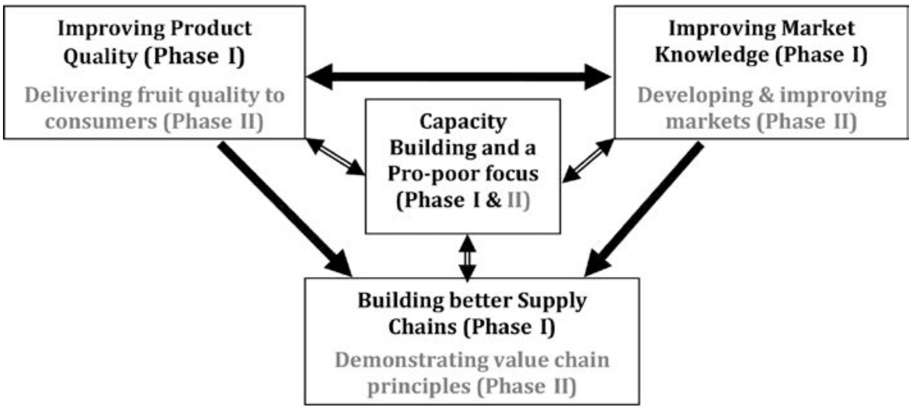

Figure 1. Concepts of the ASLP phase I and II project (phase I HORT/2005/057 Mango Supply Chain Management Project; phase II HORT/2010/001 Mango Value Chain Improvement Project).

Major activities

1. Postharvest research.

Postharvest research at UAF focused on technical aspects of commercial mango cultivars. Keeping in view the comparative economic advantages of sea-freight over air-freight in terms of low freight cost and exporting bulk volumes, special attention was given towards sea-freight protocol development. The key aspects targeted included maturity determination, harvesting and de-sapping techniques, optimizing pre-cooling, shipping (storage temperature, controlled atmosphere (CA) conditions, etc.), postharvest treatments (e.g. hot water treatment, irradiation, fungicide dips, etc.) and ripening with ethylene (replacing calcium carbide – a health-hazardous chemical traditionally used) (Amin, 2012). The R&D-based protocols developed in phase I were tested commercially during phase II in domestic and export (sea-freighted) consignments.

2. Market research.

Market research was conducted in existing (UK, Middle East) and new export markets (Malaysia, China, EU) along with the domestic market by monitoring the quality of fruit at different stages of the supply chain and documenting the responses of stakeholders.

3. Engaging stakeholders/establishing demonstration chains.

For the first time, the project introduced the concept of supply chain management in the Pakistan mango industry. The ASLP project built demonstration supply chains to work hand in hand with supply chain stakeholders, to help them better understand the requirements and responsibilities of their respective roles so that fruit conforms to buyers' choices and preferences.

4. Capacity building.

Each year, several capacity-building activities were conducted including hands-on training in mango supply chain operations and market outturn assessments. In addition, these included seminars for academics and researchers.

RESULTS

Major quality issues

The data collected from the baseline survey revealed that postharvest quality problems started from harvest with fruit maturity (mostly early or too late), under- or overripeness, poor grading, high disease incidence and blemishes including sap burn. From a sanitary and phytosanitary point of view, quarantine issues including fruit flies and chemical residues were the key concerns. While the quantitative losses (unmarketable fruit) were around 20%, the overall qualitative losses of mangoes were 65 and 70% in 'Sindhri' and 'S.B. Chaunsa', respectively (Mazhar et al., 2010).

Fruit maturity

Studies on harvest maturity have showed a significant interaction between panicle emergence and fruit maturation (harvest date) (Amin et al., 2013). Fruit shoulder development, sinus fullness, pulp colour, dry matter and TSS were found to be major maturity indicators. Most of the cultivars studied had a creamy to light yellow pulp colour near the stone at maturity. Dry matter and total soluble solids (TSS) at maturity varied among cultivars, ranging from 15.7 to 28.8% and 6.0 to 10.2 °Brix, respectively (Tables 1 and 2).

Table 1. Fruit harvest maturity indicators for two commercial mango cultivars. Source: Amin (2012).

Cultivar	Max.-min. time required for maturation (days)	Heat unit (max.-min. degree days)	Specific gravity	TSS (°Brix)	Pulp dry matter (%)
Sindhri	100.5-81.5	1298.7-1163.3	<1.0-1.02	6.0-7.5	18.0-20.0
S.B. Chaunsa	114.0-97.5	1630.2-1482.2	1.03-1.04	9.0-11.0	17.0-21.0

Table 2. Total soluble solids and dry matter percentages at fruit harvest maturity in different mango cultivars. Source: Amin (2012).

Cultivar	TSS (°Brix)	Dry matter (%)
Anwar Ratole	10.18ab	28.8a
Langra	10.32a	22.2b
Dusehri	9.30bc	21.3b
Fajri	9.30bc	15.7d
Beganpalli	9.05c	17.6cd
Sonehra	9.70abc	22.7b
Kala Chaunsa	6.06e	19.7bc
Ratole No. 12	6.17e	21.7b
Sufaid Chaunsa	7.23d	26.7a

De-sapping

Several methods of mango fruit de-sapping were tested and demonstrated to the industry to help avoid sap burn injury. These methods include short stemming (cutting the stem just over the knuckle or node where the sap spurts out), physical de-sapping (inverted fruit de-stemming close to shoulder and keeping on de-sapping racks for 1-2 h depending upon the cultivar) and lime wash de-sapping (fruit de-stemming inside 0.5% calcium hydroxide solution and keeping submerged for 2-3 minutes followed by washing in clean water) (Malik et al., 2013a, 2015). Morning was found to be the best time for mango harvest (Figure 2).

Pre-cooling and storage/low temperature shipment

Pre-cooling of fruit to 14°C before simulated shipment significantly reduced disease severity in mango fruit (Figure 3). In another study, those fruit pre-cooled within 24 h of harvest gave better fruit quality outturns (Majeed, 2012). The fruit of mango cultivars 'Sindhri' and 'Sufaid Chaunsa' need to be precooled to 14°C followed by holding at recommended storage temperatures (11-12°C; 80-85% relative humidity) until the loading of containers (Malik et al., 2015). However, the cultivar 'S.B. Chaunsa' is highly chilling sensitive, with a maximum pre-cooling duration not exceeding 8 h at 12°C. Extended pre-cooling time significantly negatively affects fruit skin colour, enzymatic activities and organoleptic fruit quality attributes of 'S.B. Chaunsa' mangoes (Yousaf, 2014).

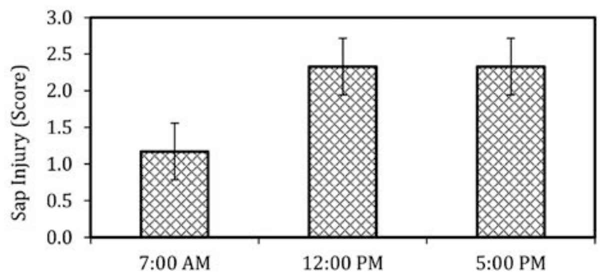

Figure 2. Sap burn injury in 'S.B. Chaunsa' harvested at different times. Severity score: 0-3, where 0 = no injury, 1 = <3 cm^2, 2 = injury of up to 25% area of fruit, and 3 = injury greater than 25% area of fruit. Source: Amin et al. (2008).

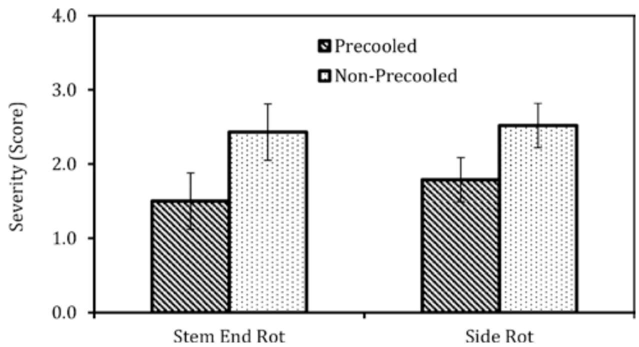

Figure 3. Impact of pre-cooling on postharvest diseases ('Sufaid Chaunsa') ($P \leq 0.05$; n=27). Severity score: 0-4, where 0 = no disease, 1 = disease covering less than 5% area of fruit, 2 = disease covering less than 5-10% area of fruit, 3 = disease covering less than 10-25% area of fruit, and 4 = disease covering greater than 25% area of fruit.

Cold storage studies indicated that 'Sindhri' mangoes can be successfully stored/shipped at temperatures of between 10 and 12°C, while 'S.B. Chaunsa' was found to be highly sensitive to low temperature storage, resulting in poor and patchy skin colour development at these temperatures (Amin, 2012). However, better fruit skin colour was observed in ripe fruit when stored at ≥17°C, without pre-cooling or after being pre-cooled to 12°C, for 8-12 h (Javed, 2013). The optimum storage temperature for 'Sufaid Chaunsa' was found to be 10-11°C (Malik, 2014); however, this cultivar shows under-skin browning if stored for more than 3 weeks. The optimal CA conditions for cultivars 'Sindhri' and 'Sufaid Chaunsa' were 4% CO_2/2% O_2 and 5% CO_2/3% O_2, respectively (Malik et al., 2015).

Farm management relations

The role of production-level practices (e.g. pruning, fungicidal spray programme and nutrients) was very important for fruit quality. Figure 4 shows the significant difference in postharvest disease incidence in the mangoes harvested from different production sites with different management practices and nutritional programs. Significant differences were found in potassium (K) and boron (B) contents in the peel of mangoes harvested from orchards with good practices compared with those having suboptimal practices, with higher nutrient contents in the fruit peel from good practice orchards. Moreover, calcium (Ca) and B were negatively correlated with stem-end rot (SER), indicating their potential role in disease resistance (Ali, 2014; Khan, 2014).

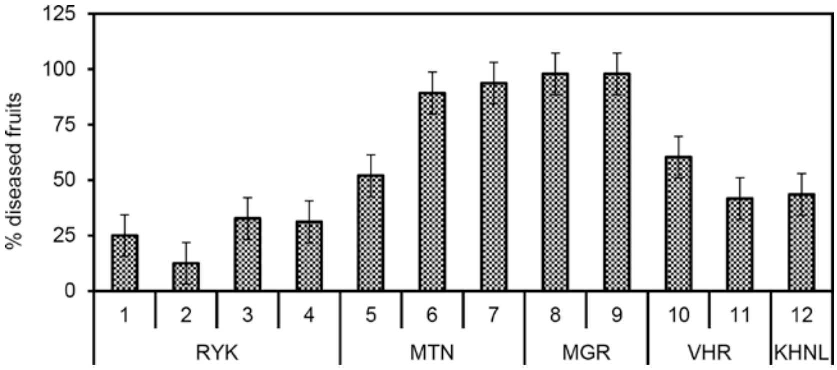

Figure 4. Disease incidence (percentage diseased fruit) at ripe stage in untreated 'Sindhri' mangoes harvested from different orchards from different locations (Khan, 2014).

Fruit fly disinfestation

For quarantine treatments (fruit fly disinfestations), cultivars 'Sindhri', 'S.B. Chaunsa' and 'Suafaid Chaunsa' can sustain extended hot water treatment at 48°C for 60 min/45°C for 75 min (Jabbar et al., 2011) or irradiation at 400 Gy (Umar, 2012; Malik et al., 2013b) as well as vapour heat treatment (observation at corporate sector export company). However, during quarantine treatments, fruit skin bruises (e.g. sap contamination, wash brush damage) become highly prominent as dark brown or grey surfaces, and many of the fruit have to be rejected at this stage, which is a significant loss. So, utmost care is required to avoid secondary fruit-skin defects and to have better fruit quality outturn.

Postharvest diseases and management

Disease isolation work showed *Alternaria alternata* (49% in 'Sindhri'; 58% in 'S.B. Chaunsa'), *Phomopsis mangiferae* (20% in 'Sindhri'; 18% in 'S.B. Chaunsa') and *Botryodiplodia* sp. (4% in 'Sindhri'; 3% in 'S.B. Chaunsa') as the main pathogens associated with mango fruit SER under the agro-ecological conditions of Punjab, Pakistan. Major postharvest diseases prevailing in the mango industry of Pakistan include SER, anthracnose and side rot (Amin et al., 2011). Preharvest application of Scholar (active ingredient (a.i.) fludioxonil) at 1.2 mL L^{-1} and postharvest hot fungicidal dips (52°C for 5 min) of Sportak (a.i. procholaz) at 0.5 mL L^{-1} gave significant fruit disease control. Postharvest hot water (52°C for 3 min) Scholar (a.i. fludioxonil) at 0.6 mL L^{-1} or Amistar (a.i. azoxystrobin) at 0.8 mL L^{-1} application in commercial sea-shipments of mango 'Sindhri' to the UK has also given significant disease control, with chemical residues within accepted limits. Cultivars 'Sindhri' and 'S.B. Chaunsa' can tolerate postharvest hot fungicidal dips at 52°C for up to 5 min (Amin, 2012).

Ripening

Studies have showed that 'Sindhri' and 'Sufaid Chaunsa' cultivars can be ripened successfully using 100 ppm ethylene (48-72 h) at 24±1°C; while the optimum temperature for 'S.B. Chaunsa' was 32±1°C (Amin, 2012; Majeed, 2012). For supply to local markets or preparing value-added products (mango dices/chunks using instant quick freezing/IQF technology), quick ripening is required. For this purpose, the fruit of commercial mango cultivars can be ripened at a temperature of 38-40°C while wrapping with a suitable cover during ripening.

Market research (export and domestic) and demonstration supply chains

The European market is currently under the development phase for Pakistani mangoes (Malik et al., 2015). Since 2012, more than 300 t mangoes have been exported to the UK/EU by CA sea freight demonstration chains using on-farm and postharvest systems developed by the ASLP project. These shipments were averaging 2.72 USD kg^{-1} compared with an industry average for exports of less than USD 1.00 kg^{-1}. Market research studies in

China indicated that the average fruit size requirement at retail is 300-400 g for customers' own consumption and 500 g for gift purposes. As regards the Malaysian market, it is small but well established with the demand of clean and unblemished fruit averaging 350 g. Results of mango export trials to China and Malaysia depicted clear economic benefits (>10% profit) through quality improvement and low wastage.

Local market research showed that growers realized 15-20% higher net returns through the ASLP project approach of self-marketing of best practice mangoes (de-sapped, ripened, packed in cardboard boxes) than with traditionally harvested and marketed mangoes. Furthermore, fruit wastage (5-10%) was far less compared with traditional handling systems (20-50%). In the domestic market, there is demand for ready-to-eat, blemish/disease-free mangoes, averaging 300-400 g.

Overall, the demonstration supply chain approach has shown how quality in the supply chain can be improved to benefit all the members of a supply chain. The consignments included for export (UK, EU, China, Malaysia, Singapore, etc.) and the domestic market were prepared, outturn was assessed and feedback was given to stakeholders.

Research communication and capacity building

R&D-based technical extension materials were developed and distributed. This included industry guides, fact sheets containing protocols for sea-shipment, air-freight, ripening, marketing in domestic and international markets, and addressing fruit quarantine and maximum residue level (MRL) issues, etc. (Malik et al., 2015). The project also collaborated with other donor projects. For instance, during the phase II, with collaboration of the European Union-funded Trade Related Technical Assistance (TRTA-II) Program, a critical control points (CCPs) based Code of Practices (CoPs) was developed, for safe handling and improving the quality of mangoes.

The project made a significant contribution to human resource capacity building across the industry. Over two-dozen postgraduate students (including Masters and PhD degrees in Horticulture, Plant Pathology and Marketing) completed their degrees. More than 160 researchers and extension workers were trained in the areas of product quality improvement and supply chain management; about 2500 stakeholders received hands-on training in postharvest product handling; and about 90 people were trained in pack-house operations and quality assurance.

Trickle-down and trickle-out effects

Research under ASLP has changed the fate of the mango industry of Pakistan. Besides the primary donor (Australian Aid), other donors including USAID and EU/UNIDO have also used the research findings for local mango industry developments. In recent years, not only is better quality fruit being sold at premium prices in the high-end domestic markets but also the quality of fruit being shipped to high-end export markets has also improved. New markets like China and Malaysia were explored, and the industry is now flourishing at a greater momentum. Feedback from industry stakeholders indicated that the project has demonstrated a 59% increase in product knowledge, 57% increase in market knowledge, 53% improvement in product presentation and 21% increase in product price.

FUTURE DIRECTIONS

Future postharvest research needs to focus on improving packaging design and sturdiness, product safety and traceability. Improved methods of fruit fly control, diseases of quarantine concern, and managing MRL issues are important. Moreover, apart from promoting ethylene-gas-based ripening only, other ripening strategies also need to be developed, especially for the local markets and small growers. R&D on developing value-added products and their market is necessary. Scaling up and scaling out of the already established postharvest management protocols are necessary. To have a wider impact, it is necessary to develop domestic market quality standards to ensure uniform quality.

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Literature cited

ACIAR. (2007). ASLP Mango Supply Chain Management Project Newsletter, No. 2. http://aciar.gov.au/files/node/741/Mango%20Newsletter%20Jul%2007.pdf.

ACIAR. (2011). Optimising Mango Supply Chains for More Profitable Horticultural Agri-Enterprises in Pakistan and Australia. http://aciar.gov.au/project/hort/2005/157.

Ali, H. (2014). Fruit quality and disease development of mango cv. Samar Bahisht Chaunsa in relation to geographic locality, production practices and storage conditions. MSc (Hons) thesis (Faisalabad, Pakistan: Institute of Horticultural Sciences, University of Agriculture).

Amin, M. (2012). Integrated approaches for improving fruit quality and shelflife for two commercial mango cultivars of Pakistan. PhD thesis (Faisalabad, Pakistan: Institute of Horticultural Sciences, University of Agriculture). http://eprints.hec.gov.pk/9022/1/7083H.html#sthash.9OPLmoch.dpuf.

Amin, M., Malik, A.U., Mazhar, M.S., Din, I., Khalid, M.S., and Ahmad, S. (2008). Mango fruit desapping in relation to time of harvesting. Pak. J. Bot. *40*, 1587–1593.

Amin, M., Malik, A.U., Khan, A.S., and Javed, N. (2011). Potential of fungicides and plant activator for postharvest disease management in mangoes. Int. J. Agric. Biol. *13*, 671–676.

Amin, M., Malik, A.U., Khalid, M.S., and Anwar, R. (2013). Fruit harvest maturity indicators for mango cv 'Sindhri' and 'Samar Bahisht Chaunsa'. Acta Hortic. *992*, 561–567 https://doi.org/10.17660/ActaHortic.2013.992.69.

Collins, R., Dunne, T., Campbell, J., Johnson, P., and Malik, A.U. (2006). A Constraint Analysis of Pakistan Mango Supply Chain: Short Research Activity Report PLIA/2005/159. Australian Centre of International Agricultural Research (ACIAR). http://aciar.gov.au/files/node/741/Constraints analysis of Pakistan mango supply chains.pdf.

FAO. (2013). FAOStat – Countries by Commodity. http://www.fao.org/faostat/en/#rankings/countries_by_commodity (accessed October 23, 2017).

Jabbar, A., Malik, A.U., Saeed, M., Malik, O.H., Amin, M., Rajwana, I.A., Khan, A.S., Saleem, B.A., Pervez, M.A., and Ayub, M. (2011). Performance of hot water phyto-sanitary treated mangoes for intended export to Iran and China. Int. J. Agric. Biol. *13*, 645–651.

Javed, H.U. (2013). Performance of Samar Bahisht Chaunsa mangoes at non-chilling storage temperature under reefer and controlled atmosphere conditions. MSc (Hons) thesis (Faisalabad, Pakistan: Institute of Horticultural Sciences, University of Agriculture).

Khan, Z.M. (2014). Influence of orchard locality, production practices and postharvest storage on postharvest disease development and quality of cv. Sindhri mangoes. MSc (Hons) thesis (Faisalabad, Pakistan: Institute of Horticultural Sciences, University of Agriculture).

Majeed, A. (2012). Effect of delayed cooling and various ripening conditions on fruit quality and shelflife of mango cv. Sindhri and Samar Bahisht Chaunsa. MSc (Hons) thesis (Faisalabad, Pakistan: Institute of Horticultural Sciences, University of Agriculture).

Malik, O.H. (2014). Evaluation of controlled and modified atmosphere conditions for transport of mangoes to distant markets. PhD thesis (Faisalabad, Pakistan: Institute of Horticultural Sciences, University of Agriculture). http://prr.hec.gov.pk/thesis/2873s.pdf#sthash.puIntlxz.dpuf.

Malik, A.U., Campbell, J., Hofman, P., Amin, M., and Collins, R. (2013a). Current Best Practices Guidelines for Mango Value Chain Management in Pakistan: Concepts and Definitions. ASLP Mango Value Chain Improvement Project (Faisalabad, Pakistan: Institute of Horticultural Sciences, University of Agriculture Faisalabad).

Malik, A.U., Umar, M., Hameed, R., Amin, M., Asad, H.U., Hafeez, O., and Hofman, P.J. (2013b). Phytosanitary irradiation treatments in relation to desapping and processing types affect mango fruit quality. Acta Hortic. *1012*, 681–692 https://doi.org/10.17660/ActaHortic.2013.1012.91.

Malik, A.U., Amin, M., and Ali, Z. (2015). ASLP Fact Sheet for Mango Value Chain Improvement, Australia-Pak ASLP-II Mango Value Chain Improvement Project (Faisalabad, Pakistan: Institute of Horticultural Sciences, University of Agriculture Faisalabad).

Mazhar, M.S., Collins, R., Campbell, J., Malik, A.U., Johnson, P., Dunne, A., Sun, X., and Amin, M. (2010). Managing mango fruit quality through the supply chain: a Pakistan case study. Acta Hortic. *880*, 117–124 https://doi.org/10.17660/ActaHortic.2010.880.12.

Rajwana, I.A., Khan, I.A., Malik, A.U., Saleem, B.A., Khan, A.S., Ziaf, K., Anwar, R., and Amin, M. (2011). Morphological and bio-chemical markers for varietal characterization and quality assessment of potential indigenous mango (*Mangifera indica* L.) germplasm. Int. J. Agric. Biol. *13*, 151–158.

Umar, M. (2012). Evaluation of phytosanitary irradiation treatment on fruit quality and shelflife of commercial mango cvs of Pakistan. MSc (Hons) thesis (Faisalabad, Pakistan: Institute of Horticultural Sciences, University of Agriculture).

Yousaf, F. (2014). Influence of low temperature precooling durations and non-chilling storage temperature on fruit quality of mango cv. Samar Bahisht Chaunsa. MSc (Hons) thesis (Faisalabad, Pakistan: Institute of Horticultural Sciences, University of Agriculture).