Postharvest
An Unsung Solution for
Food Security

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Prof. Dr. Mahmud Tengku Muda Mohamed

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PROFESSOR DR. MAHMUD TENGKU MUDA MOHAMED

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An Unsung Solution for **Food Security**

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ABSTRACT

In agriculture, postharvest is the last stage of crop production that spans from harvesting until the produce is being utilised by consumers. It includes handling practices involving harvesting, sorting, cleaning, pre-cooling, grading, packing, storage, transportation and postharvest treatments. The moment a produce is uprooted from the ground, or separated from the parent plant, it begins to deteriorate. To totally check this deterioration process is impossible, so the only alternative we have is to slow down the progression. Only then can we retain the quality of the produce longest possible. On the other hand, food waste, which is a subset of postharvest food losses, is the loss of edible food due to human action or inaction, such as throwing away produce, not consuming available food before its expiry date or taking serving sizes beyond one's ability to consume. The former is related to the early stages of the food supply chain (FSC) and refers to a system which needs investment in infrastructure. Food waste is applied to later stages of the FSC and generally, relates to the attitude of food suppliers and consumers. Like it or not, food losses and wastes will influence global food security. Increasing agricultural productivity is critical for ensuring global food security, but this may not be sufficient. The methods of increasing food supply include continous increase in the production area and yields as well as producing more crops per year. However, the other aspect that is always overlooked is the reduction of postharvest losses.

In light of these issues, this write-up highlights some of the causes of postharvest deterioration which are identified as lack of knowledge and information, inadequate transportation facilities, unavailability of needed tools and equipment and losses at the distribution level. Pre-harvest factors are crucial for retention of quality after harvest. All related factors, such as water stress,

nutrition (calcium in particular), light exposure, temperature and salinity, have a substantial influence on the postharvest quality of a produce. Quality responses to biotic and abiotic stresses are also discussed. Various strategies and interventions that have been developed and proposed, including those from UPM, to reduce postharvest losses and improve handling, storage and transportation operations of fresh produce during the entire supply chain are also highlighted. In order to control the high magnitude of postharvest losses and food waste, plausible action must be taken to upgrade the existing systems. In the present world, where millions of people go to bed without food, it would be a crime to allow continuation of postharvest losses and food wastes.

INTRODUCTION

Losses, in quantitative and qualitative terms, for horticultural crops, between harvest and consumption are natural processes which are unavoidable. Human intervention is required to minimize these losses, and to do so we ought to: 1) understand the biological and environmental factors involved in postharvest deterioration; and 2) use appropriate postharvest technology procedures that will slow down deterioration and thus maintain quality and safety of the commodities throughout the supply chain. Through proper understanding of the biological and environmental processes that influence a produce after harvest and appropriate technology, postharvest losses can be reasonably controlled. Qualitative losses of the products, such as loss in edibility, nutritional quality, caloric value and consumer acceptability, are much more difficult to assess than quantitative losses. Standards of quality, consumer preferences and purchasing power vary greatly between countries, people and cultures. For example, elimination of defects from a given commodity before marketing is much less rigorous in developing countries than in developed countries. This, however, is not necessarily bad, because appearance quality is often over-emphasized in developed countries (Kader, 2005), where for example, a bruised banana is totally rejected by the developed countries standard but can be happily consumed by consumers in developing countries. In such instances sometimes only the skins are bruised but the pulp is still in good condition.

On the other hand, food waste is a subset of postharvest food losses (Figure 1) (Buzby and Jeffrey, 2012) and is the loss of edible food due to human action or inaction, such as throwing away produce, not consuming available food before its expiry date or taking serving sizes beyond one’s ability to consume (Aulakh and Regmi, 2013). Parfitt et al. (2010) distinguished between food losses and food wastes, arguing that the former related to early stages of the food supply chain (FSC) and refers to a system which needs investment in infrastructure. Food waste on the other hand, is applied to later stages of the FSC and generally, relates to the attitude of food suppliers and consumers.

Figure 1 Postharvest food loss components (APHLIS, 2013)

The fact remains however that food losses and wastes will influence global food security. While increasing agricultural productivity is critical for ensuring global food security, this may however not be sufficient and sustainable. The three main avenues of increasing food supply are always identified as increasing the production area, increasing the yield of harvest per unit area and producing more crops per year. However, the other opportunity that is always overlooked is reducing postharvest losses.

In order to control the high magnitude of postharvest losses and food waste, plausible action must be taken to upgrade the existing systems. In the present world, where millions of people go to bed without food, it would be a crime to allow postharvest losses and food wastes to continue.

POSTHARVEST FOOD LOSSES AND FOOD WASTE

Given that the current world population is expected to reach 10.5 billion by 2050 (UN, 2013), food losses, waste or both, will further aggravate the global food security concerns. The projected population increase translates into 33% more human mouths to feed, with the greatest demand being amongst the poor communities of the world. According to Alexandratos and Bruinsma (2012), food supplies would need to increase by 60% (estimated at 2005 food production levels) in order to meet the projected food demand in 2050. Food availability and accessibility can be increased by increasing production, improving distribution and the neglected dimension of reducing losses. Thus, reduction of post-harvest food losses and food wastes are critical components of ensuring future global food security.

The Food and Agriculture Organization (FAO) of U.N. predicted that about 1.3 billion tons of food are wasted or lost globally per year (Gustavasson, et al. 2011). Reduction of these losses would increase the amount of food available for human consumption and enhance global food security which is now a growing concern with the rising food prices due to growing consumer demand, increasing demand for biofuels and other industrial uses and increased weather variability (Mundial, 2008; Trostle, 2010). A reduction in food waste will also improve food security by increasing real income for all consumers (WFLO, 2010).

Food waste not only make food less available for human consumption but can also indirectly have negative impacts on the society at large, through costs incurred in managing the wastes, greenhouse gases production and loss of the depleting resources used in their production. The amount of food waste and loss are estimated to be equivalent to 6-10% of human-generated greenhouse gases emissions (Gustavasson, et al. 2011; Vermeulen, et al. 2012). A significant contributor to this problem is methane gas generation from landfills where food waste decomposes anaerobically (Buzby and Hyman, 2012).

Malaysians are not alone in this aspect of food wastes. We have for far too long lived in affluence and thus, have a compulsive affinity for food. In jest, it is said that if Malaysians are not doing anything else, they are eating. It is a fact that while the British may be obsessed with the day's weather, in contrast, when two Malaysians meet the very first thing that they ask each other is '*sudah makan*' or have you eaten. Hence, with this scenario, food waste (Figure 2) is inevitably becoming a trend and on the increase. For example, it was reported that every year during the month of Ramadhan we throw away 270,000 tonnes of untouched edible food (mStar, 2015). That amount of food can feed 180 million people, six times the country's population. Further, Malaysia's daily food wastage of 9,000 tonnes, that is enough to feed six million or about 20% of the population, is an alarming development for a nation whose food import bill is increasing annually. The attitude of 'I spent my own money so who cares' should not be condoned as the resources used to grow and/or process the food wasted belong to the people.

Figure 2 Example of Food Wastes in Malaysia (*Masilamany, 2013)*

Increasing Production versus Reducing Postharvest Food Losses

Over the past decades, significant focus and resources have been allocated to increase food production. For example, 95% of the research investments during the past decades were reportedly focused on increasing productivity and only 5% directed towards reducing losses (Kader and Rolle, 2004; Kader 2005; WFLO 2010). Increasing agricultural productivity is critical to ensure global food security, but this may not be sufficient and sustainable.

Food production is currently facing the challenges of limited land and water and increased weather variability due to climate change. A study by the Institute of Mechanical Engineers indicated that current agricultural practices use 4.9 Gha (global hectares or 4931 million hectares) of the total 14.8 Gha (14894 million hectares) of the land surface on earth (Fox and Fimeche, 2013). In addition, they use 2.5 trillion m^3 of water per year and account for over 3% of the total global energy consumption. With food losses estimated to be about 30-50 % of total production, this translates into waste of 1.47-1.96 Gha of arable land, 0.75-1.25 trillion m^3 of water and 1 to 1.5% of global energy. Another local example is where Muda Agricutural Development Authority (MADA) has estimated the postharvest losses of padi per season to be about 28% (per. comm.). In terms of value, this is about RM980 million. With an estimate of 2,500 litres of water being needed to produce 1 kg rice, this quantum of losses means that 700 litres of water thus becomes non-productive. This amount of water could be used to produce some other food for human consumption.

Thus, food production alone will not ensure that more food can be put into the mouths of the people. The food chain not only involves production but also, moving that food through the delivery system all the way to the point of consumption, with reducing opportunities for losses to occur. Such a proper delivery system will ensure that the food that has been produced, including that from increased production, will reach the intended consumers safely. The effort of producing more food is otherwise a waste, particularly if it does not reach the stomachs where the utilization of its nutritional value begins (Bourne, 1977). To sustainably achieve the goals of food security, food availability also needs to be increased through reductions in post-harvest losses at the farm, retail and consumer levels. Spurgeon (1976) called this reduction of postharvest food losses the 'hidden harvest'. Figure 3 illustrates the importance of reducing postharvest losses. When the food pipeline is repaired through appropriate postharvest technologies, more food will be made available for consumption by the consumers.

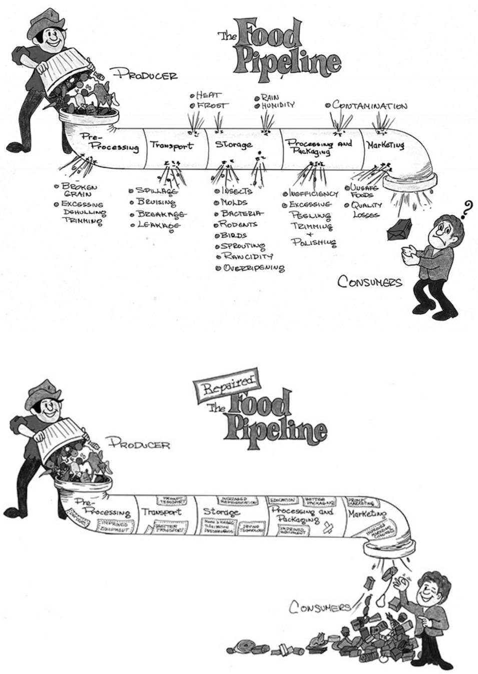


Figure 3 The Food Pipelines. Top: Unrepaired and Bottom: Repaired through appropriate technologies (Adapted from Bourne, 1977)

Consequently, there exists a dilemma of whether to concentrate on increasing food production and neglecting postharvest losses or to focus on both. Ideally, increasing food production should be done together with efforts in reducing postharvest losses. However, if a choices has to be made, it is better to reduce losses rather than increase production by the same quantum (Tables 1 & 2).

More food is made available if losses are reduced by the same amount as the increase in production (Table 1). Sometimes just through using simple postharvest technologies, such as shading the produce after harvest, proper harvesting stage and tools and using appropriate containers (bamboo or plastic crates), substantial reduction of losses can be achieved. However, increase in production with no efforts to reduce postharvest losses will not only provide a lower amount of food made available but will be at the expense of depleting resources. Reducing just 10% of losses at a time will lead to a reduction in the amount of production needed to offset postharvest losses where the quantum increases exponentially (Refer Table 2).

Table 1 Effect of improving production and postharvest losses on food availability

Condition	Yield	Losses	Available food
Average yield with 28% losses	6.8	1.9	4.9
Yield increased by 10% but losses still maintain at 28%	7.5	2.1	5.4
Average yield with losses reduced to 18%	6.8	1.2	**5.6**
Yield increased by 10% and losses reduced to 18%	7.5	1.35	**6.15**

Snapshots of Postharvest in Malaysia

The 7th Special Session of the U.N. General Assembly in 1975 passed a resolution calling for a 50 per cent reduction in postharvest losses by 1985. In this general assembly, it was resolved that reduction of postharvest losses in developing countries should be undertaken as a matter of priority, with a view to reaching the target of at least 50 per cent reduction by 1985. In line with this, the Australian Government announced the commitment of an initial $A5 million to an ASEAN-Australia Economic Cooperation Program for the implementation of projects which could be undertaken through the cooperative efforts of the member countries of ASEAN and

Australia. One of the cooperative projects identified was the development of improved techniques for postharvest handling of grains, horticulture products, livestock and fish known as the 'ASEAN Food Handling Project'. Most of the initial activities were in grains, and even up to now some policy makers associate post-harvest problems only with grains (Bautista, 2002).

Table 2 Crop production increases required to offset post-harvest losses (Bourne, 1977, mimeo)

Postharvest loss (%)	**Consumable grain (tonnes)**	***Production required to give 100 tonnes after postharvest loss (tonnes)**	**Increased production needed to offset post-harvest loss (%)**
0		100	0
10		111	11
20		125	25
30		143	43
40		166	66
50	**100**	200	100
60		250	150
70		333	233
80		500	400
90		1000	900
100		Infinite	

*Production = amount of consumable grain × $\frac{(100\%)}{(100\text{-}\%\text{ postharvest loss})}$

The average post-harvest losses reported for fruits and vegetables in Malaysia is still estimated at around 20% (Bautista, 2002). In actual practice, the losses vary greatly depending on the location, situation, crop, variety and season. Estimated postharvest losses in Malaysia for 2011-2013 are given in Table 3. Some estimates of losses in countries in the Asia-Pacific Region are shown in Table 4.

Table 3 Estimated postharvest losses of fruits and vegetables in Malaysia

	Commodity	2011	2012	2013
Total production (metric ton)	Fruits	1,622,603	1,658,332	1,765,828
	Vegetables	928,183	878,975	883,370
PH losses* (metric ton)	Fruits	324,520	331,666	353,165
	Vegetables	185,636	175,795	176,674
Available food* (metric ton)	Fruits	1,298,082	1,326,666	1,412,662
	Vegetables	742,546	703,180	706,696

Source: Statistik Tanaman (Sub-sektor Tanaman Makanan) (Department of Agriculture, Malaysia, 2013)

*PH losses and available food were derived by calculation based on 20% estimated losses in the supply chain.

Table 4 Estimated Levels of Postharvest Losses in the Asia-Pacific Region (Rolle, 2006)

Country	Estimated Level of Losses (%)
India	40
Indonesia	20–50
Iran	>35
Korea	20–50
Philippines	27–42
Sri Lanka	16–41
Thailand	17–35
Vietnam	20–25
Pakistan	35-45

Factors that contributed to the losses in the Malaysian context were identified by Azizah et al., 2009 (Figure 4). They conducted a study at different levels of the distribution chain where 634 respondents were surveyed from various zones in the country, to identify postharvest handling activities that were practised, the potential postharvest activities that can be carried out and the factors contributing to postharvest losses. They found that attitude and infrastructure were the two main factors that contributed to postharvest losses of fruits and vegetables in the country. Attitude is considered to be more important though because infrastructure alone without the proper stance will either become white elephants or not be appropriately utilised and maintained. Serious considerations should thus be given to creating awareness, not only among the users but also, the policy makers, implementers and financiers of the infrastructure. With proper consciousness among users, the infrastructures will be properly and optimally utilized. As for the other three parties mentioned, such realization will ensure that suitable infrastructure is built.

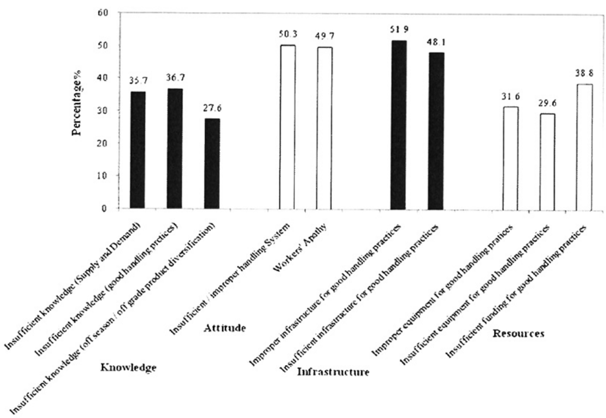


Figure 4 Factors contributing to postharvest losses of fruits and vegetables in Malaysia (Azizah et al., 2009)

Post-harvest losses are generally higher at the wholesale to retail stage than the farm to wholesale stage. An example of postharvest losses and their causes, is shown in a flow chart form in Figure 5. In Malaysia the night market or *pasar malam* (Figure 6) is still a very popular place to obtain fresh produce, not only for those from the lower income group but also a substantial number of those from the middle class. Although fruits and vegetable are generally sold in an open market, retailers have improvised, with the use of beach umbrellas arranged side by side, to provide acceptable shade to their commodities during the latter part of the day when the night market begins. When the market closes later in the night, the umbrellas are folded up and kept aside and the market area becomes an open space once again. This simple technique or similar ones should be adopted in other developing countries as a temporary measure to provide shade to the produce. However, most of the losses still occur here if the retailers are not careful when handling their produce, and excessive trimming, wilted and deteriorated vegetables and fruits are commonly seen here.

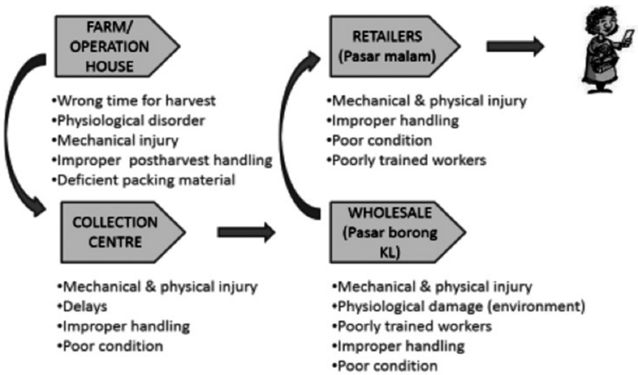


Figure 5 Postharvest losses and causes (Ahmad, 2014)

Figure 6 Night market Scene (Ahmad, 2014)

As in many other developing countries, our wholesale markets are still integrated with retail markets though ideally, wholesale and retail markets should be separated. However, this is influenced by the structure of the supply chain and the scale of the industry. Frequently wholesale markets are overcrowded, unsanitary and lack suitable facilities for display, storage, ripening, loading and unloading. A main contributory factor to losses of leafy vegetables is trimming at wholesale markets prior to delivery to retail stands. Examination of trimmings showed that wholesalers and retailers trimmed their produce mainly because of the presence of decaying portions of leaves, due to bacterial soft rot. Thus, prevention of rotting during transport and storage would result in a substantial reduction in postharvest loss of leafy vegetables. Further, the sanitary conditions of the produce at farm level should also be emphasised. Particularly for produce marketed in consignments, attention should be given to pre- and postharvest processes to ensure that the vegetables and fruits sent to the wholesalers are completely sold. Some of the common scenes found in our wholesale markets are presented in Figure 7.

Proper storage of fresh fruits and vegetables prolongs their usefulness, checks market gluts, provides a wider selection of fruits and vegetables throughout the year, helps in orderly marketing and may increase the financial gains of the producers. Proper storage may reduce subsequent losses but cannot overcome pre-storage losses. Suitable storage involves proper regulation of temperature, humidity, air circulation, proper stacking pattern, regular inspection and prompt produce disposal as soon as maximum storage life has been attained. The feasibility of the construction of cold storage facilities and interest among farmers and handlers to utilize these cold storage facilities would again depend on the economic parameters of such facilities. One of the greatest impediments to preserving quality through refrigerated storage is the consumers' strong preference for freshly harvested produce and resistance to stored produce. However, as the society becomes more affluent, as in Malaysia, the resistance is lower and thus purchasing from supermarkets or online is becoming common. Under these setups, storage cannot be avoided.

Figure 7 Common scenes at a wholesale market. Anticlockwise a) Dumping site where most of the trimmings and heavily damaged produce are disposed of;b)wet boxes have given way as they were not waterproof; c)overripe and heavily stained mangoes; and d)selection being carried out on the bare floor which can easily cause abrasion to the chillies.

Information on the storage temperature and humidity requirements of fruits and vegetables and the length of time they can be kept without any decline in market value is either inadequate or unknown to those who need such information. If a farmer is persuaded to store his produce in cold storage and the market value decreases due to inadequate knowledge of the proper methods of utilization of cold storage, it is not only the farmer who will become disillusioned but his friends too. Thus they will all be convinced of the non-profitability of cold storage. As a result, these heavily invested infrastructures will become white elephants or if utilized they will not be well maintained, especially in government establishments.

Utilizing improved postharvest practices often results in reduced food losses, improved overall quality and food safety and higher profits for growers and marketers. However, how can we teach people the postharvest handling practices that will best serve their needs? This can be attained through formal education or extension programmes among the stakeholders. The former should be carried out to inform those involved along the supply chain on the importance of appropriate postharvest techniques.

Universiti Putra Malaysia, then known as Universiti Pertanian Malaysia, pioneered the teaching and learning of postharvest way back in the early 1990s. We began with a modest course known as Postharvest Physiology. Currently, many other public and private universities are also offering courses on postharvest technologies. As for UPM, we have two other senior level courses in this area, offered to under- and post-graduates. For postgraduate studies, we have initiated M.S. and Ph.D. programmes with a thesis on postharvest.

In the early days, equipped with a grant of RM1,500, we embarked on our first postharvest research to look at the effect of *Pasar Tani* beach umbrella (shade) on the quality of the displayed vegetables. Since then, obtaining grants for postharvest research has become relatively more easy. Lately, Malaysia has identified postharvest as one of the areas that needs to be exploited to ensure the country's food security and safety.

CAUSES OF POSTHARVEST DETERIORATIONS

Lack of Knowledge and Information

Fruit and vegetables have soft structures and thus handlers with inadequate knowledge on proper harvesting, packaging, transporting and marketing methods can rough up the produce resulting in huge postharvest losses. In the handling of horticulture products, human capabilities are very important. Effective training of workers and their supervisors is essential to familiarize them with appropriate fresh produce handling techniques.

The fruits and vegetables sectors are very vulnerable to demand and supply. In most countries, high fluctuations, both in terms of production and prices, lead to low profits for growers. Sometimes, the regulatory bodies of certain countries are more consumer friendly rather than grower/producer friendly. In such instances when the prices increase, they will issue import permits to reduce the prices of local produce and when the price is low locally, no incentives are given to the farmers.

A proper regulated marketing system is therefore a prerequisite to control postharvest losses, whereby supply and demand factors are taken into consideration before fresh produce production decisions are implemented. Inaccurate market information and poor planning may lead to excessive production of certain fruits or vegetables which subsequently cannot be sold in a timely manner. When consumers are not ready to buy the products it results in rotting of fruits and vegetables when not properly handled. Thus, market intelligence is vital for proper scheduling of production. Market information will help in decision making on what, when and where to produce different crops. Through proper analysis of market requirements, production can be scheduled accordingly so as not to result in undersupply or oversupply situation. This is important because these perishables, if not properly handled, will result in losses. Such situations often arise in areas where storage and transportation facilities are lacking or if available, are not well maintained. Postharvest losses vary from one country or one location to another. It also changes from one season or even one day to another (Weinberger & Genova, 2005).

Inadequate Transportation Facilities

Transportation of fresh produce from production area to market has to be speedy and affordable for all growers. Breakdown and delay in transportation of perishable commodities are common occurrences in our local markets, particularly during the rainy season, and as such are major contributors to postharvest losses.

In all developing countries, roads and vehicles are the major issues that delay transportation of fresh produce to market. Majority of producers do not have their own vehicles because they are small growers. Cooperatives and marketing organizations do have their own transport vehicles, but unfortunately they cannot do much about poor road conditions which are usually not under their purview. Further, these organizations sometimes act not as enablers for marketing but are themselves the marketers, which results in a conflict of interest.

Unavailability of Appropriate Tools and Equipment

Most of the growers do not have appropriate tools and equipment for harvesting, cleaning, waxing, packaging, grading and cooling. Usually, handlers and growers of fresh horticultural crops are not able to find these types of equipment in their domestic markets and even if available are beyond their reach. The advanced tools are neither imported nor manufactured locally in sufficient quantity to meet local growers' demand. Only big producers have access to such expensive equipment. Sometimes, to worsen matters, several governmental rules and regulations do not allow producers to import the necessary tools directly from other countries.

Losses at Distribution Level

Retailers face problems in adjusting supply to demand. Every day huge quantities of fresh horticultural products are thrown away due to rotting or torn packaging and poor management. On the other hand, when fresh batches arrive in the market, they replace the old produce which is usually thrown away. Frequently, retailers overstock their shelves to ensure that the quantity of the produce is obvious and consequently it exceed the demand from consumers. Retailers also remove expired products from shelves even though they are still perfectly edible. Currently, however, hypermarkets and supermarkets are getting into the habit of lowering prices of products nearing their expiration dates.

Furthermore, losses often occur when the produce do not meet the Minimum Residual Limit (MRL) of certain importing countries. For example, sometimes our local produce do not pass the quarantine requirements of our neighbouring country. In this situation, lorry loads of our vegetables are turned back and amazingly, where they proceed from the checkpoint is not reported. However, this indirectly leads to loss of our vegetables.

POSTHARVEST QUALITY RESPONSES TO PRE-HARVEST FACTORS

It is imperative to describe the link between pre-harvest factors and their effects on subsequent postharvest quality of fruits or vegetables. Some of the losses incurred can be avoided by focusing on the influence of pre-harvest factors along with the use of conventional postharvest techniques.

During the production of fruits and vegetables, the occurrence of drought conditions is becoming more frequent with the changing climatic patterns (Whitmore, 2000). Thus, more work has been conducted to understand the effects of drought on the production and quality of these crops. However, in Malaysia, no serious and concerted efforts have been organised by relevant organisations to address these issues as yet. Strenuous efforts are inevitable as the challenges can really be felt day by day. Are we ready to rationalise our planting programmes? Is work on varieties that can withstand new weather conditions in place and is our farmers' readiness to face these new challenges part of the national food security agenda? Recent events in our country show us the state of preparedness. Due to the El Nino phenomenon, Malaysia experienced severe drought and hot temperatures which not only affected human activities but also crops like rice, rubber and even oil palm, where the yield and quality of the produce were affected. The situation was so bad that we even needed to close schools in several districts, which has rarely occurred before.

Additionally, water stress during production can affect the physiology of fruits and vegetables such as susceptibility to weight loss during storage. Studies have been done on the effects of pre-harvest water stress on plant responses at the postharvest stage and hence, on subsequent quality and shelf life. It has been observed that water deficiency during the growing period seriously affects cell wall related peroxidase enzymes of pepper (Hamad et al., 2004). Pak Choi grown in adverse water conditions due to salinity is also affected in its postharvest storage quality (Mahmud et al., 1999).

Proper nutrition always has positive effects on the postharvest characteristics of fruits and vegetables. Sams and Conway, (2003) reported that proper pre-harvest nutrition increased postharvest disease resistance and reduced other postharvest disorders of fruits and vegetables. Calcium is considered as being a part of a signalling molecule, induced antioxidant enzymes activities and increased tolerance against biotic and abiotic stresses (Rao et al., 2011). The role of pre-harvest calcium application in postharvest stress resistance is complex and depends on the environmental conditions to which the fresh produce is exposed. Pre-harvest calcium application improved the postharvest quality of papaya with increased firmness and reduced cell wall degrading enzymes (Madani et al., 2014a). As for disease control, calcium played a role in reducing *Colletotrichum gloeosporioides* spore germination (Figure 8), where spore germination was significantly reduced with increased concentrations of calcium applied *in vitro*. It had been reported that pre-harvest calcium application also significantly reduced physiological disorders, lipid peroxidation and increased antioxidant enzymes activities such as CAT, APX and GR in 'Microtom' tomato (Mestre et al., 2012).

The effects of high light exposure are sometimes difficult to be dissociated from that of high temperatures. It has been observed that pre-harvest low light (bagging of apples) managed to reduce the susceptibility of apples to the physiological disorder of superficial scald in cold storage (Barden and Bramlage, 1994). On the other hand, it has been reported that high ambient temperatures resulted in increased susceptibility to postharvest physiological disorders (Bramlage and Weis, 1997). Ferguson et al. (1999) also observed that apples exposed to sunlight developed scald during postharvest storage.

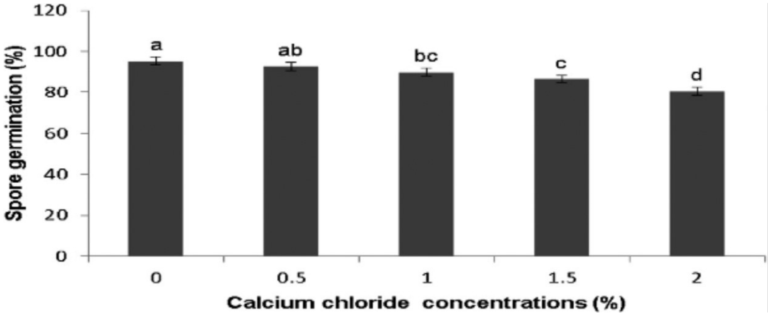


Figure 8 Effect of pre-harvest *in vitro* calcium treatment on conidial germination of *C. gloeosporioides*. (Madani et al., 2014a)
Means with different letters were significantly different according to the Waller- Duncan k-ratio t-test (p 0.05). The vertical bars represent the standard error of means for six replications.

The effects of pre-harvest temperatures (18, 21 and 25 °C) and salinity levels (1.7, 9.5 and 12.3 $mScm^{-1}$) on the ascorbic acid and total chlorophyll contents of Pak Choi (*Brassica rapa ssp*. Chinensis L) were investigated (Mahmud et Al., 1999). The relationships of the chemical content with storage period (0, 7 and 14 days) and water loss were also monitored. It was found that increased production temperatures significantly ($p \leq 0.001$) reduced the ascorbic acid and total chlorophyll ($p \leq 0.01$) contents of the produce. Ascorbic acid content in leaves grown at various salinities was also significantly ($p \leq 0.01$) reduced beyond 9.5 $mS\,cm^{-1}$. However, total chlorophyll was not affected by these different levels of salinity. Ascorbic acid content of harvested shoots also fell rapidly during the first seven days of storage, most markedly in shoots taken from plants grown at high salinity. The pattern of chlorophyll degradation depended on the plants' production environment, where higher temperatures resulted in subsequent rapid degradation during storage. For shoots grown at high salinity, the chlorophyll content was sustained during early storage. Linear relationships were apparent between water loss and the ascorbic acid and total chlorophyll contents of shoots, from the range of treatments. These results indicated that different quality characteristics resulted from the pre-harvest conditions of Pak Choi.

POSTHARVEST QUALITY RESPONSES TO BIOTIC AND ABIOTIC STRESSES

Biotic Factors

Postharvest Diseases

The majority of developing countries are situated in the world's tropical zones. In the tropical or subtropical areas, high humidity and temperatures provide a favourable environment for the proliferation of microorganisms or insects and thus, exacerbate the causes of postharvest losses. High postharvest losses result from an attack by fungi, bacteria, insects and other organisms. Microorganisms spread quickly and attack fresh produce easily, because fresh products do not have much natural defence systems but have adequate nutrients and moisture to support microbial growth. Thus, all the microclimatic conditions prevailing during the postharvest stage are biased toward the growth of microorganisms. Further, postharvest disease control is also becoming more difficult because the number of fungicides available for use, which are suitable and effective, are becoming more restrictive due to consumers' concerns about food safety. Consumers' demand for alternative techniques of controlling post-harvest diseases is on the rise. As consumers become more affluent, premium prices are easily accommodated but with the condition that the produce are chemical free.

In UPM, work on use of biocontrol agents to combat postharvest diseases began in the early 2000s. Initial publications on the use of chitosan in controlling anthracnose in papaya started with a Ph.D. dissertation by Asgar Ali, entitled "The Use of Chitosan Coating for Postharvest Quality Retention of Papaya during Storage".

The control and 0.5% chitosan coated fruits were found to be more susceptible to anthracnose where the fruits started to develop small water-soaked patches within six days after inoculation (Ali et al., 2012). Disease incidence also gradually increased over time where the water-soaked spots turned into circular sunken lesions with a translucent light brown margin. Disease incidence in the control fruits was 24% after 15 days of storage. However, when the fruits were treated with 1.0, 1.5 and 2.0% chitosan, the disease symptoms were reduced in proportion to the increasing concentrations of chitosan used (Figure 9). The fruit treated with 1.5 and 2.0% chitosan showed no visible disease symptoms at all up till the end of experiment, while the fruit treated with 1.0% chitosan showed 10% disease incidence after 15 days. The disease incidence in all chitosan treatments, except for the 0.5% treatment, was significantly ($p \leq 0.05$) lower than the control.

Bio fungicides should thus be applied for the control of postharvest diseases. Of the 27 antagonistic bacteria isolated from the fructosphere of papaya and screened by dual and concomitant test, four isolates of the bacteria (B23, B19, B04 and B15) had high antagonistic activities against the fungus *Colletotrichum gloeosporioides* that causes anthracnose of papaya (Rahman et al., 2007).

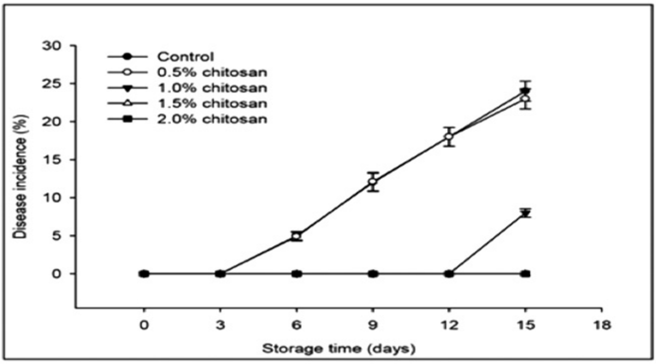
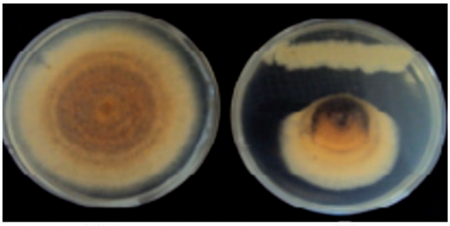


Figure 9 Effect of different concentrations of chitosan on anthracnose incidence (%) on papaya fruit. Vertical bars represent ± S.E. of the mean of four replicates (Ali et al., 2012).

Using the Biolog system, isolates B23 and B19 were identified as *Burkholderia cepacia* and B04 and B15 as *Pseudomonas aeruginosa*. Both *B. cepacia* and *P. aeruginosa* strongly inhibited the fungal growth by an average of 74.13 and 68.45%, respectively, during *in vitro* screening on PDA medium. The bacteria also produced volatile as well as diffusible substances. Malformation of hyphae occurred in the presence of both bacteria. Hyphae were thickened, vacuolar and many swellings occurred in them or at the tips of the hyphal strand. However, *B. cepacia* was found to be the most efficacious biocontrol agent in this study. Total inhibition (100%) in spore germination was noted in the presence of *B. cepacia* at 24 h after treatment. Filter sterilized culture filtrate of *B. cepacia* also significantly inhibited the mycelial growth (59.2%) and spore germination (100%) of the test fungus, thus suggesting that an antibiotic substance (s) may be produced by the bacterium. The in vitro activities of the *B. cepacia* against *C. gloeosporioides* of papaya in this study suggest that the bacterium can be an effective biological control agent. However, since *B. cepacia* is known to be pathogenic to humans, further study is warranted, in collaboration with medical personnel, to look into the pathogenicity of this bacteria to human health.

The potential of using *Bacillus subtilis* by itself or enhanced with sodium bicarbonate (SBC) and *Aloe vera* gel (aloe gel) for the control of postharvest anthracnose disease of papaya fruit and their subsequent effects on postharvest quality of fruit were investigated. *B. subtilis* B34 showed antagonistic activity against *C. gloeosporioides*, which was isolated from papaya fruit surface (Hasan et al., 2012) (Figure 10). However, when supplemented with 2% SBC and 20% aloe gel, it showed greater control by reducing 98.2% of the disease during storage for 14 days at 12°C and 95% RH, which was superior to that obtained using the fungicide, Benocide®. Furthermore, the combination of SBC-aloe gel with *B. subtilis* significantly maintained fruit quality by preserving fruit firmness and delaying changes in external colour without impairing any other fruit quality parameters, during storage at 12°C and 95% RH for 28 days. Thus, the combination of *B. subtilis* strains B34, SBC and *Aloe vera* gel could be an alternative to synthetic fungicides for the control of postharvest anthracnose disease as well as the quality of papaya.



(a) (b)

Figure 10 Dual culture assay showing the inhibition of mycelial growth of *C. gloeosporioides* untreated (a) and treated (b) with strain-B34 of *B. subtilis* after seven days of incubation at 28 ± 2° C (Hasan et al., 2012).

Postharvest Contaminations

Concerns about food safety when handling fresh fruits and vegetables have increased over the past decade. Recent outbreaks of food-borne diseases have been associated with berries, tomatoes, leafy greens and cut fruits. Wholesale buyers and consumers are thus increasingly interested in handling practices that will ensure food safety. It is the responsibility of growers and postharvest handlers to document their practices to protect fresh produce from contamination. Furthermore, retailers such as large supermarket chains are demanding compliance with food safety practices from their suppliers. Soon, it may be impossible to export produce to Europe or the U.S. without documenting its safe handling from the farm to market.

Currently, some general food safety practices are being promoted by universities, governmental agencies and private sector organizations around the world. For growers who want to export their produce to the European Community, they should be aware that new standards are being developed by the retail produce industry to guide handling practices for growers and shippers (known as EUREP-GAP). Key concepts are the implementation of GAP (Good Agricultural Practices) on the farm, in the packinghouse and during transport of all fresh produce, and HACCP (Hazard Analysis Critical Control Points) to document the safe handling of farm chemicals, pesticides, packaging materials, etc., especially for processed or fresh-cut produce. This will ensure a good and sustainable agricultural production management system. The system will not only increase farm productivity but also produce safe, quality produce, taking into consideration the welfare, safety and health of the workers, as well as sustainability.

For us in Malaysia, the Malaysian Good Agricultural Practice (myGAP) is a certification scheme developed by the Department of Agriculture in 2002 for accreditation of farms that practice GAP. It is based on the Malaysian Standard MS 1784:2005 Crop Commodities – Good Agricultural Practice (GAP).

In terms of microbial food safety, the potential sources of pre-harvest contamination of fresh produce were recently reviewed, including the use of manure fertilizers, the presence of animals in fields and the use of poor quality water for irrigation (Beuchat and Ryu, 1997; Brackett, 1999; Beuchat, 2002; Steele and Odumeru, 2004; Brandl, 2006). Organic lettuce grown in soil with ruminant manure and sewage was considered the main source of *E. coli* O157:H7 (Olaimat and Holley, 2012) which is able to survive in soils for months or years (Doyle and Erickson, 2008). So, care should be taken when dealing with produce grown in these types of soils.

Contamination of microorganisms on fresh produce is an area of concern. Butterhead lettuce, a salad crop, is prone to food safety risk because it is often consumed raw. Pathogens, including *E. coli* O157:H7, may contaminate fresh produce in the farm or at any point in the supply chain (Beuchat, 2004; Brackett, 2005). There were significant and positive quadratic relationships between *E. coli* O157:H7 colonies and storage duration for both organically (R^2=0.84) and hydroponically (R^2=0.93) produced lettuce obtained from local markets (Figure 11) (Siti Fairuz et al., 2013). However, the contamination levels were still below the microbial recommended limit, 8 log $CFUg^{-1}$ or 10^8 $CFUg^{-1}$, proposed by Debevere (1996).

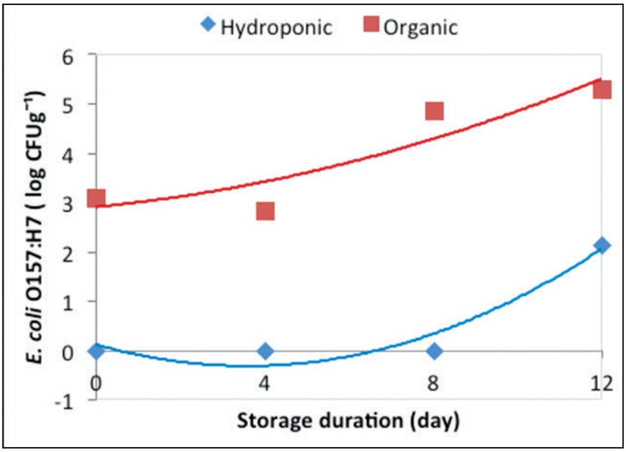


Figure 11 Relationships between *E. coli* O157:H7 contamination and storage duration of Butterhead lettuce. Organic (■) = $0.011x^2+ 0.083x+ 2.89$ ($R^2=0.84$) and hydroponic (♦) = $0.034x^2 -0.242x+0.11$ ($R^2=0.93$)

Postharvest contamination might also occur in the packaging house due to cross-contamination with raw produce, during washing or due to poor sanitation. Thus, human pathogens might contaminate the fresh produce at any stage from farm-to-fork.

Abiotic Factors

Mechanical Injury

Fresh fruits and vegetables are very susceptible to mechanical injury due to their soft texture and high moisture content. Poor handling, unsuitable containers, improper packaging and transportation can easily cause bruising, cutting, breaking, impact wounding and other forms of injuries. Mechanical damages occur during harvesting, loading, unloading and stacking operations or vibration during transport (Chonhenchob and Singh, 2003). Mechanical injuries increase respiration rate, ethylene production and cell deterioration near the site of the injury (Toivonen et al., 2005). It has been observed that bruising produced internal black spots in potato tubers during storage (Stevens and Vavelaar, 1997). Several others factors that affect severity and size of bruising include water potential, maturity and temperature of the produce.

Physiological Disorders

Physiological disorders that decrease consumers' acceptability of susceptible produce, can develop during storage. Chilling injury occurs when the produce is stored below the optimal storage temperature, which leads to a wide range of quality defects. Chilling injury is a physiological disorder caused by low but not freezing storage temperatures (Hoa et al. 2002). Most subtropical or tropical fruits are susceptible to chilling temperature injury due to their adaptability to hot climatic conditions (Singh et al., 2013). Some temperate horticultural crops also show sensitivity to low temperatures during storage. This shows that each produce has its own optimal low storage temperature which must be taken into consideration when setting up the storage temperature for a particular crop.

Chilling injury, as affected by temperatures and storage times, is presented in Table 5 (Ghulam, 2015). For mangoes stored at 2^{o}C, chilling injury symptoms were observed after seven days while at 6^{o}C it was after 14 days of storage. The chilling injury symptoms progressively increased irrespective of temperature with increasing storage period. However, the highest chilling injury by the end of the experiment was recorded in fruits stored at 2^{o}C.

Table 5 Main and interaction effects of two storage temperatures and six storage days on chilling injury index of mango fruits during storage. (Ghulam, 2015)

Factors	Chilling injury index
Temperature (T) °C	
2	1.79 a[z]
6	1.43 b
Storage (S) day	
0	0 e
7	0.17 e
14	0.84 d
21	1.94 c
28	2.76 b
28 + 5 (ripening period)	3.93 a
Interaction	
T × S	*

[z] Means followed by the same letter within a column were not significantly different at $P \leq 0.05$ using LSD. ns, non-significant and * = significant at $P \leq 0.05$ respectively.

These data support a previous report, where 'Tommy Atkins' mangoes stored at 2°C showed more chilling injury symptoms than those stored at 5°C for 20 days (Nunes et al., 2007). In contrast, Narain et al. (1998) reported that Julie and Totapuri mango fruit varieties can be stored at 5-7°C for 7 weeks without any chilling injury symptoms. The optimum storage temperature range for mango, with low possibility of chilling injuries, is 12-13°C (Mitra, 1997). However, Pairi and Taimour mangoes can be kept in good condition for 28 days at 5°C and 80-90% RH (Narain et al., 1998). These inconsistent results suggest that the occurrence of chilling injury depends not only on storage temperatures but also on cultivars, maturity stage, temperatures, storage duration and postharvest treatments. Low temperature is useful to reduce metabolic changes, but mango is tropical in nature and so, very sensitive to chilling temperature.

Mitochondria are the most important organelles and considered as the powerhouse of the cell for energy production. It has a central role in the process of respiration. Mitochondria are vulnerable to different stress conditions.

Ultrastructural changes in treated or untreated mango fruit stored at 6 °C are shown in Figure 12 (Ghulam, 2015). The changes in the untreated fruits are more obvious than that in the treated fruits. The micrograph of the mitochondria structure in the control fruits show that the whole structure is swollen and the membrane ruptured and fragmented (Figure 12A), while the structure of the cristae is blurry and disorganized. For fruits treated with calcium chloride (CA) 3%, the micrograph of the mitochondria shows that the mitochondria structure is generally normal and the cristae clear, although minor changes are observed in the mitochondria membrane (Figure 12B). In gum Arabic (GA) 10% and CA 3% + GA 10% treated mango, the micrographs of the mitochondria reveal that the entire structure of the mitochondria is well organized, the cristae normal and the mitochondria membrane intact (Figures 12C and D).

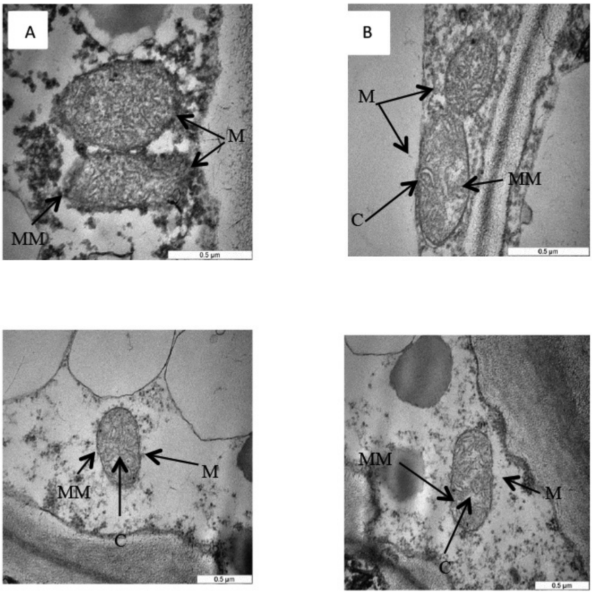


Figure 12 Transmission electron micrographs of mitochondria in the peel of mango fruit after 4 weeks storage at 6 °C. A = control, B = CA 3%, C = GA 10%, D = CA 3% + GA 10%. Mitochondria: M, Mitochondria membrane: MM, Cristae: C. (Ghulam, 2015)

During respiration, the mitochondria produce the energy needed by the cells to perform various functions and thus any abnormal changes in its structure will seriously affect plant health. Mango is a climacteric fruit, where there is an abrupt increase in respiration rate and ethylene production which cause rapid biochemical changes in the fruit composition (Mitra, 1997). Mitochondria is the primary site of ROS production and an important organelle for the study of biochemical changes during fruit ripening and senescence processes. Excess production of ROS by mitochondria causes oxidative damage and other physiological disorders, which ultimately induce senescence in fruits (Tian et al., 2013).

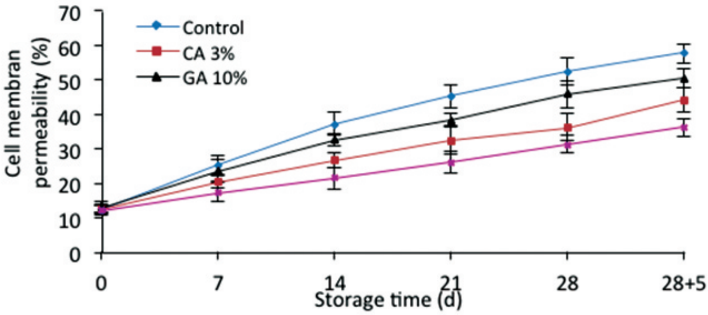
Several other factors, including high levels of carbon dioxide or ethylene, low levels of oxygen, water stress due to high transpiration, high temperatures and irradiation also affect fresh produce quality (Negi and Handa, 2008). Further, physiological disorders may occur due to mineral deficiency, undesirable atmospheric conditions and the storage environment (Wills et al., 2007). Physiological disorders, also associated with enzyme actions which occur spontaneously in fruits, lead to induction of the ripening process and senescence.

Working with 'Eksotika II' papaya, Babak (2014) showed that increasing Ca concentrations caused a significant decrease in ethylene production and increase in ascorbic acid content. It is known that ethylene is a ripening hormone and its synthesis after harvest results in softening of fruits, which leads to attack by post-harvest pathogens. Decrease in ethylene production is one of the factors that can delay the senescence process in fruits (Bakshi et al., 2005) and also, reduce ethylene-induced physiological disorders (Kader, 1985). Reduction in ethylene production with increasing Ca concentrations in papaya fruits suggest that Ca delays fruit ripening by reducing ethylene emissions, thereby slightly retarding the climacteric rise (Hansford, 1994). Tzoutzoukou and Bouranis (1997) also reported a reduction in ethylene production in apricots treated with $CaCl_2$. Thus, indirectly, physiological disorders can be controlled with proper management of ethylene gas.

More than 90% of the vitamin C in human regimes is delivered by fruits and vegetables (Lee and Kader, 2000). Ascorbic acid is an antioxidant that can be used to control postharvest oxidative damage in fruits and vegetables which will eventually lead to physiological disorders. Significantly higher levels of ascorbic acid observed in Ca-treated papaya fruits could be due to the inhibiting actions of Ca on the activities of many oxidizing enzymes like ascorbic acid oxidase, peroxidase, catalase and polyphenol oxidase that use ascorbate as the substrate (Singh et al., 2005). Considering the antioxidative role of vitamin C and its beneficial effects on human health, the positive relationship between exogenous Ca application and ascorbic acid fruit content can be of particular interest for neutraceutical purposes. These results confirm that of Ramezanian et al. (2009) who reported increased ascorbic acid concentration in pomegranate as a consequence of pre-harvest foliar spray of $CaCl_2$.

Temperature

Temperature plays a significant role in the determination of postharvest life and quality maintenance of fresh horticulture produce. Postharvest temperature management of fresh produce during transportation is a constant challenge, especially for products being exported far away (East et al., 2008). Low-temperature storage is used to delay ripening and senescence processes, decrease metabolic activity, reduce water loss, lessen decay incidence, and thus, preserve postharvest quality and extend the shelf life of fruits (Yehia, 2011). Higher temperatures on the other hand increase metabolic processes and respiration rates which in turn induce rapid utilization of carbohydrates resulting in quick deterioration of products. Thus, low temperature is useful to reduce ripening and general perishability of mangos during post-harvest handling, storage and long distance transportation (Junmatong et al., 2012). At the same time, chilling injury is a physiological disorder caused by low but not freezing temperatures (Hoa et al., 2002). As shown in Figure 13, calcium chloride in combination with gum Arabic reduced chilling injury and ion leakage in mangos during storage at low temperatures (Khaliq et al., 2016).



***, **, ns: significant at $p \leq 0.001$, $p \leq 0.01$ and not significant at $p > 0.05$, respectively

Figure 13 Effect of calcium chloride (CA) and gum arabic (GA) on cell membrane permeability in the peel of mango fruit stored at 6 °C for 28 d and then transferred to 25 °C for 5 d shelf life. Vertical bars indicate standard error of means for three replicates. (Khaliq et al., 2016)

The effects of growing temperatures on ascorbic acid and total chlorophyll contents are significant ($p \leq 0.001$/$p \leq 0.01$, respectively), as shown in Table 6 (Mahmud et al., 1999). The findings show that ascorbic acid content was significantly reduced by increased growing temperatures. The higher content was in plants grown at 18 °C compared to the two other production temperatures. Significant differences were observed between plants grown at 18°C with those at 21°C and 25 °C but not between the latter two growing temperatures.

Total chlorophyll content was significantly higher in plants grown at 21 °C compared to plants produced at 18°C and 25 °C. Significant differences were only observed between the former temperature and the latter two production temperatures but not between 18°C and 25 °C.

Table 6 Effects of different growing temperatures on ascorbic acid (gkg^{-1} fresh weight) and total chlorophyll ($\mu g.g^{-1}$ fresh weight) content in leaves of Pak Choi cv F_1 MQC after 14 days storage. Means of four replicates. (Mahmud et al., 1999).

	GROWING TEMPERATURE (°C)		
	18	21	25
Ascorbic Acid	0.59	0.36	0.4
Total chlorophyll	16.5	17.7	15.5
SED (Growing Temperature)			
Ascorbic Acid	0.027^{***} (df = 2)		
Total chlorophyll	0.623^{**} (df = 2)		

Low Oxygen and High Carbon Dioxide

Low levels of oxygen are known to promote stress and induce alterations in metabolism which result in metabolite accumulations (Kanellis et al., 2009). When fruit tissues are re-aerated, it increases free radicals such as hydrogen peroxide or superoxide anion, resulting in protein degradation, lipid peroxidation and membrane destruction (Blokhina et al., 2003). When handling fresh produce in modified atmosphere (MA) packages, controlling low oxygen or high carbon dioxide stress is a continuous challenge for the transporter. High carbon dioxide stress induces several physiological disorders, such as brown stain of lettuce, surface bronzing in apples and brown heart in pears (Meheriuk et al., 1994).

Storage in modified atmosphere at 10°C extended the storage life of Eksotika papaya (Rohani *et. al*, 1997). It was found that bulk packaging (9–10 fruit/ pack) with CO_2 and O_2 levels at 5 and 4%, respectively, helped to extend the storage life of the fruit up to 3 – 4 weeks. Nevertheless, storage life was further extended to about 5–6 weeks when the fruits were wrapped individually with gas compositions in the environment containing 4% CO_2 and 8% O_2.

In Malaysia, MA packaging is the main technique used for manipulation of atmospheric gas compositions. Due to natural respiration, the CO_2 levels will be elevated with reduction of O_2. However, when their concentrations cannot be controlled it can lead to the occurrence of CO_2 injury.

MA conditions can also be affected by the quality of the produce. It was shown that during sprouting in a hermetically sealed chamber, sprouts produced at a lower seeding density (lower respirational CO_2 produced) had 2.7% lower soluble solids concentration, but they had 18% higher content of ascorbic acid as compared to the ones produced in higher seeding density where respirational CO_2 is higher (Choon et. al, 2010). Similarly, there were significant differences in the total phenolic compounds of the sprouts and the contents decreased by 43% as the seeding densities increased. Overcrowding and lack of watering seemed to produce poor quality sprouts.

Weight Loss

Transpiration water loss from fruits and vegetable tissues is a common physiological process which results in deterioration of appearance quality, such as wilting, shrivelling and acceleration in development of injuries. In terms of textural value, it means loss of crispiness, juiciness and firmness. Nutritional content is also sometimes compromised, such as reduction in vitamins A and C contents. This occurs during the handling and distribution phase (Ben-Yehoshua and Rodov, 2003).

Moreover, excessive removal of water from tissues leads to enhancement of senescence or ripening which appears as softening of tissues, yellowing and membrane destruction (Burdon et al., 1994). Moisture evaporation from the fruit surface and oxidation of organic acids during respiration are the main causes of weight loss in fruits and vegetables. Relative humidity and temperature play significant roles in water loss from the fruit surface in the storage environment. Water transfer also depends on the cultivar, maturity stage, morphological structure and surface coating.

Since vegetables and fruits are normally sold in terms of their weight, weight or water loss not only causes reduced quality but also the monetary value of the produce. If excessive the produce tends not to be marketable. Thus, controlling water loss is extremely important in the postharvest management of horticultural produce.

POSTHARVEST STRATEGIES AND PROPOSED INTERVENTIONS

Various strategies have been developed and proposed to reduce postharvest losses and improve the handling, storage and transportation operations of fresh produce throughout the supply chain. Global markets need comparatively sophisticated marketing information and cold chain transportation networks. Improvements in the postharvest sector include developing pre- and postharvest technologies, integrating market information systems and price fluctuations on seasonality. Small farmers require training to meet the challenges of supplying fresh produce to global supermarket chains and large processors that are becoming the main buyers of fresh horticulture produces**.** Awareness of the importance of MyGAP is crucial if our farmers are going to join other global players as suppliers of exotic tropical fresh fruits and vegetables. With awareness and proper rewards in terms of pricing, adherence to MyGAP by our farmers will not be an issue.

Treatments to Enhance Stress Resistance

Many treatments have been used for improving stress resistance of fruits and vegetables at postharvest.

Calcium

There are an increasing number of studies that suggest that calcium plays an important role in the postharvest physiology of fruits and vegetables. Calcium is an essential component of the cell wall structure, to mediate signal responses and regulate a cascade of events in the postharvest physiology of fruits (Aghdam et al., 2012). Calcium chloride 2% combined with pullulan coating reduced brown spot disorder, malondialdehyde (MDA) content, increased antioxidant enzymes activities and inhibited loss of phenolic compounds in pear fruits stored at 0^oC for eight months (Kou et al., 2015). Calcium is extensively used for increasing stress tolerance and as a firming agent. Mahmud et al., (2008) reported that calcium chloride application delayed the ripening or senescence processes and increased the storage life of papaya. Similarly, calcium application reduced anthracnose disease of papaya (Madani et al., 2014b). The combined application of calcium chloride and chitosan reduced the severity of anthracnose disease and maintained the postharvest quality of papaya (Eryani-Raqeeb et al., 2009; Rahman et al., 2009). As shown in Figure 14, weight loss of untreated mango fruits was significantly ($P \leq 0.05$) higher than that of calcium treated fruits after 14 days up to the end of the storage period (Ghulam *et. al*, 2015).

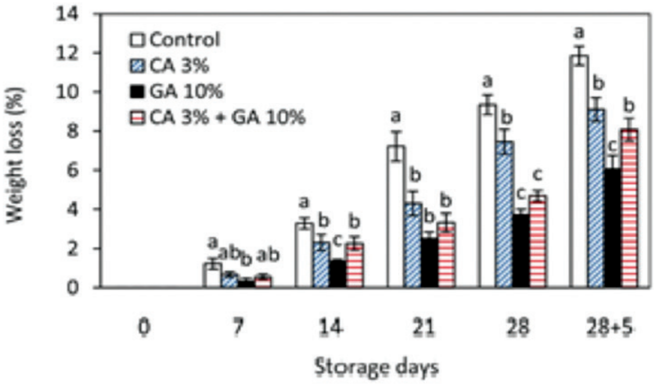


Figure 14 Effects of different treatments on weight loss of mango fruit during storage at 6◦C for 28 days and subsequent transfer to 25◦C for 5 days shelf life. Vertical bars indicate standard error of means for three replicates. Mean values with different letters for each day are significantly different at ($P \leq 0.05$). (Ghulam *et. al*, 2015)

It has been reported that calcium infiltration reduced internal breakdown of pineapple during cold storage (Youryon et al., 2013). Calcium dipping treatments also reduced weight loss, the breakdown of cell wall pectin and improved the quality of strawberry fruits during storage at 4°C (Chen et al., 2011).

At the market level, only products that are acceptable to consumers are appropriate. It is therefore critical to estimate the effects of calcium treatments on the overall quality of fruits and vegetables (Tzortzakis et al., 2007). It is generally found that calcium treatments maintain the overall quality of fruit by maintaining firmness and decreasing fungal spots.

The effects of preharvest application of calcium chloride on ripening, activity patterns of pectin modifying enzymes and overall quality of papaya (*Carica papaya* L. cv. 'Eksotika II') fruits have been investigated by Madani et al. (2014). Foliar sprays of 0, 0.5, 1, 1.5 and 2% (w/v) calcium chloride were applied six times during the growing season and subsequently, the fruits were stored at 12°C for up to three weeks after harvest. The findings showed that calcium concentrations in the peel and pulp tissues increased with the concentration in the sprays. The treatment concentrations also coincided with higher firmness and titratable acidity with reduced respiration rate, ethylene production and soluble solids concentrations, compared with those of the untreated control fruits. This clearly shows that all the ripening processes were positively regulated by the calcium treatments, by delaying them. The overall quality of the fruits treated with calcium pre-harvest was better than that of the control fruits. Additionally, the fruits sprayed with calcium had decreased activities of polygalacturonase (PG) and pectin methylesterase (PME), indicated by delayed ripening during storage. Microscopic results also confirmed that the middle lamellae of the cell walls were more intact in the calcium chloride-treated fruits. In conclusion, calcium application in the field appears to be a useful tool to decrease disease severity and maintain the firmness of papaya fruits.

Edible Coatings

Edible coatings can act as antimicrobials, antioxidants and have the ability to preserve and prolong the shelf life of fresh produce (González-Aguilar et al., 2010). The coatings create a modified atmosphere around the fruits surface by increasing CO_2 and decreasing O_2 concentrations thus, reducing the ripening process by lessening the respiration rate and thus preserving fruit quality (Ali et al., 2011). It has been reported that chitosan coatings effectively delayed the ripening process, reduced weight loss and prolonged the storage life of papaya during cold storage (Ali et al., 2008; Ali et al., 2010). Khaliq et al., (2015), observed that the combined application of gum arabic and calcium chloride reduced colour changes, maintained cell integrity and improved the overall quality of stressed 'Choke Anan' mangos stored at low temperature. Weight loss during storage for gum Arabic coated mangos was also lower compared to other treatments (Figure 15). Further, throughout the storage period, the ripening process was significantly delayed with this treatment. This was indicated by the lower soluble solid concentrations (SSC) during the course of storage. However, one of the setbacks of this treatment was that five days post-storage, SSC was significantly lower than that for the other potential treatment of gum Arabic supplemented with calcium chloride.

Similarly, the combined application of calcium chloride and chitosan enhanced the shelf life and improved the quality of papaya (El Eryani et al., 2008; Mahmud et al., 2010; Rahman et al., 2012). Chitosan coating enriched with essential oils controlled the anthracnose disease in banana and papaya and also improved their quality (Maqbool et al., 2011).

Grading

Modern marketing systems need specific grading standards for each type of fresh produce. Usually, products are manually graded by visual appearance. In more sophisticated marketing, colour is judged by electronic eyes for grading (Dhatt and Mahajan, 2007). For grading tools should have a smooth, soft surface to reduce injuries, for example, when the produce is sorted according to colour, weight and size. In packinghouses, automated weight sizers of different capacities are used.

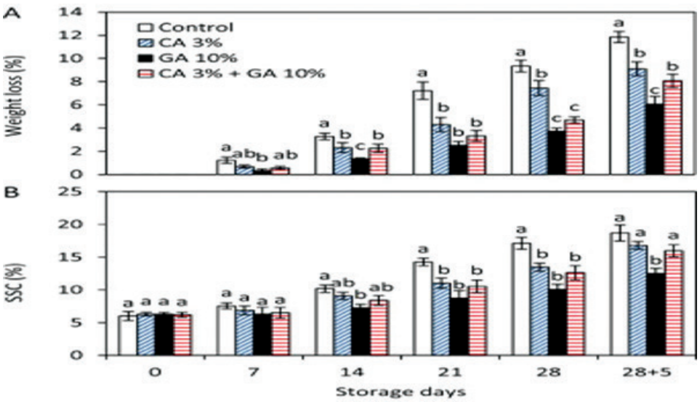


Figure 15 Effects of different treatments on weight loss (A) and soluble solid concentrations (B) of mango fruit during storage at 6 °C for 28 days and subsequent transfer to 25 °C for 5 days shelf life. Vertical bars indicate standard error of means for three replicates. Mean values with different letters for each day are significantly different at ($p \leq 0.05$). (Khaliq et al., 2015)

In Malaysia, Federal Agricultural Marketing Authority (FAMA) regulations on Grading, Packaging and Labelling of Agriculture Products, known as the GPL Regulations, were gazetted on 18th August 2008 (FAMA accessed on 23rd April 2016). The regulations were drafted in accordance with Section 3 (2) (c) of Act 141 which explains the authority of FAMA to undertake the activities of grading, packaging and labelling of agricultural products. The 3P Regulation Draft was also forwarded to the WTO Notification Committee on 24 June 2008 to notify the WTO members about Malaysia's plan to enforce the 3P regulations. This grading is based on the grade specifications found in the Malaysian Standards (MS). Where there is no MS specification available for a particular agricultural produce, it will be based on the grade standard of the country of origin or the grade standard specified by the Board from time to time. At the moment, there are 21 specifications for fresh fruits, 23 for vegetables and two for cash crops.

Packaging

Packaging involves simple units that are easy to handle for marketing and distribution. It is multi-purpose, protects the product against external injuries such as cuts and bruises, improves preservation, provides consumers with information and must be user-friendly. Their shapes and strength can be sustained throughout the supply chain. For long distance transportation, packaging must be waterproof because, under certain conditions, the humidity is almost saturated. The packages must also accommodate the needs of pre-cooling so that the cooling media are able to access the commodities to remove heat which is able to escape continuously. They must also be able to withstand stacking and be attractive to buyers, especially if they are going to be used during display. The materials and shapes depend on the commodity being packed. Users often put economic considerations first when selecting containers for their produce. Impressive containers such as fibreboard boxes, or wooden or plastic crates, are commonly used for high-value products while low-cost packaging materials, such as nylon net sacks or bamboo baskets are used for low-priced products. Currently, biodegradable packaging materials are gaining popularity due to their environmentally friendly characteristics however they are costly.

In Malaysia, use of bamboo baskets is slowly being phased out. This is because of the many disadvantages of this packaging material. It does not have the mechanical strength needed for stacking and it also causes a lot of injuries to the produce, such as cuts, bruises and snapping due to its naturally sharp edges.

Recently, titanium dioxide (TiO_2) has been used in various applications which include the food industry. The TiO_2 nanoparticles of varying concentrations (0–0.11 g/ 100 mL organic solvent) have been coated on food packaging film, particularly low-density polyethylene (LDPE) film (Othman et. al, 2014). The antimicrobial activity of these films was investigated, in terms of their capability to arrest *Escherichia coli,* in an actual food packaging application test under various conditions, including types of light (fluorescent and ultraviolet [UV]) and the length of time the film was exposed to light (one to three days). The antimicrobial activity of the TiO_2 nanoparticle-coated films exposed under both types of lighting was found to increase with TiO_2 nanoparticle concentrations and light exposure time. It was also found that the antimicrobial activity of the films exposed to UV light was higher than that under fluorescent light. The film developed has the potential to be used as a food packaging film that can extend the shelf life, maintain the quality and assure the safety of food.

Precooling

Temperatures play a crucial role in slowing down physiological activity and delaying the senescence of produce. Low temperatures decrease microbial growth rates and the rate of decay. Produce harvested from hot fields have high respiration rate due to field heat and quick removal of field heat by precooling is an effective method for the preservation of quality. Hence, this procedure is extensively used for highly perishable fruits and vegetables where different precooling methods are used, such as forced-air cooling, room cooling, water cooling, package icing and vacuum cooling.
Pre-cooling managed to reduce browning of Kampuchea Guava during storage (Silip and Hajar, 2005). The exposure time in the precooling process depends greatly on the physiological or physical

characteristics of the fruits and anticipated storage temperature (Kuan et Al., 2015). Although several studies found that seven-eighth cooling time is acceptably close to the required storage or transport temperature, this concept cannot be applied to all types of commodities, especially not for chilling sensitive fruit such as bananas. Thus, specificity in pre-cooling techniques and time is required for each individual type of produce.

When using the pre-cooling techniques on tropical produce such as banana, attention should be given to the occurrence of chilling injury. In a study on banana, Kuan et al. (2015) used different forced-air precooling times applied on Musa AAA Berangan to investigate the influence of forced-air precooling time on changes in quality attributes and consumer acceptance. Blackening of peel as a result of chilling injury occurred in the fruits treated with forced-air precooling for 50 and 120 min. This blackening significantly influenced consumer acceptance even though it did not affect the pulp colour and taste.

Storage

Fresh products' shelf life can be prolonged by keeping it at optimum storage temperature, relative humidity and environmental conditions, as well as by application of chemical preservatives (Lee and Kader, 2000). Most horticulture crops have a short shelf life, particularly crops grown in tropical and subtropical regions. Proper storage is thus required to prolong the marketing period.

Abidin et al. (2013) worked on cantaloupe fruits stored for three weeks at 10°C and relative humidity (RH) of 90±5%. In addition, fresh-cut samples were stored for a further 19 days at 2°C and 87% RH. They found that the orange colour and intensity of the flesh did not differ significantly during storage. The good maintenance of the product quality of cantaloupe stored for three weeks at the low temperature indicates potential for fresh-cut processing. Surface coating of N19 (Gandul) and N36 pineapples reduced weight loss and extended storage life by up to 5 and 9 weeks, respectively at 10 ± 1°C, 85-88% RH, as compared to 1 and 5 weeks, respectively, at ambient temperature(Mohamed et al., 1998).

Many storage methods have been used on a commercial scale, including air-cooled storage, refrigerated storage, controlled atmosphere storage and modified atmosphere storage. However, storage management is equally as important as the technique used. Since storage incurs cost, proper planning of suitable storage areas is needed, while the range of temperatures required and arrangement of produce, especially when it involves cross commodities, are equally important.

Postharvest Innovations

The aim of new research in postharvest is to improve facilities, equipment and methods, and to make them more effective, cheap and easily accessible to all stakeholders. To solve specific problems, applied research is probably more productive than fundamental research. In this respect it should be noted that each crop requires different postharvest treatments and so it is essential to develop proper tools and equipment, particularly for each major crop. An area which is urgently in need of new technology is postharvest disease and insect control. Currently, postharvest application of fungicides is decreasing because fungicides are not eco-friendly, create health problems and raise consumer concerns.

Recent findings show that many biocontrol treatments are more efficient than chemicals, such as the use of chitosan for control of anthracnose in papaya (Ali et al., 2011), gum arabic plus calcium chloride for reducing decay incidence in mango (Khaliq et al., 2015) and low dose gamma irradiation with hot water to lessen fungal infection in papaya (Rashid et al., 2015). It has been reported that chitosan coating induced a defence system against diseases and improved the quality of papaya fruits (El Eryani et al., 2008; Ali et al. 2012). Hamizah et al. (2013) on the other hand, observed biological control of postharvest disease through antagonistic yeast to be effective in reducing the severity of anthracnose in papaya.

Currently, one of the best techniques is the use of plastic film packaging to inhibit dehydration, which results in improved quality and extended shelf life for many fruits and vegetables (Mangaraj et al., 2009).

Biotechnology is a new technique that can be used to control deterioration and maintain the quality parameters of harvested products. Lukatkin et al. (2012) suggested that in biotechnological work priority be given to the following areas: (1) nutritional quality, to maintain good flavour, consumers' satisfaction and to induce larger consumption of fresh fruits and vegetables; (2) introduce tolerance to pathogens and physiological disorders in order to decrease the use of chemicals; and (3) adjust the composition of certain produce to inhibit microbial growth.

CONCLUSIONS

Currently, a number of deficiencies are present in postharvest management and processing of fruits and vegetables throughout the world. In order to control the high magnitude of postharvest losses and food waste, action must be taken to upgrade the existing systems. In the present world, where millions of people go to bed without food, it would be a crime to allow the continuation of postharvest losses and food wastes.

It is unfortunate that planners and policy makers only set targets for increasing production without making any effort to control postharvest losses. Investment in crop production on an annual basis is compulsory, whereas, for postharvest operations, only one-off expenditures are required for the establishment of appropriate infrastructural facilities. Proper human resources, logistics and management are necessary to improve the existing postharvest handling techniques and marketing system of fruits and vegetables. Transfer of technologies to farmers should also be properly addressed by the relevant authorities. More funds should be allocated for research and development in postharvest in order to reduce losses and wastage of food. The current world food supply is barely meeting the needs of the increasing population. The natural resources used for creating food are also fast being depleted and contaminated. Controlling postharvest food losses must thus be an integral part of any policy in order to ensure that more food is made available without exhausting the natural environment.

In terms of food security, producing more food is only possible if done in a sustainable manner. It is projected that by 2050, in order to meet increasing demand, there must be an increase in food production of approximately 70% for developed countries, while for developing countries it is projected at 100%. Achieving these figures will be costly, not easy and require resources which are rapidly depleting. Futhermore, given the current magnitude of food losses and wastes, merely producing more food is not an intelligent decision. Food security can be easier, faster and less expensive to achieve through the reduction of postharvest losses and food wastes, rather than by just increasing food production alone. Such a stance will not only increase the availability of quality food, it will also help save our diminishing resources.

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BIOGRAPHY

Mahmud Tengku Muda Mohamed, Ph.D. (Prof.) was born on 20th February 1959 in Singapore. He began his early primary education in Pasir Panjang English Primary School, Kuala Terengganu, from 1966 to 1972, and finished his secondary education at Sultan Sulaiman Secondary School, Kuala Terengganu, in 1976. He then enrolled as a student at UPM Serdang for the 1977/78 session in Diploma of Agriculture and was promoted to the bachelor degree program in the following session. He graduated with a Bachelor's degree in Agricultural Science from Universiti Pertanian Malaysia (presently known as Universiti Putra Malaysia) in April 1982 and in December the same year he was recruited as a tutor in the Department of Agronomy and Horticulture, Faculty of Agriculture, UPM. He obtained his Masters of Science degree in Postharvest Physiology from the Postharvest Laboratory, Department of Horticulture, University of Georgia, Athens, USA, in 1986, and subsequently continued his career as a lecturer in Universiti Pertanian Malaysia till 1992 when he went abroad again to read for his doctorate degree at the University of Nottingham, United Kingdom. He gained his doctorate in Postharvest Physiology in February 1996. He is currently a Professor in the Department of Crop Science, Faculty of Agriculture, UPM. He also plays a role as an expert and resource person in Postharvest Physiology.

Todate, he has contributed 30 years of service to UPM. He has fulfilled almost all the major responsibilities laid on him as a lecturer in UPM and has been engaged in teaching both at diploma, undergraduate and postgraduate levels since his early appointment to the faculty. He began developing his teaching skills as an Agriculturist and Postharvest Physiologist while attached to the Faculty of Agriculture in 1982. He also spent part of his career at UPM Bintulu Campus, from 1987 till 1989, where he was given the opportunity to get involved in management. UPM Bintulu Campus being a branch campus, he was called on to teach diploma students various courses which were outside his area of specialization. While there he handled courses such plant breeding, crop production, oil palm and farm practices. Being an agricultural graduate, he managed to handle the agriculture-based courses with minimum difficulties.

Back in the Serdang campus, however, apart from teaching Plant Physiology, he is also entrusted with other courses which he has manages to handle well. This is reflected in the student assessments where he consistently obtained grades of above 4.0 (80%) for all the courses taught. Apart from teaching, Mahmud Tengku Muda Mohamed has also supervises final year projects and to date 83 undergraduate students have completed their final year projects under his supervision.

The experience gained through research as well as a deep interest in postgraduate works has led him to focus his efforts and contributions to the smooth implementation of postgraduate research programs, through the various management capacities he has served the university. Till present, he has supervised and co-supervised more than 49 postgraduate students of which 28 have completed their M.S and Ph.D. degrees. He has managed to graduate seven PhDs and three Master students as their principal supervisor. As for the year 2016, he is now heading the supervisory committee of two Ph.D. and four M.S. students and also supervising two final year students on their research projects.

As a researcher, postharvest biocontrol and more recently, food safety, are his subjects of interest. Typically, he tailors all his research projects to include postharvest as part of the main research area. He works in various capacities including directing the research plan, coordinating field works and charting the publication of research outputs for his research groups, which include postgraduate students. His untiring efforts are reflected by the intensive publications accumulated by him over the past 10 years.

In total, he has handled and completed 18 research projects during his entire career with UPM. Up till 2016, he has completed nine national funded projects, from KPT (Ministry of Higher Education), MOSTI (Ministry of Science Technology & Innovation Malaysia) and UPM, working on various aspects of postharvest. His research interest on bio control using chitosan based coating agents is a pioneering effort in the country. He is also among the few researchers in the country that work on bio control agents for postharvest treatments. Majority of his Ph.D students graduated working in this area. Many of the findings from his research are new in the Malaysian context and have been published in high impact factor journals. Recently he was awarded a TRGS (MOE) Grant to work on 'Regenerating farmers' income post-flood through sustainable agricultural projects'. He also received the Putra Grant, to work on postharvest handling of soursop. His authority in the Postharvest area has also received some degree of recognition from other local universities through appointment to the panel of experts to design and evaluate their curriculums, i.e. by UMT, UniSZA and UPSI. He has also been appointed as the external examiner of thesis not only by local universities but also by universities abroad. Throughout his engagement in academic activities, he has written and co-authored 72 papers in cited journals, 13 non-cited journals, 57 refereed proceedings, six articles, one country report and two consultation reports. His number of citations from Scopus is h-index 11 with citations of 441 and from Goggle Scholar, h-index 14/i10-index 21 with 554 citations.

Mahmud Tengku Muda Mohamed has participated in various local and international conferences and seminars as well as in exhibitions on research products that portrayed the highlight of his achievements in research. He has also won several medals of different categories from participation in local exhibitions. His expertise and interests have also been generously shared with the Malaysian public while doing extension work in the field or as an expert in outreach clinics. His experience has also gained some recognition from local media where he has been invited to participate in live interactive forums on several topics, e.g. by RTM and Putra FM and the TV talk show, TV1-Malaysia Today.

His proficiency and competence in the postharvest subject area as well as other areas in agriculture is academically recognised and he has been entrusted to referee several papers for journals, including the Editorial Board for Journal of Rubber Research, HortScience, Journal of the Science of Food and Agriculture, Crop Protection, Food Bioscience, Food Biocontrol, African Journal of Biotechnology, Africa Journal of Agricultural Research, International Food Research Journal, International Journal of Biological and Chemical Sciences, Thai Journal of Agricultural Science, Journal of Tropical Agriculture and Food Science and Journal of Tropical Agricultural Science. He has also edited and co-authored proceedings and technical reports that involved his area of expertise and other areas in agriculture. He was also an assessor for MOSTI research proposal applications under the Agriculture category at the university level and Head of Panel (Agriculture) for Putra Grants.

Mahmud Tengku Muda Mohamed also contributes his expertise to relevant government institutions where he has been appointed as member of the Senior Evaluation Panel (Agriculture) for the Malaysian Qualifications Agency (MQA) and Chairman of SIRIM's

Technical Committee for Fresh Fruits (producing Malaysian Standards for Export of Fruits). For the past ten consecutive years he has been appointed by the Malaysian Examinations Council as an examiner of Biology paper 2 for STPM and also, for the past six years, as the chief examiner. He has served in a similar capacity for Matriculation studies. In addition, he is also a panel member in the vetting of STPM and matriculation studies examination questions. Currently, he is the Chairman of the Review Committee for the new STPM Biology syllabus.

As for co-curriculum activities, Mahmud Tengku Muda Mohamed is a member of the International Society of Horticultural Science (ISHS), Malaysian Plant Physiology Society (MSPP), life member of Malaysian Society of Horticultural Science (MSHS) and Academic Officers Society (PPA), UPM, in various capacities. He has also been appointed to serve as chairperson and member of several organising committees for both national and international meetings.

At present, he is serving as Deputy Dean (Post-graduates, Research and Internationalization) at the Faculty of Agriculture in UPM. He was also the former Director and Deputy Director of TPU, Deputy Director of the Centre for Extension, Entrepreneurship and Professional Advancement (APEEC) and Head, Laboratory for Operation of Incubators, Centre for Development of Agro-Entrepreneurs.

He has also been actively involved in several university, faculty and departmental committees on curriculum, research, postgraduate studies, senior officers and safety. He is also an elected university Senate Member.

Mahmud Tengku Muda Mohamed strives for the best in whatever tasks he undertakes and excellence is his ultimate goal. He received the Excellent Service Award from the university in the years of 2000, 2004 and 2014. He has been fairly diligent in his work performance and since 2000, he has consistently been achieving excellent performance status for his services to the department, faculty and university. All these recognitions have inspired him to further elevate himself towards greater achievements in future years as an academician in UPM, in line with UPM's tradition of '*With Knowledge We Serve*'. He is married and blessed with five children and seven grandchildren.

ACKNOWLEDGEMENT

In the Name of Allah the most Beneficent, the Merciful

The ultimate gratitude, devotion and dedication surely belongs to Allah SWT. Alhamdulillah for granting us safe passage through the vicissitude of life to see this day in an excellent state of iman, a'mal and health.

I would like to acknowledge the vast contributions and amazing spirit of teamwork, diligence, sharing and kindness of many wonderful people. The constraints of time and space will however only permit me to show indebtedness to a handful of them as well as some organizations:

- First and foremost I would like to extend my gratitude to the present and past top management of UPM and Deans of Faculty of Agriculture, for their strong support and encouragement;
- My primary and secondary school teachers;
- All my lecturers;
- All my colleagues, especially Assoc. Prof. Dr. Siti Hajar Ahmad (kak Siti), for the mutual respect in our dealings with the ups and downs of Postharvest, particularly during its infancy;
- Dozens of people have helped by contributing at various levels of research work, including co-researchers, research officers, research assistants and most of all, my undergraduate and postgraduate students;
- Sponsors of my R & D work which include UPM, MOHE, MOE and MOSTI; and
- Assistance provided by Management and Professional and Implementation staff at the Department and Faculty is also greatly appreciated.

May I also express my appreciation to my Wok and Mok, both of whom are now Allahyarham and Allahyarhamah, respectively. Even though they left me in my early teens, Alhamdulillah I can still feel their love till today. May Allah SWT rest their souls and also that of my late sisters amongst His pieties.

My deep appreciation also to my wife Zuriah, children Mastura, Muhammad Mu'az, Mutheerah, Ebtisam and Haalah, and grandchildren Hanna, Uwais, Umaira, Sofia, Munjir and Fatimah, for their love, physical and emotional support, patience and understanding in going through the rough terrain of an academician.

May Allah SWT reward and bless us all.

LIST OF INAUGURAL LECTURES

1. Prof. Dr. Sulaiman M. Yassin
   The Challenge to Communication Research in Extension
   22 July 1989

2. Prof. Ir. Abang Abdullah Abang Ali
   Indigenous Materials and Technology for Low Cost Housing
   30 August 1990

3. Prof. Dr. Abdul Rahman Abdul Razak
   Plant Parasitic Nematodes, Lesser Known Pests of Agricultural Crops
   30 January 1993

4. Prof. Dr. Mohamed Suleiman
   Numerical Solution of Ordinary Differential Equations: A Historical Perspective
   11 December 1993

5. Prof. Dr. Mohd. Ariff Hussein
   Changing Roles of Agricultural Economics
   5 March 1994

6. Prof. Dr. Mohd. Ismail Ahmad
   Marketing Management: Prospects and Challenges for Agriculture
   6 April 1994

7. Prof. Dr. Mohamed Mahyuddin Mohd. Dahan
   The Changing Demand for Livestock Products
   20 April 1994

8. Prof. Dr. Ruth Kiew
   Plant Taxonomy, Biodiversity and Conservation
   11 May 1994

9. Prof. Ir. Dr. Mohd. Zohadie Bardaie
   Engineering Technological Developments Propelling Agriculture into the 21st Century
   28 May 1994

10. Prof. Dr. Shamsuddin Jusop
    Rock, Mineral and Soil
    18 June 1994

11. Prof. Dr. Abdul Salam Abdullah
    Natural Toxicants Affecting Animal Health and Production
    29 June 1994

12. Prof. Dr. Mohd. Yusof Hussein
    Pest Control: A Challenge in Applied Ecology
    9 July 1994

13. Prof. Dr. Kapt. Mohd. Ibrahim Haji Mohamed
    Managing Challenges in Fisheries Development through Science and Technology
    23 July 1994

14. Prof. Dr. Hj. Amat Juhari Moain
    Sejarah Keagungan Bahasa Melayu
    6 August 1994

15. Prof. Dr. Law Ah Theem
    Oil Pollution in the Malaysian Seas
    24 September 1994

16. Prof. Dr. Md. Nordin Hj. Lajis
    Fine Chemicals from Biological Resources: The Wealth from Nature
    21 January 1995

17. Prof. Dr. Sheikh Omar Abdul Rahman
    Health, Disease and Death in Creatures Great and Small
    25 February 1995

18. Prof. Dr. Mohamed Shariff Mohamed Din
Fish Health: An Odyssey through the Asia - Pacific Region
25 March 1995

19. Prof. Dr. Tengku Azmi Tengku Ibrahim
Chromosome Distribution and Production Performance of Water Buffaloes
6 May 1995

20. Prof. Dr. Abdul Hamid Mahmood
Bahasa Melayu sebagai Bahasa Ilmu- Cabaran dan Harapan
10 June 1995

21. Prof. Dr. Rahim Md. Sail
Extension Education for Industrialising Malaysia: Trends, Priorities and Emerging Issues
22 July 1995

22. Prof. Dr. Nik Muhammad Nik Abd. Majid
The Diminishing Tropical Rain Forest: Causes, Symptoms and Cure
19 August 1995

23. Prof. Dr. Ang Kok Jee
The Evolution of an Environmentally Friendly Hatchery Technology for Udang Galah, the King of Freshwater Prawns and a Glimpse into the Future of Aquaculture in the 21st Century
14 October 1995

24. Prof. Dr. Sharifuddin Haji Abdul Hamid
Management of Highly Weathered Acid Soils for Sustainable Crop Production
28 October 1995

25. Prof. Dr. Yu Swee Yean
Fish Processing and Preservation: Recent Advances and Future Directions
9 December 1995

26. Prof. Dr. Rosli Mohamad
Pesticide Usage: Concern and Options
10 February 1996

27. Prof. Dr. Mohamed Ismail Abdul Karim
Microbial Fermentation and Utilization of Agricultural Bioresources and Wastes in Malaysia
2 March 1996

28. Prof. Dr. Wan Sulaiman Wan Harun
Soil Physics: From Glass Beads to Precision Agriculture
16 March 1996

29. Prof. Dr. Abdul Aziz Abdul Rahman
Sustained Growth and Sustainable Development: Is there a Trade-Off 1 or Malaysia
13 April 1996

30. Prof. Dr. Chew Tek Ann
Sharecropping in Perfectly Competitive Markets: A Contradiction in Terms
27 April 1996

31. Prof. Dr. Mohd. Yusuf Sulaiman
Back to the Future with the Sun
18 May 1996

32. Prof. Dr. Abu Bakar Salleh
Enzyme Technology: The Basis for Biotechnological Development
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33. Prof. Dr. Kamel Ariffin Mohd. Atan
The Fascinating Numbers
29 June 1996

34. Prof. Dr. Ho Yin Wan
Fungi: Friends or Foes
27 July 1996

35. Prof. Dr. Tan Soon Guan
Genetic Diversity of Some Southeast Asian Animals: Of Buffaloes and Goats and Fishes Too
10 August 1996

36. Prof. Dr. Nazaruddin Mohd. Jali
Will Rural Sociology Remain Relevant in the 21st Century?
21 September 1996

37. Prof. Dr. Abdul Rani Bahaman
Leptospirosis-A Model for Epidemiology, Diagnosis and Control of Infectious Diseases
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38. Prof. Dr. Marziah Mahmood
Plant Biotechnology - Strategies for Commercialization
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39. Prof. Dr. Ishak Hj. Omar
Market Relationships in the Malaysian Fish Trade: Theory and Application
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40. Prof. Dr. Suhaila Mohamad
Food and Its Healing Power
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41. Prof. Dr. Malay Raj Mukerjee
A Distributed Collaborative Environment for Distance Learning Applications
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42. Prof. Dr. Wong Kai Choo
Advancing the Fruit Industry in Malaysia: A Need to Shift Research Emphasis
15 May 1999

43. Prof. Dr. Aini Ideris
Avian Respiratory and Immunosuppressive Diseases- A Fatal Attraction
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44. Prof. Dr. Sariah Meon
Biological Control of Plant Pathogens: Harnessing the Richness of Microbial Diversity
14 August 1999

45. Prof. Dr. Azizah Hashim
The Endomycorrhiza: A Futile Investment?
23 October 1999

46. Prof. Dr. Noraini Abdul Samad
Molecular Plant Virology: The Way Forward
2 February 2000

47. Prof. Dr. Muhamad Awang
Do We Have Enough Clean Air to Breathe?
7 April 2000

48. Prof. Dr. Lee Chnoong Kheng
Green Environment, Clean Power
24 June 2000

49. Prof. Dr. Mohd. Ghazali Mohayidin
Managing Change in the Agriculture Sector: The Need for Innovative Educational Initiatives
12 January 2002

50. Prof. Dr. Fatimah Mohd. Arshad
Analisis Pemasaran Pertanian di Malaysia: Keperluan Agenda Pembaharuan
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51. Prof. Dr. Nik Mustapha R. Abdullah
Fisheries Co-Management: An Institutional Innovation Towards Sustainable Fisheries Industry
28 February 2002

52. Prof. Dr. Gulam Rusul Rahmat Ali
Food Safety: Perspectives and Challenges
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53. Prof. Dr. Zaharah A. Rahman
Nutrient Management Strategies for Sustainable Crop Production in Acid Soils: The Role of Research Using Isotopes
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54. Prof. Dr. Maisom Abdullah
Productivity Driven Growth: Problems & Possibilities
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55. Prof. Dr. Wan Omar Abdullah
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56. Prof. Dr. Syed Tajuddin Syed Hassan
Agro-ento Bioinformation: Towards the Edge of Reality
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57. Prof. Dr. Dahlan Ismail
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58. Prof. Dr. Ahmad Zubaidi Baharumshah
The Economics of Exchange Rates in the East Asian Countries
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59. Prof. Dr. Shaik Md. Noor Alam S.M. Hussain
Contractual Justice in Asean: A Comparative View of Coercion
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60. Prof. Dr. Wan Md. Zin Wan Yunus
Chemical Modification of Polymers: Current and Future Routes for Synthesizing New Polymeric Compounds
9 November 2002

61. Prof. Dr. Annuar Md. Nassir
Is the KLSE Efficient? Efficient Market Hypothesis vs Behavioural Finance
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62. Prof. Ir. Dr. Radin Umar Radin Sohadi
Road Safety Interventions in Malaysia: How Effective Are They?
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63. Prof. Dr. Shamsher Mohamad
The New Shares Market: Regulatory Intervention, Forecast Errors and Challenges
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64. Prof. Dr. Han Chun Kwong
Blueprint for Transformation or Business as Usual? A Structurational Perspective of the Knowledge-Based Economy in Malaysia
31 May 2003

65. Prof. Dr. Mawardi Rahmani
Chemical Diversity of Malaysian Flora: Potential Source of Rich Therapeutic Chemicals
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66. Prof. Dr. Fatimah Md. Yusoff
An Ecological Approach: A Viable Option for Aquaculture Industry in Malaysia
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67. Prof. Dr. Mohamed Ali Rajion
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68. Prof. Dr. Azhar Md. Zain
Psychotheraphy for Rural Malays - Does it Work?
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69. Prof. Dr. Mohd. Zamri Saad
Respiratory Tract Infection: Establishment and Control
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70. Prof. Dr. Jinap Selamat
Cocoa-Wonders for Chocolate Lovers
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71. Prof. Dr. Abdul Halim Shaari
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72. Prof. Dr. Yaakob Che Man
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73. Prof. Dr. Kaida Khalid
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74. Prof. Dr. Hasanah Mohd. Ghazali
Tapping the Power of Enzymes- Greening the Food Industry
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75. Prof. Dr. Yusof Ibrahim
The Spider Mite Saga: Quest for Biorational Management Strategies
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76. Prof. Datin Dr. Sharifah Md. Nor
The Education of At-Risk Children: The Challenges Ahead
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77. Prof. Dr. Ir. Wan Ishak Wan Ismail
Agricultural Robot: A New Technology Development for Agro-Based Industry
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79. Prof. Dr. Aminah Ahmad
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80. Prof. Dr. Abdul Razak Alimon
Challenges in Feeding Livestock: From Wastes to Feed
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81. Prof. Dr. Haji Azimi Hj. Hamzah
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87. Prof. Ir. Dr. Mohd Amin Mohd Soom
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90. Prof. Dr. Norhani Abdullah
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91. Prof. Dr. Abdul Aziz Saharee
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103. Prof. Dr. Jayum A. Jawan
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Palm Oil: Still the Best Choice
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Waste-to-Wealth Through Biotechnology: For Profit, People and Planet
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110. Prof. Dr. Dzolkhifli Omar
The Future of Pesticides Technology in Agriculture: Maximum Target Kill with Minimum Collateral Damage
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111. Prof. Dr. Mohd. Yazid Abd. Manap
Probiotics: Your Friendly Gut Bacteria
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112. Prof. Dr. Hamami Sahri
Sustainable Supply of Wood and Fibre: Does Malaysia have Enough?
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113. Prof. Dato' Dr. Makhdzir Mardan
Connecting the Bee Dots
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119. Prof. Dr. Jariah Masud
Gender in Everyday Life
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120 Prof. Dr. Mohd Shahwahid Haji Othman
Mainstreaming Environment: Incorporating Economic Valuation and Market-Based Instruments in Decision Making
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121. Prof. Dr. Son Radu
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Responding to Changing Lifestyles: Engineering the Convenience Foods
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Aesthetics in the Environment an Exploration of Environmental: Perception Through Landscape Preference
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124. Prof. Dr. Abu Daud Silong
Leadership Theories, Research & Practices: Farming Future Leadership Thinking
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126. Prof. Dr. Jamilah Bakar
Freshwater Fish: The Overlooked Alternative
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127. Prof. Dr. Mohd. Zobir Hussein
The Chemistry of Nanomaterial and Nanobiomaterial
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128. Prof. Ir. Dr. Lee Teang Shui
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132. Prof. Dr. Turiman Suandi
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133. Prof. Dr. Arbakariya Ariff
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134. Prof. Ir. Dr. Desa Ahmad
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