CHAPTER 1

INTRODUCTION

1.1. OVERVIEW TO THE RESEARCH TOPIC

Horticulture, an important branch of agriculture, has the highest potential for export, owing to the wide diversity of horticultural flora, agro-climatic conditions coupled with efficient low cost labour and advantageous geographic locations. India has an edge over other producing countries to expand its export basket. Due to the advance of cultivation technology, the total cultivation areas and yields for agricultural products have increased rapidly in recent years, generating tremendous market values (Saldaña *et al.*, 2013).

According to http://www.apeda.gov.in, the diverse climate in India has ensured the availability of fruits and vegetables and ranks second in fruits and vegetables production in the world, after China. As per National Horticulture Database published by National Horticulture Board, during 2012-13 India produced 81.285 million metric tonnes of fruits and 162.19 million metric tonnes of vegetables. The major destinations for Indian fruits and vegetables are UAE (United Arab Emirates), Bangladesh, Malaysia, UK (United Kingdom), Netherland, Pakistan, Saudi Arabia, Sri Lanka and Nepal.

Among the various food and non-food products being exported, the mango is one of the most consumed fresh fruits in the world, with worldwide production exceeding 45 tons in 2015 (International Trade Centre, 2015). Mango has an established export market and poses bright opportunities for export in the international market whether in fresh or processed forms. Asia, where the mango is native, is the largest mango producer, representing 77 per cent of global production, followed by the Americas with 13 per cent and Africa with 10 per cent (http://www.unctad.info).

Though the above statistics suggests vast potential for India to emerge as a major exporter of mangoes, its share in global market is still very low (~1 per

cent) (Patil and Nirban, 2013). This is mainly due to the very high post harvest losses in handling and processing of the mango fruit along with the mismanagement of trades and procurements, lack of knowledge of preservation and quick quality evaluation techniques. As the ability to consistently produce high quality products is important to the success of horticultural industry, ensuring mango product recognition and quality has become one of the most important and challenging tasks in this field.

One main task during quality inspection and assurance is the detection of defects before marketing and export (Cubero, 2012). Traditionally, quality assurance methods have often relied on human operators who use visual clues in order to determine the quality of the mangoes. These methods are tedious, time consuming and inconsistent (Majidi and Moshiri, 2003). Since, the late 1970s, computer-based image processing technology applied in the agricultural engineering research has become common (Moshashai et al., 2008, Ghaiwat and Arora, 2014).

In particular, the application of machine vision and image processing technologies for the purpose of surface quality of fruits has increased considerably in recent years. This is mainly due to the fact that these systems provide vast improvements in regions where human eye is not sensitive (Lorente *et al.*, 2012). Moreover, the usage of computer vision and image processing algorithms simplifies the tedious and subjective industrial quality control procedures.

However, the automated inspection of agricultural production has some peculiarities and problems that other sectors of industrial production do not have, due to the biological nature of the products inspected. While manufactured products often exhibit similar colours, shapes, sizes and other external features, fruits and vegetables show a wide variety of characteristics. A fruit may show a different colour, size and shape from another, even if collected on the same day from the same tree. Food products naturally evolve

in colour or texture after harvesting and these characteristics depend on their maturity and their storage conditions (humidity and temperature, fungal infections, presence of volatile substances, storage duration, etc.). In addition, the colour of a particular area of the skin of a healthy fruit can match the colour of a spot on the surface of another fruit of the same variety. Moreover, it is essential to detect the presence of stems, leaves, dirt or any foreign material on quality control lines and not confuse these with other skin blemishes.

All these factors greatly complicates the development of algorithms capable of extracting quality decisions from image analysis, especially taking into account the fact that markets demand very fast image processing to achieve commercial production. As the market constantly requires higher quality products and consequently, additional features have to be developed to enhance machine vision and image analysis systems for quality inspection. This research in an attempt to aid this demand is focused on developing automated external skin defect detection system for mangoes using computational intelligence and machine learning techniques. This chapter provides the introductory materials related to mangoes along with details regarding the various defects. The problem statement along with the research objectives is also presented.

1.2. MANGO – THE KING OF FRUITS

Mango is an important fruit crop in India and popularly called the 'king of fruits'. India has the richest collection of mango cultivators. Cultivation of mangoes is deeply embedded in Indian history. Mangoes are mentioned in early Arialkrit literature. Mangoes are widely available year-round, as fresh fruit and in frozen and processed foods (Wua *et al.*, 2014). Mangoes thrive in tropical regions and are cultivated throughout India and even in home yards, along field boundaries and roadside avenues.

1.2.1. Origin of Mango

As mentioned earlier, mango belongs to the family Anacardiaceae, also known as the cashew family and consists of 62 species in the genus of which 15 are edible fruits (Snyman, 1998a). Mango previously was assumed to have originated from India, but now have been discovered to have originated from the Burma-Malaysian region (Popenoe, 1920, Samson, 1986).

It has been grown in India for more than 4000 years. From India, mango was disseminated to Africa, Asia, Australia and rest of the world by sailors, traders and missionaries (Kwee and Chong, 1985).

The Portuguese were the first Europeans to establish trade routes with India, transporting mangoes from East Africa and Brazill. Spanish traders took these fruit from the Philippines to the West Coast of Mexico before the English arrived on the Hawaiian Island in 1778. Since then, mango has been introduced into every tropical and subtropical country around the world (Nakasone and Paull, 1998).

1.2.2. Botanical Description

The botanical name of mango is *Mangifera indica*, where, the first word Mangifera refers to the genus and the second word indica to the species (Silva-Bedoya *et al.*, 2014). Biologically, it is closely related with other flowering plants like cashew and pistachio. It is a large, branched perennial erect tree with wide evergreen crown which attains a great height (Figure 1.1).

Flowers appear in large terminal inflorescences producing fruit. The skin of the fruits comes with different colors depending upon the variety of the fruit. The fruits have a small point at one end, known as the beak. The seed within the fruit is large and flattened. A mango tree is medium to large in height, evergreen with symmetrical, rounded canopy ranging from low and dense to upright and open. A single mature mango tree can produce 2000 to 2500 ripe fruits (Jiron and Headström, 1985).

Figure 1.1 : Mango Tree (*Mangifera indica*)

Mangoes vary in shape (nearly round, oval, ovoid-oblong), size and color, depending upon the variety. Ripe Mangoes may be greenish, greenish-yellow, yellow, red, orange, or purple and weigh from a few ounces to more than 5 pounds (2.3 kg). The skin is smooth and leathery, surrounding the fleshy, pale-yellow to deep-orange edible portion. The fruits possess a single large, flattened, kidney-shaped seed that is enclosed in a woody husk. Some examples are shown in Figure 1.2.

Figures 1.2 : Different Colored Mangoes

The phenological growth of mango in Tamil Nadu, India, consists of five stages. They are budding stage, leaf and shoot development stage, inflorescence emergence and flowering stage, fruit development stage and fruit maturity and harvesting stage. The mature fruit is the stage at which the fruit is

ready for harvesting. This stage is reached when the flesh is still quite firm and has not become juicy but has started coloring around the seed. The ripe fruit is sthe fruit at the stage ready for harvesting and consumption. This stage is reached when the fruit is juicy and has become colored. It is at this stage when the quality assessment is performed and is the focal point of this research.

1.2.3. Uses of Mango

The fruit is very popular with the masses due to its wide range of adaptability, high nutritive value, richness in variety, delicious taste and excellent flavour. The fruit is consumed in both forms raw and ripe. It is a rich source of vitamin A and C. Good mango varieties contain 20 per cent of total soluble sugars. The acid content of ripe desert fruit varies from 0.2 to 0.5 per cent and protein content is about one per cent. The mango kernel also contains about 8-10 per cent good quality fat which can be used for saponification. Its starch is used in confectionery industry.

It is a commonly used herb in ayurvedic medicine. It has several health benefits as listed below (http://www.care2.com).

1. **Prevents Cancer:** The antioxidant compounds in mango fruit have been found to protect against colon, breast, leukemia and prostate cancers.
2. **Lowers Cholesterol:** The high levels of fiber, pectin and vitamin C help to lower serum cholesterol levels, specifically Low-Density Lipoprotein
3. **Clears the Skin:** Can be used both internally and externally for the skin. Mangos clear clogged pores and eliminate pimples.
4. **Eye Health:** One cup of sliced mangoes supplies 25 percent of the needed daily value of vitamin A, which promotes good eyesight and prevents night blindness and dry eyes.
5. **Alkalizes the Whole Body:** The tartaric acid, malic acid, and a trace of citric acid found in the fruit help to maintain the alkali reserve of the body.

6. **Helps in Diabetes:** Mango leaves help normalize insulin levels in the blood.
7. **Improves Digestion:** The fiber in mangos also helps digestion and elimination.
8. **Improved Sex:** Mangos are a great source of vitamin E, which can improve sex drive.
9. **Remedy for Heat Stroke** : Juicing the fruit from green mango and mixing with water and a sweetener helps to cool down the body and prevent harm to the body.
10. **Boosts Immune system** : The generous amounts of vitamin C and vitamin A in mangos, plus 25 different kinds of carotenoids helps to keep the immune system healthy and strong.

1.2.4. Varieties of Mangoes

The number of different mango cultivars in India is estimated between 500 and 1,000 (Koley *et al.*, 2011). Figure 1.3 and Table 1.1 present some famous mango varieties available in India. Hybrid varieties like Mallikka, Amrapali, Ratna (Neelam X Alphonso) are also available in the market. A partial list of some hybrid varieties mangoes are shown in Figure 1.4 and Table 1.2. Some of the other hybrid varieties are Alfazali, Sundar Langra, Sabri, Jawahar, Neelphonso, Neeleshan, Neeleshwari and PKM2. Among the different varieties, this research work considers four types, namely, Alphonsa, Neelam, Banganapalli and Sendura are considered in this research work. These varieties were chosen because of easy availability.

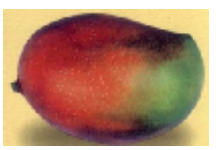
Alphonso 	**Bangalora** 	**Banganapalli** 	**Bombay Green** 	**Chaunsa** 
Dasehri 	**Dashehari** 	**Fajri** 	**Fernandin** 	**Himsagar** 
Kesar 	**Kishen Bhog** 	**Langra** 	**Mulgova** 	**Neelam** 
Sendura 	**Suvernarekha** 	**Vanraj** 	**Zardalu** 	**Totapuri** 

Figure 1.3 : Varieties of Mangoes

TABLE 1.1

VARIETIES OF MANGOES

S. No.	Name	Description
1	Alphonso	This is the most expensive variety of mangoes in India. Maharashtra, Gujarat and Karnataka are its prime producers. It has a fibreless pulp and douses into the mouth as a smooth-creamy mango. This variety of mango is popular all over the world
2	Bangalora	The fruit is medium-large, oblong shaped with pointed base with golden yellow colour. Used for processing; heavy and regular bears variety.
3	Banganapalli	These mangoes have a very beautiful yellow color and are sweet and fibreless. It is the most popular variety of mangoes which comes straight from Andhra Pradesh.
4	Bombay Green	Fruit size is medium, shape ovate oblong with spinach green colour. Biennial in habit highly susceptible to both vegetative and floral malformation.
5	Chaunsa	The name was given by the Muslim Suri Emperor Sher Shah Suri. It is sweet, juicy and very nutritious. It is mostly grown in the northern parts of India.
6	Dasehri	It is the oldest variety of Mangoes in India, since its origin can be traced back to almost 200 years ago. Uttar Pradesh is the largest producer of this variety of mangoes.
7	Dashehari	Best varieties of the country. Fruit size is small-medium, shape is elongated with yellow fruit colour. Flesh is fibreless. Mainly used for table purpose.
8	Fajri	Fruit is very large, obliquely oval in shape. Fruit colour is light chrome.
9	Fernandin	Fruit shape is oval to obliquely oval and yellow in colour with a blush of red on shoulders. Mostly used for table purpose.
10	Himsagar	Fruit is medium sized ovate fruit with yellow colour. Early season variety and mostly used for table purpose.
11	Kesar	This variety of mangoes is precisely consumed raw or used for making Aamrus. It comes from the Ahmedabad region of Gujarat and thus is also known as the Gujarat Kesari. It has a very intense aroma

12	Kishen Bhog	Fruit is medium oval oblique with yellow colour. Keeping quality is good. Bearing heavy.
13	Langra	The mother tree of this variety exists in Varanasi. Since the owner of that tree was unfortunately lame, the mango was thus named as "Langra". This variety is distinctively fibrous, with a unique taste as well. It is majorly grown in Haryana, Bihar, Uttar Pradesh and West Bengal.
14	Mulgova	Fruit is large roundish-oblique in shape and yellow in colour.
15	Neelam	This is one variety that grows throughout the country. With its specialty in Hyderabad, it is a large-yielding variety of mangoes.
16	Sendura	Its reddish color at the top has entitled this variety with the name of Sendura. Extremely juicy and pulpy.
17	Suvernarekha	Fruit is medium ovate oblong fruit, green in colour with prominent red blush on the shoulders. Bearing is heavy.
18	Vanraj	Fruit is medium, ovate oblong in shape with a blush of jasper red on the shoulders; good keeping quality.
19	Zardalu	Fruit size is medium, oblong to obliquely oblong and golden yellow in colour.

Amrapalli 	**Arka Anmol** 	**Arka Aruna** 	**Arka Neelakiran** 	**Arka Puneet** 
Au Rumani 	**Malika** 	**Manjeera** 	**Ratna** 	**Sindhu** 

Figure 1.4 : Hybrid Mangoes

TABLE 1.2

HYBRID VARIETIES OF MANGO

S. No.	Name	Description
1	Amrapali (Dashehari X Neelam)	Dwarf, regular bearing and late maturing variety. Suitable for high density planting. Flesh is fibreless. (X refers hybrid variety of mangoes).
2	Arka Anmol (Alphoso x Janardhan Pasand)	This hybrid is from a cross of Alphonso and Janardhan Pasand. It is regular bearer and good yielder. Fruits are medium sized having uniform yellow peel colour and free from spongy tissue.
3	Arka Aruna (Banganapalli X Alphonso)	Fruits are oblong and skin is thin, rough and dull yellow in colour with slight red blush. Pulp is soft, pale yellow in colour. Free from spongy tissue and fiber.
4	Arka Neelkiran (Alphoso x Neelam)	Tree is semi-vigorous in nature. Fruit is elliptical, medium size golden yellow in colour, average weight 270-280g. Free from fiber and spongy tissue.
5	Arka Puneet (Alphoso x Banganpalli)	It is a hybrid between Alphonso and Banganpalli. It is regular and prolific bearer. Fruits are medium sized having attractive skin colour with red blush and free from spongy tissue.
6	Au Rumani (Rumani x Mulgoa)	It is from a cross of Rumani and Mulgova. It is precocious, heavy and regular bearing with large fruits having yellow cadmium skin colour.
7	Malika (Neelam X Dashehari)	Fruit is large, oblong elliptical yellow in colour. Keeping quality is good and is mostly used for table purpose
8	Manjeera (Rumani x Neelam)	This hybrid is from a cross of Rumani and Neelam. It is dwarf, regular and prolific bearer with firm and fibre less flesh.
9	Ratna (Neelam X Alphonso)	Tree moderately vigorous, precocious. Fruits are medium sized, attractive in colour and free from spongy tissue
10	Sindhu (Ratna back-crossed with Alphonso)	Fruits are medium sized, fibreless, free from spongy tissue with high pulp to stone ratio and very thin and small stone.

1.3. QUALITY AND DEFECTS

Exports form the most important source of foreign exchange for developing countries. All developing countries, including, India strive to increase their exports as a means for mobilizing resources for their development plans. Increase in export can be envisaged only when high quality of product being exported is maintained. Losses due to low quality are estimated to be around 20-40% in developing countries and 10-15% in developed countries, depending on the food product. It is estimated that more than four billion dollars is lost due to postharvest losses and reduced quality of fruit (Koley *et al.*, 2014). Thus, quality control and improvement has become an imperative fact during fruit marketing and export. The main causes of degraded quality are physiological (wilting, shriveling, chilling injury, etc), pathological (decay due to fungi and bacteria) and physical (mechanical injury).

Mango fruits are rejected due to various reasons that damage the fruit, which may occur during different phases of growth, distribution and retail chain. Damage is defined as any defect that materially affects the appearance, or the edibility quality of the mango. Consumers purchase fruits on the basis of quality. Quality of mango fruit is an important subject and is defined as 'the degree of excellence or superiority". It is a combination of characteristics, attributes and properties that have significance and make for acceptability. Acceptability is dependent on highly subjective factors including sight, touch, smell and taste. The various components of quality are used to evaluate mango fruit.

Depending on the quality of the fruit, it belongs to either Extra Class or Class I or class II category (Bhushan *et al.*, 2013). Mangoes in Extra Class are of superior quality. For a mango to belong to this class, they must be

- characteristic of the variety

- Free from defects with the exception of very slight superficial defects, provided these do not affect the general appearance of the fruit and its quality during package.

Mangoes in class I must be of good quality. Again, all these mangoes must be characteristic of the variety. However, the following slight skin defects in shape and defects due to rubbing or sunburn, suberized stains due to resin exudation (elongated trails included) and healed bruises not exceeding 3, 4, 5 cm^2 are allowed.

Class II includes mangoes, which do not qualify for higher grades. However, the following skin defects in shape, slight defects, due to rubbing or sun burn and bruises not exceeding 4,5,6,7 sqcm.

All mangoes which do not fall in the mentioned class and which satisfy the minimum requirements as listed below are satisfied.

- Whole, clean, firm and fresh in appearance
- Sound, produce affected by rotting or deteriorate on such as to make it unfit for consumption is excluded;
- Free of
    - any visible foreign matter
    - damage caused by pests;
    - abnormal external moisture, excluding condensation following removal from cold storage;
    - foreign smell and/or taste;
    - damage caused by low temperatures;
    - black necrotic stains or trails;
    - marked bruising
- Sufficiently grown with satisfactory ripeness.

The following defects, however, are allowed, provided the mangoes retain their essential characteristics as regards to the quality.

a. defects in shape;
b. skin defects due to rubbing or sunburn, suberized stains due to resin exudation (elongated trails included) and healed bruises not exceeding 5, 6, 7 cm².

In Classes I and II, scattered suberized rusty lenticels, as well as yellowing of green varieties due to exposure to direct sunlight, not exceeding 40 per cent of the surface and not showing any signs of necrosis are allowed. Tolerances in respect of quality and size shall be allowed in each package for produce not satisfying the requirements of the class indicated.

With Extra Class Mangoes, five percent by number or weight of mangoes not satisfying the requirements of the class, but meeting those of Class I come within the tolerances of that class. With Class I mangoes, ten percent by number or weight of mangoes not satisfying the requirements of the class, but meeting those of Class II come within the tolerances of this class. With Class II mangoes, ten percent by number or weight of mangoes satisfying neither the requirements of the class nor the minimum requirements, with the exception of produce affected by rotting, marked bruising or any other deterioration renders it unfit for consumption.

Quality of mango fruit is classified into external and internal component (Table 1.3). Appearance, flavor, texture, nutritive value and defect factors are generally recognized as five quality factors of mango fruit during inspection and quality control. As traditional imaging techniques cannot provide enough information for detecting internal defects (Mittal, 1997; Throop *et al.*,1989) and as devices like Nuclear Magnetic Resonance (NMR), ultrasonic and X-ray imaging techniques have the potential, they are generally used to detect internal defects in mango. These devices have the advantage of making almost all internal defects visible and therefore are widely used during quality control. External defects, on the other hand, are visible to human eyes and occur on the skin surface of the mango fruit and hence are also referred to as skin or surface

defects. Example of external and internal defect in mangoes is shown in Figure 1.5. As this research work is more oriented towards identifying external defects, it is explained more in the following paragraphs.

TABLE 1.3

COMPONENTS OF QUALITY FOR MANGOES

External Qualities		Size(Weight, Volume, Dimension)
Internal Qualities	Flavor	Sweetness, Sourness, Astringency, Aroma
	Texture	Firmness, Crispness, Juiciness
	Nutrition	Carbohydrates, Proteins, Vitamins, Functional Property
	Defects	Internal Cavity, Water Core, Frost Damage, Rotten

Internal Defect **External Defect**

Figure 1.5 : Defect Categorization

External defects or damages may be caused either due to fruit decomposition or poor handling of the fruit. According to Mango Defect Guide (2014), the common external defects caused due to the decay of fruits are listed below.

i. **Stem end rots** : Stem end rots are fast-growing watery soft rots that penetrate deep into the mango flesh. They appear as grey-brown or black without any spores. An example is shown in Figure 1.6a.

ii. **Dendritic spots** : Dendritic spot defect in mango appears as small black spots with irregular edges. The rot is slow growing and does not penetrate deep into the flesh. An example is shown in Figure 1.6b.

iii. **Anthracos** : This defect is found either near the stem (stem end anthracos) or in the body (body anthracnose). Body anthracnose appears as a black rot, usually rounded and slightly sunken. It appears on the body of the fruit (surface) or around the stem. The rot does not penetrate deep into the flesh. On the other hand Stem end anthracnose type of defect is present as pink spores when the rot is advanced. An example is shown in Figure 1.6c.

iv. **Sapburn** : Sapburns are dark brown spots and blotches, which are often slightly sunken in the surface of mango. It can appear around the stem or body of the mango fruit. An example is shown in Figure 1.6d.

v. **Skin browning**: This defect comes in two forms. The first is abrasion and the second is sap. Abrasions are defined as fine brown scratches or rub marks. Saps on mango surface are light to dark brown flecking spots, blotches, smears or rings. An example is shown in Figure 1.6e.

vi. **Lenticel spots**: These defects are present as round or star shaped brown spots scattered over the skin of mango. An example is shown in Figure 1.6f.

Poor or rough handling of fruits during packaging and transporting is a critical factor that reduces the skin quality of mangoes. Improper or inefficient storage also reduces the quality of mangoes (http://www.fruitprofits.com). Apart from the above, other defects, like bruise, blemishes, russets and shrinks are also found in the surface or skin of mangoes.

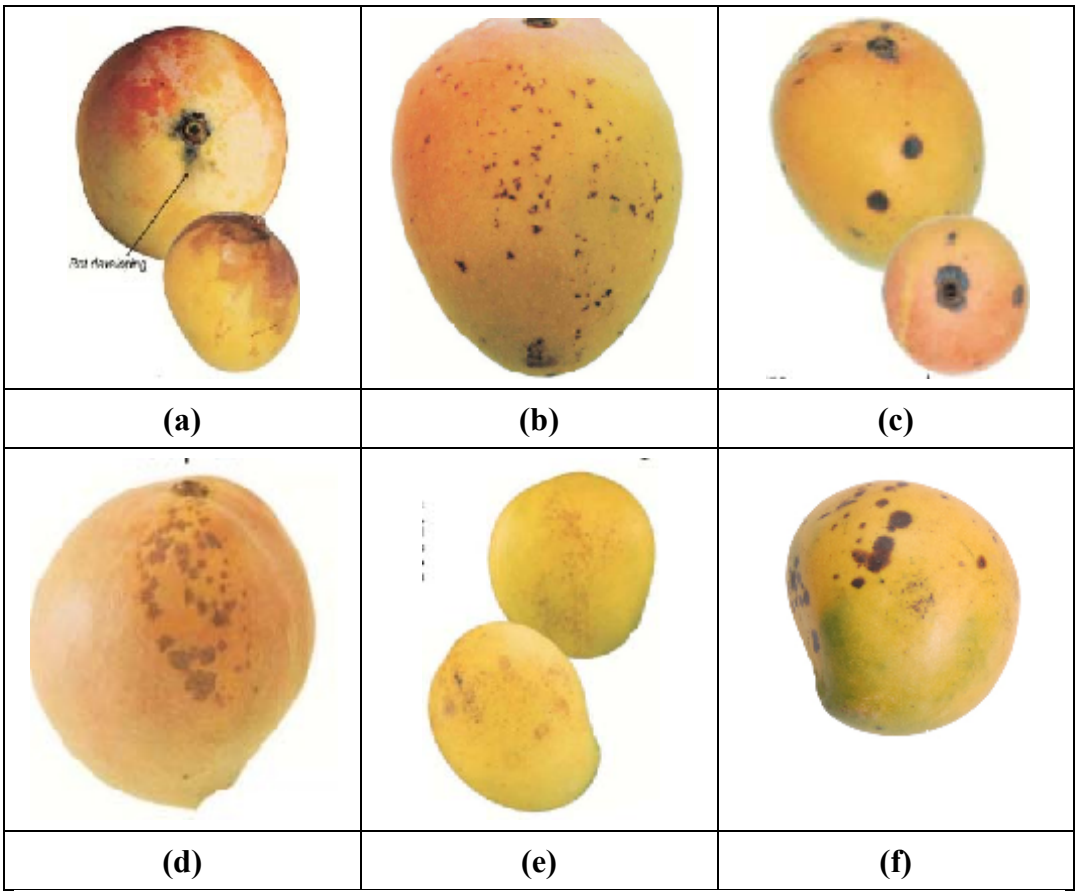


Figure 1.6 : External Defects Caused by Decay of Mango Fruit

All the above defects are external defects, which affect the quality of mango skin. Although much progress has been made in fruit automatic grading worldwide, the detection of fruit surface defects is considered as the most difficult task and has become of the limiting factors of automated grading systems (Sun *et al.*, 2011; Blasco *et al.*, 2003). Thus, the current requirement of the market is for automated systems that improve the process of quality control by identifying various skin surface defects that degrade the quality of mangoes.

A typical Automatic Defect Detection System (ADDS) consists of various tasks that are grouped into four main steps, as listed below.

(i) Image acquisition
(ii) Preprocessing
(iii) Segmentation

(iv) Feature extraction

(v) Defect detection

All these steps aim to improve the accuracy and speed of defect detection and use variety of technologies like image processing, pattern recognition and machine learning algorithms.

1.4. MOTIVATION AND RESEARCH OBJECTIVES

Consumer satisfaction with product quality is the main objective of the production, handling, storage and distribution of fresh horticultural produce. Consumers primarily judge fruit quality based on appearance and even a moderate amount of defect on the fruit surface can reduce consumer acceptance (Figure 1.7).

Figure 1.7 : Moderate Defects in Mangoes
(Source : www.docstoc.com)

With the long marketing chain of many fruit and vegetables that is currently in place, surface (physical) defects is a common problem (Sablani *et al.*, 2006) and is considered as the major contributing factor for the downgrading and post harvest loss of fresh mango produce (Opara, 2007). India being an agricultural country, exports a huge quantity of fruits abroad. But still 40 per cent produce is wasted for want of facilities for preservation and processing (http://nhb.gov.in). The fruits have to be graded before being packed and sent to the international market for pricing. As manual process is slow and could be error prone, automated defect detection systems are desired.

According to Kader (2002), visual quality plays a vital role (up to 83 per cent) in consumer choice and it is highly affected by the presence of defects. In another study, surface defect was found to be a more important barrier to purchasing than price (Harker, 2009). The presence of surface defects and damages like cuts, puncture, split and abrasion causes significant economic loss of fresh produce resulting in downgrading quality factor or rejection of the fruit by the consumer (Van Zeebroeck *et al.*, 2007c; Prusky, 2011).

The presence of skin defects is one of the most influential factors in the price of fruit. The detection of defects during packing operations ensures that only fruits with a good quality reach the market. At the present time, fruit with slight defects is marketed together with sound fruit, thus depreciating the quality of the batch or it is removed together with seriously damaged fruit, thereby causing economic losses.

Quality control is a major concern worldwide as it can cause significant reduction in the quantity of agricultural products (Weizheng *et al.*, 2008) and has a negative influence on the countries that primarily depend on agriculture in its economy (Babu and Srinivasa Rao, 2010). Von Witzke *et al.* (2008) demonstrated that the worldwide demand for agricultural products exceeds the supply. Hence, there is an urgent need to manage the worldwide production of agricultural commodities, especially vegetables and fruits, more efficiently. The potential yield of vegetables and fruit is affected by different stresses (e.g. pest, nutrition deficiencies, duration, packing material used), which can reduce the production capacity and quality.

Existing ADDS still have many issues that need to be solved. The challenges faced by them are listed below.

- Many defects are very small and indistinguishable and therefore are very difficult to detect (Kerruish and Walkington, 2006). In some cases, the defect size and skin color are similar, thus increasing the false acceptance / rejection rates of the system.

- The influence of light reflection of different curvatures on fruit surface, seems to be noise that reduce the efficiency of the Automatic Defect Detection System (ADDS)

- Lack of tools that operate efficiently on the extremes of three requirements simultaneously high accuracy, scalability and high speed

Thus, to answer the various challenges present in the existing systems, this research work proposes techniques that aim to design and develop an ADDS with the following primary objective.

> "To design and develop an Automated External Skin Defect Detection System for Mangoes (AESDDM) by using computational intelligence techniques and machine learning techniques to identify the surface or skin defects in mangoes in an accurate and time efficient manner"

In order to achieve this primary objective the following secondary objectives were formulated.

- To improve the quality of the mango images using denoising methods to reduce the impulse noise for further processing.
- To perform clustering based segmentation on mango images to segment the defected regions.
- To perform feature extraction techniques to identify and extract characteristics that represents a mango image for quality classification.
- To design and develop classification model that uses the features extracted to detect the defects.

1.5 LAYOUT OF THE CHAPTERS

The underlying objective of this research work is to develop an automatic defect detection system to identify defective and defect free mangoes. This chapter presented introduction to various aspects of the fruit

mango along with research objectives. The rest of the dissertation is organized as below.

The literature review is a critical look at the existing research that is significant to the work that is carried out. In case of fruits and vegetables, several researchers have addressed the problem of defect detection. A critical look at the various available literatures related to the present research work is given in **Chapter 2, Review of Literature**.

Chapter 3, Methodology, presents the research methodology and identifies the different steps of AESDDM. The various methods and techniques used are briefly explained in this chapter. **Chapters 4 (Preprocessing Algorithm)** presents detailed description on the proposed noise removal algorithm to enhance the quality of the mango fruit image. **Chapter 5 (Segmentation Algorithm)** presents the proposed algorithm that groups similar regions into segments. **Chapter 6 (Feature Extraction and Defect Detection)** has description of the features surface features extracted and used to detect external skin defects in mangoes.

Chapter 7, Results and Discussion, tabulates and discusses the various results obtained while testing the proposed algorithms. The findings of the study are summarized along with future research directions in **Chapter 8, Summary and Conclusion**. The work of several researchers are quoted and used as evidence to support the concepts explained in this dissertation. All such evidences used are listed in the **Bibliography** of the dissertation.

1.6. CHAPTER SUMMARY

This chapter provided a brief introduction to the fruit mango, the various defects that reduce its external quality and the basic steps during defect detection. The research objectives formulated were also outlined. To achieve the objectives outlined in this chapter, a review of the previous research work was studied and the scrutinized works are summarized in the next chapter, Review of Literature.