Centre of Excellence AGROPHYSICS
for Applied Physics in Sustainable Agriculture

Handling of Apple

transport techniques and efficiency
vibration, damage and bruising
texture, firmness and quality

Bohdan Dobrzański, jr.
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PREFACE

Based on experience and results of scientific cooperation between B. Dobrzański Institute of Agrophysics of Polish Academy of Sciences in Lublin and Research Institute of Pomology and Floriculture, which is located in Skierniewice, the authors prepared the monograph on Handling of Apple, transport techniques and efficiency, vibration, damage and bruising, texture, firmness and quality. This is a book following the monograph "Sweet Corn, Harvest and Technology, Physical Properties and Quality" previously printed in 2005 in the frame of activity of Work Package 9 (WP9). WP9 - Physical Methods of Evaluation of Fruit and Vegetable Quality is leaded by prof. dr. eng. Bohdan Dobrzański, jr., who is also a co-author of this work. The authors are grateful to the 5th EU Framework for Research, Technological Development and Demonstration Activities, which founded the Centre of Excellence (CE) for Applied Physics in Sustainable Agriculture with the acronym Agrophysics and especially to dr. eng. Andrzej Stępniewski – a coordinator of CE, who prepared this project excellent, being a person responsible for positive reviewer's opinion and the acceptance of the Commission of EU. We also owe thanks and appreciation to Director of the Centre - prof. dr. Ryszard T. Walczak, a member of Polish Academy of Sciences, who made the opportunity of editing several monographs, including presented herein work.

This is a book about apple. Apple is a tree and its pomaceous fruit, of species *Malus domestica* Borkh. in the rose family Rosaceae, is one of the most widely cultivated tree fruits. There are more than 7,500 known cultivars of apples. Different cultivars are available for temperate and subtropical climates. 48 million tons of apples were grown worldwide in 2001, while in following years world total production decreased to 42 million tons of apples in 2005. China produced almost half of this total. The United States is the second leading producer. Poland is also a leading producer reaching more than 2.4 million tons of apples.

In chapter 1, the authors describes botanical origin of apple and quality characteristics, health benefits, production and uses, beginnings of apple cultivation and the World's leading producers and exporters of fresh and processed apples. The overview covers market trends and development, the market in majors producers as China, U.S., Poland, Germany, France, and Argentina. Production, supply and demand consumption and trade, as well as, directions of use and nutritional value of apple are also presented. Harvesting and handling apples fulfil chapter 2. In detail is described: harvesting, packaging and transportation, harvest maturity, apple maturity indices, preparing the orchard for harvest, mechanical and physiological disorders, bruising, storage (optimum storage conditions, and apple varieties recommended for CA storage). In chapter 3, readers can find characterization of transport techniques and vehicles used in orchard and storage.

Efficiency of the transport techniques and vehicles used in orchard, the methods of efficiency estimation in transport techniques, economic evaluation of transport technologies, costs and fuel consumption are submitted in chapter 4. In chapter 5 are described factors affecting damages in transport of apples, procedures of study effect of transport on apple damage, vibrations, fruit accelerations in bin as a consequence of vehicle vibrations, effect of vehicle type and driving speed on fruit damage, fruit position in the bin on the extent of damage and damage classification of apple. Physical methods for fruit quality evaluation, non-destructive measurements, physiological basis of texture, sensory evaluation of texture, mechanical properties related to fruit firmness, instrumental measurement of texture and firmness, are presented in chapter 6 "Fruit quality and texture".

Quality properties of apple are presented in chapters 7. The results of the measurements of size, shape and weight, mechanical parameters of apple, apple firmness (background for the study of firmness), friction between apple and flat surfaces are included in subchapters 7.1. to 7.5. In following subchapter 7.6. - color of apple and in subchapter 7.7., a nutritional value of apple is described. Transport requirements for apples (product information, packaging, risk factors and loss prevention) are presented in chapter 8. In chapter 9 are printed European Communities Regulations and Standards for Apples covering Commission Regulation (EC) No 85/2004 of 15 January 2004. In this regulation, Annex includes definition of produce, quality, sizing, tolerance, presentation, marking, while Appendix presents colouring, russeting, size criteria and the apple varieties, listed in table, which are classified according to their colouring, russeting and size criteria.

The quality of fruits for direct consumption depends not only on correct technology of their production. In spite of the high quality of apples grown in Polish orchards, fruits offered to the consumer, due to incorrect handling, sometimes lack in their appearance (Pieniążek, 1981). Proper utilization of fruits after harvest is – according to that author – the most important problem of Polish fruit farming. The first post-harvest operation that has an effect on the quality of fruits is their transport from the orchard to the storage facility. Rapid loading on refrigeration chambers and refrigeration of fruits (within 3-4 days) is one of the fundamental conditions of correct storage of apples in controlled atmosphere (Lange, Ostrowski, 1992). However, to ensure smooth loading of refrigeration chambers one has to deliver the harvested fruits to the storage facility rapidly and efficiently. This requires the use of efficient methods and means of transportation.

Texture measurement has become widely accepted by horticultural industries as a critical indicator of non-visual aspects of quality. The ability to measure texture has allowed industries to set standards for quality at pack-out and to monitor deterioration in quality that occurs during storage and distribution. Furthermore, the study of the chemical, physiological, and molecular changes that control and/or influence texture has been underpinned by the development of methods for quantifying texture change. Much of the commercial and research interest in texture has focused primarily on the mechanical properties of the tissues. The diversity of tissues involved, the variety of attributes required to fully describe textural properties, and the changes in these attributes as the product ripens and senesces contribute to the complexity of texture measurement. This complexity of texture can still only be fully measured by sensory evaluation, which involves using a panel of assessors that have been trained to score defined attributes against a set of standards. However, instrumental measurements are preferred over sensory evaluations for both commercial and research applications because instruments are more convenient to use, widely available, tend to provide consistent values when used by different (often untrained) people, and are less expensive than sensory panels. These instrumental measurements are widely understood and can provide a common language among researchers, industry, and customers. There are numerous empirical and fundamental measurements that relate to textural attributes. Mechanical methods measure functions of force, deformation, and time. Some indirect methods measure chemical constituents or physical characteristics. Destructive mechanical methods generally relate more closely to sensory evaluations than do nondestructive measurements; but, by their destructive nature, they cannot be used for sorting produce. Therefore, the commodity, purpose of measurement, and sometimes regulations, guide the choice of textural measurement.

The study presented below is aimed at permitting optimum choice of technology of apple transport from the orchard to the storage facility. Field experiments were conducted at the Experimental Orchard (Dąbrowice/ Skierniewice) of the Research Institute of Pomology and Floriculture (ISK). The experiments were preceded by the design and development of an original self-unloading trailer for the harvest and transport of fruits (Patent No. 142 295). Apples were transported over internal roads within the orchard area (gravel) and on roads outside the orchard (tarmac). The laboratory part of the experiments was performed at the Department of Horticulture Engineering (ISK), and at the Institute of Agrophysics, Polish Academy of Sciences, Lublin. The results will broaden the knowledge on the effect of the type of transport means, driving speed, and road surface condition on transport efficiency and on damage sustained by fruit during transport. They will also facilitate the process of selection of suitable transport means, from the viewpoint of a specific fruit farm, taking into consideration the mass of fruits transported during the season and the distance between the orchard and the storage facility. Correct selection of technical means is the more important as the level of apple production in Poland vastly exceeds that of other orchard species. The scale of the problem is considerable and any improvement brings notable economic effects. It should be kept in mind, however, that fruit transport does not end with their delivery to the storage area.

The apples are on the forth place as far as the overall crop is concerned; after grapes, citrus fruits and bananas. Poland is in world vanguard of apple's producers, being situated at the entry to the Eastern markets might play important role among European exporters. Poland develops apple production, however, exports cover most industrial apples and it's concentrate.

The study presented here is concerned with the problems involved in apple turnover on the long way from the orchard to the consumer's table. Although other books on handling of apple, transport and vibration, mechanical properties, firmness, bruising and quality have been published, none is recent. Much new knowledge is contained in this book. Anyone interested in any aspect of handling of apple research and development, marketing, transport utilization, etc., should find this monograph useful.

The editors, as representatives of the Centre of Excellence, are grateful to each of the authors and reviewer. We also wish to thank the Institute of Agrophysics staff - in person of prof. dr. Ryszard T. Walczak, member of Polish Academy of Sciences – director of the Institute and deputy director for scientific affair - prof. Józef Horabik, for their advice, help, and technical editing. However, we should don't forget Bohdan Dobrzański, III, who designed the cover of each book edited in the frame of WP9 activity, that it allow to distinguish them.

INTRODUCTION

The apple is a tree and its pomaceous fruit, of species *Malus domestica* Borkh. in the rose family Rosaceae, is one of the most widely cultivated tree fruits. There are more than 7,500 known cultivars of apples.

48 million tons of apples were grown worldwide in 2001, while in following years world total production decreased to 42 million tons of apples in 2005. China produced almost half of this total. The United States is the second leading producer, accounting for 7.5% of world production. Poland is also a leading producer reaching more than 2.4 million tons of apples. World production of apple juice for market year (MY) 2003/04 (July-June) is revised up from 1.14 million metric tons to 1.2 million. World production for 2004/05 reach 1.3 million metric tons. Since 2002/03, global juice production has hit a new record each year. China continues to be the world’s top producer, followed by Poland.

Growing apples profitably for today's market is a challenge. Growers must continue to enhance their management skills in order to improve their chances for success. Bruising is the most common defect of apples. Postharvest diseases due to fungi, bacteria, and viruses are often due to mechanical or insect damage, followed by the invasion of infecting organisms.

The harvest and transport of fruits are responsible for 60-70% of the labour expenditure involved in the production of seed fruits (Ostrowski, 1977). Improvement of the efficiency of transport operations permits notable savings, but requires the application of technologies specific to particular production conditions. The choice of technical means for the transport of fruits from the orchard to the storage facility is related primarily to their efficiency, and that in turn depends on the type of containers in which the fruits are to be transported, on the distance between the orchard and the storage area or facility, on driving speed, load capacity of the means of transport used, and on the time of loading and unloading.

Application of specialized means of transport, usually more expensive than universal trailers, does not always bring the expected results. This especially concerns the obtained levels of efficiency that are fundamentally affected by the conditions under which fruits are transported. The technology applied, the number of reloading operations involved, and the distance and road surface condition also play a significant role in the occurrence of damage to the transported apples. Comparison of technical means on the basis of results of studies performed at various times and at various farms is difficult and sometimes downright impossible. Review of the available literature has not revealed many studies conducted simultaneously on several different technologies of apple transport. Also, only some determinations have been made of the applicability of specialized self-loading and self-unloading equipment for fruit transport, especially in the aspect of mechanical damage to transported apples.

The material presented herein is based on a study that comprised the effect of a number of factors and conditions on the optimisation of transport with simultaneous minimisation of damage to apples. The study involved the estimation of four methods of apple transport from the orchard to the storage facility, most commonly used in Poland. Primary objectives of the study included the determination of the following:

- effect of transport means and road surface on apple transport efficiency,
- effect of transport means on the type and extent of mechanical damage to apples,
- effect of speed of transport on mechanical damage to apples,
- costs of apple transport from the orchard to the storage facility in relation to the amount of fruit transported during the season and to the distance between the orchard and the storage facility.

The study was focused on apple transport technologies and equipment most commonly used in fruit farming. The experiments were carried out on two types of road surface - tarmac and gravel. The following types of equipment were involved in the experiments:

- tractor with front and rear forklifts,
- specialized self-loading/unloading trailer, type Pyro-s,
- self-unloading orchard trailer,
- an aggregate of universal agricultural trailers.

Field experiments were conducted near Skierniewice at Dąbrowice Experimental Orchard of the Research Institute of Pomology and Floriculture (ISK), some part of laboratory experiments was performed at Department of Horticulture Engineering, (ISK), while other part concerning on quality and physical properties of fruits were performed at the Institute of Agrophysics, Polish Academy of Sciences in Lublin.

The fundamental objective of using specialized transport vehicles in fruit transport is the improvement of transport efficiency through reduction of loading and unloading times. The results of our own studies confirmed a considerable reduction of the time of those operations as a result of application of the Pyro-s and self-unloading trailers with relation to forklifts and general-purpose trailers. Therefore, the Pyro-s trailer should be considered as a transport vehicle whose application results in considerable savings of time used for the loading and unloading operations.

Due to the possibility of damage to the fruits, the speed of vehicles transporting apples from the orchard to the storage facility should be adapted to the road surface over which they have to travel.

The transport methods applied should ensure possibly low level of damage to apples, both during transport and in the course of loading-unloading operations. Research results indicate that transport is the production stage when fruits are most exposed to damage. Bruising occurring in the course of harvest and transport affect the storage of fruits. Bruising is the major reason fruit is culled from packing lines. Recent studies at harvest indicate bruising can come from a source other than rough picking. The damage suffered by fruit is dependent on the number of individual shocks and their severity, and is directly related to the energy absorbed by the fruit. One of the most significant sources was directly related to the bulk handling of the full bins by forklift and truck. Damage inflicted on fruit is related to the energy available for bruising and the characteristics of the product. The energy available for bruising is in turn related to:

1. the suspension characteristics of the vehicle transporting the fruit,
2. the energy input to the system (a function of roughness of the road and vehicle speed),
3. a third engineering factor involving both the properties and the packaging of fruit.

So, fresh-market fruit growers have long been concerned about bruising. Processing-fruit growers also have grown concerned, because unbruised fruit commands the best prices.

The occurrence of damage to apples in transport is related to a number of factors, out of which the most important include the fruit resistance to mechanical damage, related to variety and harvest ripeness, type of packing and transport means used, number of reloading operations, road surface condition, and proper choice of transport speed. To minimize the damage occurring during that production stage it was even suggested to collect harvested apples in containers with water and to transport them to special storage silos.

The resistance of apples to mechanical damage and the methods of avoiding such damage at particular stages of production and handling are the subject of numerous research works. The studies attempt to define the factors that affect the character and extent of damage to fruit: the mechanical properties of fruit skin and flesh, temperature, permissible heights of drop onto various surfaces.

Mechanical tests performed on apple flesh and skin shown different behaviour of apple firmness. The bending technique (flesh beam and flesh beam with skin) allowed to evaluate a flesh firmness of apple from the under skin layer. The estimations of the mechanical resistance of apple using bending test evaluate a susceptibility to bruising and skin damage. According to this method the values related to the modulus of elasticity more distinctly show the changes of apple firmness after storage.

Some of results obtained using Elasticity Meter, designed by authors, presented in this book gives hope that the modulus of elasticity more distinctly shows slightly changes of apple firmness during storage and shelf life. The similar value of modulus of elasticity was obtained in both of cases: for apple with skin and for apple after skin removed (plunger pressed only the flesh). It's prove that elasticity meter allows on the measure independent to the strength of skin, and firmness determined in this way, more correctly than with Magness-Tylor method, reflects the mechanical properties of flesh. The similar values, determined for fruit with skin and for apple after skin removed prove that the Elasticity Meter allow on the measure of flesh firmness. The modulus of elasticity determined with elasticity meter indicates a slightly changes of firmness allowing to compare the influence of storage conditions on the fruit firmness and significant differences were observed.

The Elasticity Meter has been used successfully to measure of apple firmness a specially for apple with skin, as a quasi non-destructive method and allows to measure a values at limit force corresponding to the fingers touch.

The water potential of apple tissue is mostly connected with fruit's firmness and determines the physical state of apples during storage. The obtained results show that the water potential allows to determine the quality of apple during storage and shelf life, however is difficult method to adapt and develop in practice.

Although, these mechanical tests are still destructive ones, but are very useful as resource of basic information and comparing to the tests that will be developed and designed as non destructive.

Determination of fruit quality based on L*a*b* system colour should be useful in handling of apples, make decision easy for marketing and being helpful in establish of consumer preferences. The L*a*b* system make these techniques affordable in the marketplace and especially to relate the measurement parameters to the very subjective, sensory evaluation of quality by consumers.

There are many different factors which can be included in any discussion of quality, however, it should be given appropriate care and attention for nutritional quality of fruit after storage.

Quality evaluation of horticultural products has been a subject of interest to many researchers for many years. There are many different factors that can be included in any discussion of quality. Texture is a quality attribute that is critical in determining the acceptability of fruits. It is convenient to define quality as the composite of intrinsic characteristics that differentiate units of the commodity - individual pieces of the product - and to think of acceptability as people’s perceptions of and reactions to those characteristics. Although the term is widely used, texture is not a single, well-defined attribute.

Although some definitions of texture restrict its use to only sensory attributes or to sensory attributes and the mechanical properties directly related to them, the term texture is sometimes extended to include some mechanical properties of commercial interest that may not be of direct interest to consumers, such as resistance to mechanical damage.

Chapter 1

APPLE*

1.1. BOTANICAL ORIGINS

The wild ancestor of *Malus domestica* is *Malus sieversii*. It has no common name in English, but is known where it is native as "alma"; in fact, the city where it is thought to originate is called Alma-Ata, or "father of the apples". This tree is still found wild in the mountains of Central Asia in southern Kazakhstan, Kyrgyzstan, Tajikistan, and Xinjiang, China. Some individual *M. sieversii*, recently planted at a research facility, resist many diseases and pests that affect domestic apples, and are the subject of continuing research to develop new disease-resistant apples.

Other species that were previously thought to have made contributions to the genome of the domestic apples are *Malus baccata* and *Malus sylvestris*, but there is no hard evidence for this in older apple cultivars. These and other *Malus* species have been used in some recent breeding programmes to develop apples suitable for growing in climates unsuitable for *M. domestica*, mainly for increased cold tolerance.

The apple tree was probably the earliest tree to be cultivated, and apples have remained an important food in all cooler climates. To a greater degree than other tree fruit, except possibly citrus, apples store for months while still retaining much of their nutritive value. Winter apples, picked in late autumn and stored just above freezing, have been an important food in Asia and Europe for millennia, as well as in Argentina and in the United States since the arrival of Europeans.

The word **apple** comes from the Old English word **aeppel**, which in turn has recognisable cognates in a number of the northern branches of the Indo-European language family. The prevailing theory is that "apple" may be one of the most ancient Indo-European words (**abl*-) to come down to English in a recognisable form. The scientific name *malus*, on the other hand, comes from the Latin word for apple, and ultimately from the Greek *mēlon*. The legendary placename Avalon is thought to come from a Celtic evolution of the same root as the English "apple", as is the name of the town of Avellino, near Naples in Italy.

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* all about apple in this chapter except production and quality characteristics is based on free encyclopedia Wikipedia® which is a registered trademark of the Wikimedia Foundation, Inc. (source: http://en.wikipedia.org/wiki/Apple)

1.2. SCIENTIFIC CLASSIFICATION

The apple is a tree and its pomaceous fruit, of species *Malus domestica* in the rose family Rosaceae, is one of the most widely cultivated tree fruits. It is a small deciduous tree reaching 5-12 m tall, with a broad, often densely twiggy crown. The leaves are alternately arranged, simple oval with an acute tip and serrated margin, slightly downy below, 5-12 cm long and 3-6 cm broad on a 2-5 cm petiole. The flowers are produced in spring with the leaves, white, usually tinged pink at first, 2.5-3.5 cm diameter, with five petals. The fruit matures in Autumn, and is typically 5-8 cm diameter (rarely up to 15 cm).

Table 1. Scientific classification

Kingdom	Plantae
Division	Magnoliophyta
Class	Magnoliopsida
Order	Rosales
Family	Rosaceae
Subfamily	Maloideae
Genus	*Malus*
Species	*M. domestica*
Binomial name	*Malus domestica* Borkh.

(http://en.wikipedia.org/wiki/Apple)

1.3. APPLE CULTIVARS

There are more than 7,500 known cultivars of apples. Different cultivars are available for temperate and subtropical climates. Apples do not flower in tropical climates because they have a chilling requirement.

Commercially-popular apple cultivars are soft but crisp. Other desired qualities in modern commercial apple breeding are a colourful skin, absence of russeting, ease of shipping, lengthy storage ability, high yields, disease resistance, typical 'Red Delicious' apple shape, long stem (to allow pesticides to penetrate the top of the fruit), and popular flavour.

Old cultivars are often oddly shaped, russeted, and have a variety of textures and colours. Many of them have excellent flavour (often better than most modern cultivars), but may have other problems which make them commercially unviable, such as low yield, liability to disease, or poor tolerance for storage or transport. A few old cultivars are still produced on a large scale, but many have been kept alive by home gardeners and farmers that sell directly to local markets. Many unusual and locally important cultivars with their own unique taste and appearance are out there to discover; apple conservation campaigns have sprung up around the world to preserve such local cultivars from extinction.

Although most cultivars are bred for eating fresh (dessert apples), some are cultivated specifically for cooking (cooking apples) or producing cider. Cider apples are typically too tart and astringent to eat fresh, but they give the beverage a rich flavour that dessert apples cannot.

Modern apples are, as a rule, sweeter than older cultivars. Most North Americans and Europeans favour sweet, subacid apples, but tart apples have a strong minority following. Extremely sweet apples with barely any acid flavour are popular in Asia and especially India.

1.4. Quality Characteristics

Quality consists of a combination of visual appearance, texture and flavor. Modern consumers demand impeccable appearance and optimum texture and firmness typical of the variety (Watkins *et al*., 2002).

1.4.1. Skin Color

Each variety has specific commercial requirements for skin color ranging from green or yellow for varieties such as ‘Golden Delicious’ and ‘Granny Smith’ to red for varieties such as ‘Red Delicious.’ Bi-colored apples such as ‘Gala’ and ‘Braeburn’ are also popular (Watkins *et al*., 2002). Some varieties are currently marketable only if they meet strict standards for red color intensity and coverage. There is a tendency for wholesalers to gradually increase color standards, thereby encouraging growers to select redder strains of previously acceptable bi-colored apples. Red color is not an indicator of fruit maturity or quality, however. With few exceptions, the ground (background) color requirement for apples is light green, as yellowness is regarded as an indication of overmature or senescent fruit. Recently, consumers have preferred ‘Golden Delicious’ apples that have a white skin color, rather than green or yellow. Consumers demand fully green ‘Granny Smith’ apples without a red blush and 100% red color for ‘Red Delicious’ (Watkins *et al*., 2002).

1.4.2. Blemish

A high quality apple in the marketplace is free from blemish, although there may be a greater tolerance for defects in certain markets such as organic outlets. Occurrences of physically induced damage such as bruising or stem-punctures and physiological and pathological disorders are not acceptable in any market. The prevalence of these defects can be affected greatly by variety characteristics such as stem length, skin tenderness, softness of the fruit, and genetically based resistance to physiological and pathological disorders. The density of the flesh and the skin thickness can also contribute to resistance of fruit to bruising under normal handling conditions, and susceptibility to bruising can determine the commercial success of a variety (Watkins *et al*., 2002).

1.4.3. TEXTURE

A universal constituent of quality regardless of variety is firmness. Consumers demand apples that are crisp and crunchy. Other textural or flavor components are secondary. All apples are not required to have the same firmness values, and optimum values are dependent upon the characteristics of an individual variety. For example, a crisp ‘Granny Smith’ apple is often 80 to 98 N while a crisp ‘Golden Delicious’ is above 53 N (Watkins *et al*., 2002).

1.4.4. FLAVOR

Sweetness and acidity vary by variety. For example, the acidity of ‘Granny Smith’ apples is high (0.8 to 1.2% malate) while that of ‘Red Delicious’ is low (0.2 to 0.4%). Similarly, sugar content of apples also varies by variety. ‘Fuji’ apples can have 20% or more SSC (Watkins *et al*., 2002).

1.5. HEALTH BENEFITS

Apples have long been considered healthy, as indicated by the proverb an apple a day keeps the doctor away. Research suggests that apples may reduce the risk of colon cancer, prostate cancer and lung cancer. They may also help with heart disease, weight loss and controlling cholesterol.

A group of chemicals in apples could protect the brain from the type of damage that triggers such neurodegenerative diseases as Alzheimer's and Parkinsonism. Apples are historically known for producing "apple milk". A derivative of apple curd, apple milk is widely used throughout Tibet.

1.6. CULTURAL ASPECTS

Apples appear in many religious traditions, often as a mystical and forbidden fruit. One of the Greek hero Heracles' Twelve Labours was to travel to the Garden of the Hesperides and pick the golden apples off the Tree of Life growing at its center. In Norse mythology, Iðunn was the keeper of the 'apples of immortality' which kept the Gods young. The 'fruit-bearing tree' referred to by Tacitus in his description of Norse runic divination may have been the apple, or the rowan. This tradition is also reflected in the book of Genesis. Though the forbidden fruit in that account is not identified, popular European Christian tradition has held that it was an apple that Eve incited Adam to share with her. The influence of the antiquity was still strong, and the pagan symbology was absorbed into the new religion. This tradition was reflected in artistic renderings of the fall from Eden. The larynx in the human throat has been called Adam's apple because of a notion that it was caused by the forbidden fruit sticking in the throat of Adam. Celtic mythology includes a story about Conle who receives an apple which feeds him for a year but also makes him irresistibly desire fairyland.

Another reason for the adoption of the apple as Christian symbol is that in Latin, the words for "apple" and for "evil" are identical (malum). It is often used to symbolise the fall into sin, or sin itself. When Christ is portrayed holding an apple, he represents the Second Adam who brings life. When held in Adam's hand, the apple symbolises sin. This also reflects the evolution of the symbol in religion. In the Old Testament the apple was significant of the fall of man; in the New Testament it is an emblem of the redemption from that fall, and as such is also represented in pictures of the Madonna and Infant Jesus.

Another Greek mythological figure, Paris, had to give a golden apple inscribed Kallisti "To the most beautiful one", (which had come from the goddess of discord, Eris) to the most beautiful goddess, thus indirectly causing the Trojan War. Atalanta, also of Greek mythology, was distracted during a race by three golden apples thrown for that purpose by a suitor, Hippomenes. In ancient Greece, throwing an apple at a person's bed was an invitation for sexual intercourse. Another instance in Roman and Greek mythology is the story of the Pleiades.

At times artists would co-opt the apple, as well as other religious symbology, whether for ironic effect or as a stock element of symbolic vocabulary. Thus, secular art as well made use of the apple as symbol of love and sexuality. It is often an attribute associated with Venus who is shown holding it.

According to a popular legend, Isaac Newton, upon witnessing an apple fall from its tree, was inspired to conclude that a similar 'universal gravitation' attracted the moon toward the Earth as well (this legend is discussed in more detail in the article on Isaac Newton).

In the European fairy tale Snow White, the titular princess is killed by choking on an apple given to her by her stepmother. Later, the princess is jostled into coughing up the piece, miraculously returning to life.

The ancient Kazakh city of Almaty, 'Father of Apples' (Turkic language alma, apple, + ata, father), owes its name to the forests of wild apples (Malus sieversii) found naturally in the area. The apple blossom is the state flower of Arkansas and

Michigan. The name of the Russian party Yabloko means "apple". Its logo represents an apple in the constructivist style.

Apple Computer and Apple records have also adopted the apple for their companies. Swiss folklore holds that William Tell courageously shot an apple from his son's head with his crossbow, defying a tyrannical ruler and bringing freedom to his people. Irish folklore claims that if an apple is peeled into one continuous ribbon and thrown behind a woman's shoulder, it will land in the shape of the future husband's initials. Danish folklore says that apples wither around adulterers.

In some places, bobbing for apples is a traditional Halloween activity. Apples are said to increase a woman's chances of conception as well as remove birthmarks when rubbed on the skin.

In the United States, Denmark and Sweden, an apple (polished) is a traditional gift for a teacher. This stemmed from the fact that teachers during the 16th to 18th centuries were poorly paid, so parents would compensate the teacher by providing food. As apples were a very common crop, teachers would often be given baskets of apples by students. As wages increased, the quantity of apples was toned down to a single fruit.

1.7. PRODUCTION AND USES

48 million tons of apples were grown worldwide in 2001, while in following years world total production decreased to 42 million tons of apples in 2005. China produced almost half of this total. The United States is the second leading producer, accounting for 7.5% of world production, however, more than 60% of all the apples sold commercially are grown in Washington state. Poland is also a leading producer reaching more than 2.4 million tons of apples. Germany, New Zeland, Turkey, France, Italy, South Africa, Argentina and Chile are among the leading apple exporters.

Apples can be canned, juiced, and optionally fermented to produce apple juice, cider, vinegar, and pectin. Distilled apple cider produces the spirits applejack and Calvados. Apple wine can also be made. They make a popular lunchbox fruit as well.

Apples are an important ingredient in many winter desserts, for example apple pie, apple crumble, apple crisp and apple cake. They are often eaten baked or stewed, and they can also be dried and eaten or re-consitituted (soaked in water, alcohol or some other liquid) for later use. Puréed apples are generally known as apple sauce. Apples are also made into apple butter and apple jelly. They are also used cooked in meat dishes.

In the UK, a toffee apple is a traditional confection made by coating an apple in hot toffee and allowing it to cool. Similar treats in the US are candy apples (coated in a hard shell of crystallised sugar syrup), and caramel apples, coated with cooled caramel.

Apples are eaten with honey at the Jewish New Year of Rosh Hashanah to symbolise a sweet new year.

Table 2. European Union apple production, by country (10^3 Tons)

Country	2000	2001	2002	2003	2004	2005	Average
Italy	2 206	2 172	2 171	2 152	2 035	2 145	2 147
France	2 260	1 938	1 966	1 728	1 708	1 778	1 920
Germany	1 131	922	763	818	945	915	916
Spain	683	806	646	704	553	671	678
Netherlands	500	475	370	405	435	380	437
Belgium	500	337	349	319	356	325	372
Portugal	206	240	295	280	284	288	261
Greece	288	194	244	165	282	265	235
United Kingdom	195	212	124	156	163	183	170
Austria*	161	156	163	152	163	169	159
Denmark	31	29	25	25	26	26	27
Sweden	23	23	20	NA	NA	NA	NA
Ireland	5	NA	NA	NA	NA	NA	NA
Luxembourg	3	NA	NA	NA	NA	NA	NA
TOTAL	8 193	7 504	7 136	6 905	6 949	7 143	7 435

(Source: prognosfruit, http://www.fas.usda.gov)

Table 3. Other European apple production, by country (10^3 Tons)

Country	2000	2001	2002	2003	2004	2005	Average
Poland*	2 000	2 484	2 168	2 428	2 522	2 200	2 270
Hungary*	695	605	527	488	700	489	579
Czech Republic*	195	141	164	152	164	119	163
Slovenia	59	38	42	62	60	57	50
Slovakia*	27	27	27	34	31	29	29
Lithuania*	100	155	120	180	70	130	139
Switzerland	167	124	147	123	132	NA	140
S.R.Yugoslavia	92	67	39	107	98	NA	76
Bulgaria	92	78	73	58	58	NA	75
Croatia	30	10	21	25	38	NA	22
TOTAL	3 457	3 729	3 328	3 657	3 873	3 024	3 543

* asterisk denotes new EU members (since 1 May 2004)
(Source: prognosfruit, http://www.fas.usda.gov)

Table 4. European Union apple production, by variety from countries incl. in table 2 (10^3 Tons)

Variety	2000	2001	2002	2003	2004	2005	Average
Golden Delicious	2 721	2 738	2 639	2 352	2 248	2 391	2 540
Gala	643	676	718	689	712	803	688
Jonagold	977	763	733	736	777	732	797
Red Delicious	791	749	703	549	678	654	694
Elstar	406	395	338	338	428	370	381
Granny Smith	424	346	358	315	307	326	350
Braeburn	207	210	248	239	285	305	238
Morgenduft	157	137	134	145	106	125	136
Boskoop	174	142	89	92	109	105	121
Idared	148	122	117	106	117	91	122
Cox Orange	143	163	83	104	91	102	117
Fuji	70	71	80	85	88	124	79
Bramley	95	99	60	64	90	85	82
Renette	102	89	98	78	85	87	90
Pink Lady	26	50	70	69	90	108	61
Gloster	105	82	52	68	NA	NA	77
Other	912	793	693	808	742	NA	790
TOTAL	8 101	7 625	7 213	6 837	6 953	6 408	7 346

(Source: prognosfruit, http://www.fas.usda.gov)

Table 5. Apple supply and utilization in major producing and trading countries (2004/2005)

Country/ Marketing Year	Total Production	Total Imports	Total Supply/ Distribution	Fresh Domestic Consumption	Exports, Fresh Only	Total Processed
Argentina						
2000/2001	1 330 800	4 397	1 335 197	357 907	194 490	782 800
2001/2002	900 000	369	900 369	375 369	165 000	360 000
2002/2003	1 000 000	500	1 000 500	350 000	200 500	450 000
2003/2004	900 000	600	900 600	250 600	200 000	450 000
2004/2005	1 100 000	0	1 100 000	350 000	250 000	500 000
Australia						
2000/2001	285 000	0	285 000	130 000	33 857	121 143
2001/2002	320 526	0	320 526	138 000	25 670	156 856
2002/2003	326 000	0	326 000	135 000	32 099	158 901
2003/2004	250 000	0	250 000	110 000	15 000	125 000
2004/2005	300 000	0	300 000	120 000	30 000	150 000

Belgium*	Total Production	Total Imports	Total Supply/ Distribution	Fresh Domestic Consumption	Exports, Fresh Only	Total Processed
2000/2001	511 640	229 941	741 581	206 551	354 285	140 000
2001/2002	343 564	232 811	576 375	181 423	330 395	64 400
2002/2003	352 617	257 528	610 145	182 573	367 238	60 000
2003/2004	322 100	257 000	579 100	179 000	340 000	60 000
Brazil*						
2000/2001	705 515	80 374	785 889	750 103	35 786	0
2001/2002	857 340	53 487	910 827	844 900	65 927	0
2002/2003	825 000	56 162	881 162	808 642	72 520	0
Canada						
2000/2001	532 218	120 692	652 910	404 996	62 914	185 000
2001/2002	466 602	122 053	588 655	345 127	59 578	183 950
2002/2003	402 454	144 768	547 222	335 348	61 874	150 000
2003/2004	379 192	135 934	515 126	313 509	41 617	160 000
2004/2005	382 000	130 000	512 000	302 000	45 000	165 000
Chile						
2000/2001	1 000 000	60	1 000 060	90 000	540 516	369 544
2001/2002	1 010 000	0	1 010 000	110 000	548 194	351 806
2002/2003	1 090 000	20	1 090 020	113 612	596 408	380 000
2003/2004	1 252 000	15	1 252 015	119 015	723 000	410 000
2004/2005	1 190 000	15	1 190 015	120 015	720 000	350 000
China						
2000/2001	20 431 230	34 856	20 466 086	19 159 235	281 851	1 025 000
2001/2002	20 014 986	50 003	20 064 989	17 704 937	360 052	2 000 000
2002/2003	19 241 000	51 256	19 292 256	15 892 353	499 903	2 900 000
2003/2004	21 000 000	36 853	21 036 853	16 528 447	708 406	3 800 000
2004/2005	20 200 000	45 000	20 245 000	15 295 000	850 000	4 100 000
France*						
2000/2001	2 300 000	95 000	2 395 000	1 141 900	863 000	310 000
2001/2002	2 055 000	105 000	2 160 000	1 045 000	750 000	310 000
2002/2003	2 060 000	95 000	2 155 000	1 050 000	720 000	310 000
2003/2004	2 080 000	90 000	2 170 000	1 060 000	720 000	310 000
Germany						
2000/2001	2 630 802	642 038	3 272 840	2 080 571	72 720	1 108 000
2001/2002	1 522 433	680 604	2 203 037	1 452 892	66 555	683 000
2002/2003	1 562 800	851 491	2 414 291	1 580 567	65 705	768 000
2003/2004	1 518 000	768 822	2 286 822	1 475 000	77 622	734 200
2004/2005	1 770 000	770 000	2 540 000	1 594 990	85 000	860 000

Greece	Total Production	Total Imports	Total Supply/ Distribution	Fresh Domestic Consumption	Exports, Fresh Only	Total Processed
2000/2001	315 000	14 000	329 000	249 300	28 500	5 500
2001/2002	260 000	18 000	278 000	237 000	20 000	1 000
2002/2003	235 000	16 000	251 000	230 000	16 000	1 500
2003/2004	169 000	21 000	190 000	170 000	17 000	1 000
2004/2005	287 500	18 000	305 500	245 000	38 000	2 500
Hungary						
2000/2001	700 000	6 000	706 000	140 000	7 000	559 000
2001/2002	605 000	4 100	609 100	135 000	24 500	449 600
2002/2003	540 000	9 210	549 210	145 000	9 000	395 210
2003/2004	500 000	11 000	511 000	140 000	8 000	363 000
2004/2005	680 000	8 000	688 000	147 000	12 000	529 000
Italy						
2000/2001	2 267 000	33 000	2 300 000	1 363 000	527 000	390 000
2001/2002	2 220 000	52 000	2 272 000	1 232 500	659 000	370 000
2002/2003	2 206 000	53 618	2 259 618	1 213 941	670 677	375 000
2003/2004	1 877 524	77 244	1 954 768	1 032 000	622 768	300 000
2004/2005	2 109 600	63 000	2 172 600	1 109 000	663 600	400 000
Japan						
2000/2001	799 600	2 405	802 005	672 359	2 246	127 400
2001/2002	930 700	349	931 049	776 203	6 546	148 300
2002/2003	925 800	108	925 908	768 705	12 203	145 000
2003/2004	842 100	0	842 100	681 468	15 632	145 000
2004/2005	881 100	0	881 100	716 100	20 000	145 000
Mexico						
2000/2001	338 245	228 063	566 308	496 308	0	70 000
2001/2002	442 679	189 581	632 260	542 260	0	90 000
2002/2003	479 616	170 808	650 424	560 424	0	90 000
2003/2004	579 000	149 338	728 338	636 338	0	92 000
2004/2005	510 000	174 000	684 000	592 000	0	92 000
Netherlands						
2000/2001	500 000	300 528	800 528	325 528	360 000	85 000
2001/2002	500 000	300 528	800 528	325 528	360 000	85 000
2002/2003	370 000	296 000	666 000	314 000	265 000	77 000
2003/2004	385 000	290 000	675 000	310 000	270 000	85 000
2004/2005	0	0	0	0	0	0

New Zealand	Total Production	Total Imports	Total Supply/ Distribution	Fresh Domestic Consumption	Exports, Fresh Only	Total Processed
2000/2001	413 000	23	413 023	60 000	260 000	93 023
2001/2002	480 000	70	480 070	70 070	325 000	85 000
2002/2003	495 000	350	495 350	65 075	327 000	103 275
2003/2004	550 000	680	550 680	56 000	390 000	104 680
2004/2005	500 000	700	500 700	56 000	350 000	94 700
Poland						
2000/2001	2 400 800	19 100	2 419 900	764 000	205 900	1 450 000
2001/2002	2 710 000	12 100	2 722 100	653 200	245 900	1 823 000
2002/2003	2 168 000	7 500	2 175 500	500 100	386 400	1 289 000
2003/2004	2 427 800	14 000	2 441 800	515 100	340 000	1 586 700
2004/2005	2 400 000	18 000	2 418 000	500 000	310 000	1 608 000
Russia						
2000/2001	1 589 600	334 800	1 924 400	1 073 505	1 555	770 000
2001/2002	1 227 600	330 950	1 558 550	770 000	1 455	770 000
2002/2003	1 722 500	443 563	2 166 063	920 136	984	1 209 100
2003/2004	1 488 800	689 000	2 177 800	925 000	1 885	1 236 800
2004/2005	1 500 000	680 000	2 180 000	920 000	1 000	1 245 000
Slovakia						
2000/2001	80 000	27 000	107 000	78 000	4 000	25 000
2001/2002	55 817	23 755	79 572	47 612	6 960	25 000
2002/2003	51 172	29 992	81 164	47 769	6 895	26 500
2003/2004	60 685	32 967	93 652	48 500	6 165	38 987
2004/2005	60 500	33 000	93 500	48 500	8 000	37 000
South Africa						
2000/2001	667 730	0	667 730	248 466	244 819	174 445
2001/2002	591 414	20	591 434	152 779	257 583	181 072
2002/2003	681 953	7	681 960	175 923	326 045	179 992
2003/2004	724 490	10	724 500	180 155	300 000	244 345
2004/2005	706 000	0	706 000	175 000	285 000	246 000
Spain						
2000/2001	698 500	273 800	972 300	721 000	65 000	165 800
2001/2002	962 000	176 376	1 138 376	751 636	119 540	235 000
2002/2003	651 200	271 125	922 325	730 000	69 086	103 339
2003/2004	791 100	235 686	1 026 786	735 000	112 633	159 153
2004/2005	576 900	318 100	895 000	730 000	65 000	85 000

Sweden	Total Production	Total Imports	Total Supply/ Distribution	Fresh Domestic Consumption	Exports, Fresh Only	Total Processed
2000/2001	68 000	86 398	154 398	148 070	1 328	5 000
2001/2002	63 103	79 023	142 126	135 868	1 258	5 000
2002/2003	55 005	80 502	135 507	129 616	891	5 000
2003/2004	51 500	92 795	144 295	137 846	1 449	5 000
2004/2005	46 000	94 000	140 000	133 800	1 200	5 000
Taiwan						
2000/2001	7 670	135 163	142 833	142 763	0	0
2001/2002	8 180	121 912	130 092	130 022	0	0
2002/2003	9 720	110 099	119 819	119 749	0	0
2003/2004	3 425	111 330	114 755	114 685	0	0
2004/2005	9 070	114 000	123 070	123 000	0	0
Turkey						
2000/2001	2 400 000	1 795	2 401 795	2 265 291	16 504	120 000
2001/2002	2 450 000	2 892	2 452 892	2 312 287	18 605	122 000
2002/2003	2 200 000	2 820	2 202 820	2 075 620	17 200	110 000
2003/2004	2 600 000	2 540	2 602 540	2 455 610	21 930	125 000
2004/2005	2 300 000	3 000	2 303 000	2 178 000	15 000	110 000
United Kingdom						
2000/2001	162 200	455 850	618 050	582 450	13 400	22 000
2001/2002	169 140	432 320	601 460	541 220	16 240	44 000
2002/2003	111 380	494 440	605 820	560 020	13 300	32 500
2003/2004	135 500	486 100	621 600	563 080	20 720	37 800
2004/2005	121 200	489 800	611 000	565 000	13 000	33 000
United States						
2000/2001	4 800 686	163 610	4 964 296	2 375 655	749 142	1 839 499
2001/2002	4 274 204	166 540	4 440 744	2 123 420	620 324	1 697 000
2002/2003	3 866 379	177 815	4 044 194	2 156 616	523 578	1 364 000
2003/2004	3 952 196	213 568	4 165 764	2 267 199	455 597	1 442 968
2004/2005	4 571 440	192 200	4 763 640	2 582 911	519 400	1 661 329
World Grand Total						
2000/2001	47 935 236	3 288 893	51 224 129	36 026 958	4 925 813	9 943 154
2001/2002	45 440 288	3 154 843	48 595 131	33 134 253	5 054 282	10 240 984
2002/2003	43 628 596	3 620 682	47 249 278	31 160 789	5 260 506	10 683 317
2003/2004	44 839 412	3 716 482	48 555 894	31 003 552	5 409 424	12 016 633
2004/2005	42 201 310	3 150 815	45 352 125	28 603 316	4 281 200	12 418 529

(Source: prognosfruit, http://www.fas.usda.gov)

* Asterix denotes countries, that production data of 2003/2004 or/and 2004/2005 are not available

1.7.1. JUICE PRODUCTION

Concentrated apple juice is the product obtained by the concentration of the juice of different varieties of apples meeting the requirements of the Food Quality Code. There are two types of concentrated apple juice: the "clarified" (70º-71º Brix) used in the juice industry and as soft drinks sweetener, and the so called "with pulp" or "cloudy" (45º Brix) for juices and nectars. Apart from the Brix degrees, the acidity is another important technical specification considered at the time of selling.

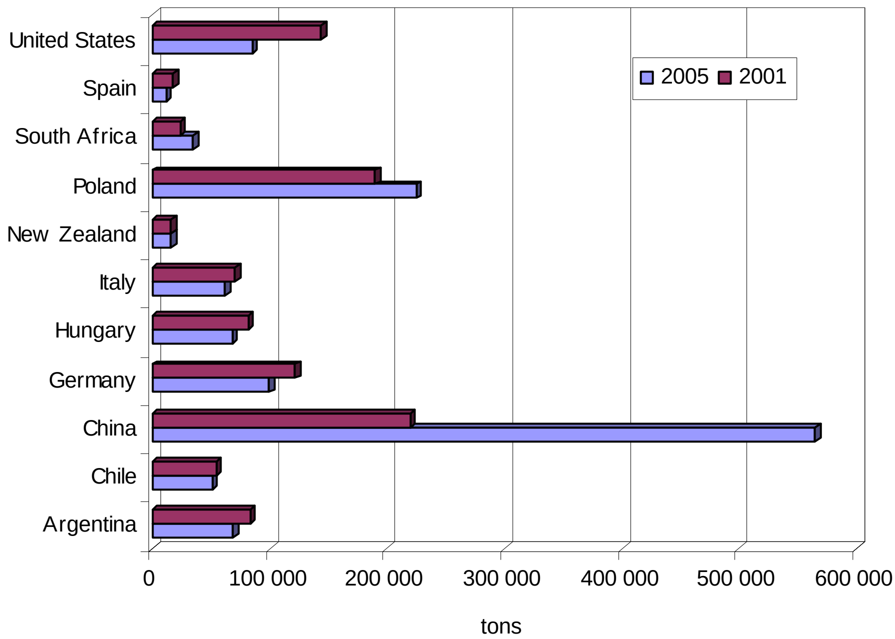

Fig. 1. World apple juice producers 2004/05 (10^3 Tons) (source: USDA/FAS, Attache Reports)

In the period 1999/2004, the world production of concentrated apple juice increased 30%, with a growing tendency. This increase is explained by the extraordinary progress made by China – principal producer – which elaborates half of the world total and grows at an annual rate of 40%.

Combined apple juice production in major producing and trading countries in 2004/05 is estimated at 1.288 million tons, over 89,000 tons above the previous season. The increase is mainly due to an estimated increase in Chinese production of 46,000 tons, a more modest increase compared to last year's 100,000 tons.

Exports from selected countries are estimated at 1.138 million tons, up 4 percent (FAS/USDA, 2005). Imports are estimated to reach 775,600 tons, down 7 percent. Imports are off slightly due to declines from the United States and Germany. Germany's production was up 28 percent from the previous level. The increase is due to growing demand for pure apple and blended juice beverages, and as an additive in cosmetics and various types of medicines. Germany and the United States, the two largest importing countries, are expected to import 410,000 tons and 302,500 tons of apple juice in 2004/05, respectively.

1.7.1.1. China Juice Production

The Chinese presence in the international market, has been a determinant factor in the price fall (FAS/USDA, 2005). In recent years, China's apple juice industry is responding to growing global demand China is planting more high acid or "high-sour" apple varieties more suitable for processing into juice. China's apple juice production expansion is expected to continue as more marketing opportunities develop, prompting ongoing increases in high-sour juicing apple plantings.

China's apple juice production is gradually shifting to the western regions of the country, mainly to Shaanxi province. Typically, Shandong province has been the center of apple juice production in China, accounting for about half of the country's annual output. However, during the last few years, many apple farmers in Shandong have been cutting down apple trees and switching to other fruits in search of better returns. Fruit juice plants in Shaanxi continue to introduce new processing equipment and expand their investments. Shaanxi is now the largest apple juice-producing province, followed by Shandong.

1.7.1.2. U.S. Apple Juice Production

At only 85,000 tons, 2004/05 U.S. apple juice production will likely decline for the sixth consecutive year (FAS/USDA, 2005). The United States utilized around 3 billion pounds for processing during 2003. In the United States, few apples are grown just for juicing. Most juice apples are culled fruit from fresh packing lines. Moreover, profits to growers from processing apples are generally lower than fruit directed to the fresh market. Of all apples processed for other than the fresh market in 2003, about 44 percent went into the juice and cider market. This is about 16 percent of total apple production. Also, of all apples processed, 38 percent were canned (up from 36 percent), 44 percent were processed into juice or cider (down from 49 percent last year), 1 percent were frozen (down from 6 percent), and 6 percent were dried (down from 7 percent). The United States is the third largest producer, but with lower U.S. production and increased global production, exports are going to decline, perhaps by 9 percent.

1.7.1.3. Poland Apple Juice Production

2004/05 season's apple crop in Poland, the second largest producer, is larger than 2003/2004 and therefore bolster the amount of apples processed into juice. With larger supplies, Poland can offer better prices and is expected to be able to export slightly more juice (FAS/USDA, 2005).

China and Poland are the two largest exporters. China, although shipping high acid apple juice, mainly exports low acid apple juice concentrate, while Poland ships mostly medium and high acid apple juice. High acid apple juice is in particularly high demand in Japan and European markets.

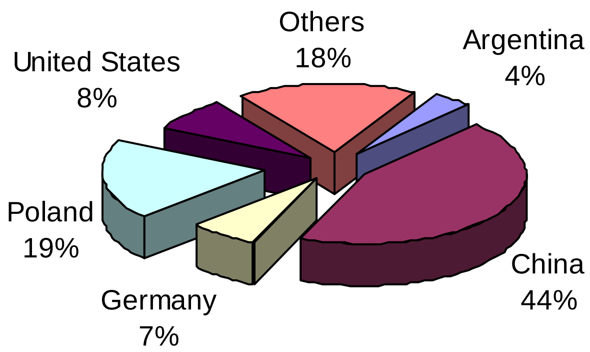

Fig. 2. Share of apple juice production, by country – 2004/05 (%) Source: Food Industry Direction, based on data provided by the USDA.

1.7.1.4. Germany Apple Juice Production

Imports are off slightly due to declines from the United States and Germany. Germany is the main world importer, with 50% of purchases, followed by the USA, with 40% of world demand. Germany's production was up 28 percent from the previous level. The increase is due to growing demand for pure apple and blended juice beverages, and as an additive in cosmetics and various types of medicines. Germany and the United States, the two largest importing countries, that import reach 410,000 tons and 302,500 tons of apple juice in 2004/05, respectively (FAS/USDA, 2005).

1.7.1.5. Argentina Apple Juice Production

Argentina is leading the production of concentrated juice in the southern hemisphere. In 2004, the Argentine production of concentrated apple juice was 45.3 thousand tons. Half of Argentine apples production – averaging one million tons – is devoted to the industry, due to the volume of fruit which does not meet the quality requirements of the fresh market. 80% of the industrial production, is to be grinded for elaborating concentrated juice. Production is seasonal. The period of higher elaboration is between January and May. In average, 95% of Argentine production of concentrated juice is exported, mainly to the USA, showing a high dependency on the American market, demanding clarified concentrated juice (Bruzone A., 2005).

In the period 1999-2004, shipments to the USA decreased at an annual rate of 10% in volume, while the FOB price per ton grew 3% during all the period. During the first quarter of 2005, shipments were tripled in volume and value as regards the same period of the previous year. The increase of the world offer, implies greater demands for Argentina as to quality and the need for new alternatives to reduce costs.

1.7.2. World Trade in Apple Juice

World production of apple juice for market year (MY) 2003/04 (July-June) is revised up from 1.14 million metric tons to 1.2 million. World production for 2004/05 reach 1.3 million metric tons. Since 2002/03, global juice production has hit a new record each year. China continues to be the world's top producer, followed by Poland. Production increases in Argentina, Germany, Hungary, and Italy are offsetting declines in Chile and Spain. U.S. production levels continue to wane, estimated down 2 percent during 2005/06 (Bruzone A., 2005).

The apple volume entering the industry, depends on the fruit quality and on the price in the fresh market. The fruit is the factor of higher incidence on the cost structure; followed by enzymes (imported from Germany and France) and packaging. Reefer ships are used to transport the product at a temperature of 0ºC for clarified juice and of -20ºC for juice with pulp. Apart from traceability requirements, HACCP and good manufacturing practices (GMP) imposed by the USA, it is necessary to comply with the Bioterrorism act that has been in full force since December 2004 (Bruzone A., 2005).

Global apple juice trade is expected to have another record year in 2005/2006. World apple juice exports of select countries will be more 1.2 million tons. China is expected to export about 50 percent of this world total. Total apple juice imports of select countries are estimated to be off slightly. The United States, one of the world's largest importers, is expected to take less based on most recent trade data, while Germany's larger domestic production will reduce the demand for imported product.

Chapter 2

HARVESTING AND HANDLING APPLES*

Growing apples profitably for today's market is a challenge. Growers must continue to enhance their management skills in order to improve their chances for success. Many growers experience difficulty harvesting and handling the fruit. All too often poor harvesting and handling procedures nullify the expertise and hard work in producing quality fruit on the tree. A grower's ability to successfully harvest and handle fruit could be the difference between financial success and failure.

2.1. HARVESTING, PACKAGING AND TRANSPORTATION

The generally accepted commercial practice is to pick fruit before the onset of the respiratory climacteric. It is important to know the appropriate harvest dates for several apple varieties. Apples picked too early are susceptible to shrivel, scald, and bitter pit. They also may not ripen appropriately after harvest. Apples picked too late may begin the respiratory rise, which will decrease their shelf life and lead to disorders such as flesh browning and breakdown (Matzinger B., Tong C., 2006)

Commonly used harvest indexes are based on days from bloom, external and internal fruit color, flesh firmness, ease of separation from spurs, and starch, sugar, or acid content. No one index is a completely reliable measure of harvest readiness, but days from full bloom gives the most reliable guide.

Hand-pick fruit into bags, transfer gently into field bins, shade fruit in bins, then transport to packing sheds. At the shed, submerge the fruit in water dumps, wash, and sort into fresh-market, processing, and cull fruit. In general, small to medium sized apples keep the longest, while the most mature have the shortest shelf life and should be removed from storage first. Cool fruit as rapidly as possible following harvest, using forced air or hydrocooling.

Packaging keeps the product in convenient units for handling and protects it during marketing and storage. It should be easy to handle, protect the fruit from

* some parts of this chapter based on information published in Factsheet (Order No. 89-175) Ontario Ministry of Agriculture, Food and Rural Affairs written by Ken Wilson - Apple Specialist/OMAF from Agriculture and Rural Division

mechanical damage and temperature extremes, allow for rapid cooling, and allow for standardization. Apples for roadside stands will need minimal packaging. Apples that will be stored or shipped can be packed into plastic bags or corrugated cardboard boxes (either volume-filled or with individually wrapped fruit in trays).

Matzinger B., Tong C., 2006 suggest to protect fruit from mechanical damage and extreme temperatures during transport. Pack fruit carefully, use proper refrigeration (0 to 2 degrees C) and relative humidity (95%), and insulation. In mixed loads, apples can be shipped with berries, cherries, pears, plums, and quince.

2.2. HARVEST MATURITY

Apples picked at the correct stage of maturity ripen and develop the full flavour and aroma of that particular cultivar. Unbruised, well-coloured large fruit of this quality is in high demand and will return premium prices (Wilson, 2003).

The purpose for which the fruit are picked determines the optimum picking maturity. Correct maturity is not only important for quality, but also for successful storage. Fruit for long-term controlled atmosphere and low oxygen storage is usually picked slightly less mature - to maximize storage success - than fruit destined for short-term storage. However, if fruit is picked too early (when it is still growing) you will sacrifice fruit size. If an apple was a perfect sphere, an increase in diameter of ¼ in., from 2 3/8 to 2 5/8 inches, is an increase in volume of about 35%. In most cases, delaying picking for correct maturity translates directly into increased profits (Wilson, 2003). Also, fruit picked early usually involves excessive spot picking, which is both inefficient and costly. This immature fruit bruises easily and is subject to scald and extreme shrivelling in storage. It may also be less coloured and be of poor eating and culinary quality.

On the other hand, fruit picked overmature can also have problems (Wilson, 2003). This fruit is subject to senescent or old age breakdown, as well as other storage problems. With most cultivars there is also an increased chance of preharvest drop or even frost damage to the fruit.

There is a time limit to harvest all apple cultivars. Watch maturity closely and adjust your picking procedure to get the most quality fruit picked at the peak of perfection. To preserve this quality, immediately cool all harvested fruit. The starch-iodine test helps grower's determine correct harvest maturity. This is a simple test showing the starch to sugar conversion as the fruit matures.

2.2.1. Apple Maturity Indices

To allow time to schedule labor, growers must estimate optimum harvest dates well before picking fruit. In addition, there are different optimum maturity levels for the same cultivars, depending on intended use and storage life desired. Harvesting too early results in fruit that is off-flavor or lacking flavor, poorly colored, small, and subject to bitter pit and storage scald. Leaving fruit on the tree too long results in softer fruit, the potential development of watercore, and a shorter storage life (Pennsylvania Tree Fruit Production Guide, 2005).

The obvious first step in marketing a high-quality product is to grow a high-quality product. Early tree training, annual pruning, proper fertilization, and sound pest management can greatly affect tree vigor and, thus, fruit condition. Light crops, crops from extended bloom periods, or crops with high nitrogen levels may differ markedly in maturity date and subsequent storage potential (Pennsylvania Tree Fruit Production Guide, 2005). Each block and cultivar or strain should be evaluated separately for its maturity and storage potential.

Within the list of maturity indices (starch, firmness, juice sugar and acid content, seed color, flesh color, presence of watercore, background color, and internal ethylene concentration [IEC]), there is a priority order for making decisions. Identifying the targeted consumer is the first decision to make. Will the harvested fruit be made available for immediate fresh market consumption, future fresh market consumption following regular or controlled atmosphere storage, or is the fruit destined for the processor? Once the targeted consumer is identified, the relative importance of the specific maturity indicators will be known. With the exception of IEC, which involves the use of a gas chromatograph, all these indicators are relatively easily measured (http://tfpg.cas.psu.edu).

Of all the indicators, background color, starch content, and firmness are the most important factors in guiding harvest timing (http://tfpg.cas.psu.edu). They are correlated to some extent with sugar content, acidity, flavor, aroma, texture, IEC, and potential storage life. If a fruit lacks the characteristic background color of a specific variety, obviously it will be difficult to sell as a fresh market item. A fruit harvested without desirable color will not change significantly during storage. Fruit lacking characteristic background color is most likely going to be firm, starchy, and immature. The only viable outlet for such fruit is most likely the processing market. However, fruit destined for processing also has minimum maturity standards. Fruit with low starch readings of 1-2 on an index of 1-8 are still immature and will lack flavor and sugar content. They will have a desirable firmness, but the flavor aspect will overshadow this. In general, a combination of the presence of background color, starch conversion of 25-35 percent, and firmness above 15 pounds will qualify for a good storage or processing candidate. For immediate consumer consumption, the presence of background color, starches in the range of 4.5-6, sugar content above 13%, and firmness readings greater than 13 pounds should meet consumer expectations.

Before doing any measurements, collect a representative sample of fruit. Choose five to eight trees per block per cultivar and rootstock that are typical of the trees in the block, and carefully mark them so that you can collect weekly samples. Trees should have a uniform crop load and be of uniform vigor. Begin sampling approximately 4 to 5 weeks before normal harvest is anticipated. Sample four fruits from the periphery of each tree (recognizing that this represents the most mature fruit on the tree), selecting fruit that is free of any visible insect injury or disease damage. Fruit temperature can affect certain test results; therefore, measurements of the samples' maturity should be performed within 2 hours of harvest.

2.2.2. Fruit Firmness

Fruit firmness can be measured with either an Effigi fruit tester or a Magness-Taylor pressure tester (Pennsylvania Tree Fruit Production Guide, 2005). Both work on the principle that fruit flesh becomes softer as it matures. Many factors, including watercore and fruit size, can affect firmness readings. The presence of watercore will give higher readings that are inaccurate. Therefore, discard firmness measurements of apples that have watercore. Large apples are usually softer than smaller ones, so for firmness measurements try to choose apples of a relatively uniform diameter and that are representative of the fruit in the block.

The most critical feature of firmness testing is the speed with which you apply force to the plunger. The proper speed is about 2 seconds, and to regulate your speed you might say to yourself, "one, one thousand, two, one thousand" as you insert the plunger into the fruit. Applying pressure too fast is probably the most common way of getting a false reading.

For apples, use the 11 mm tip supplied with the pressure tester and penetrate to a depth of 7.9 mm as marked on the plunger. Test each apple on both the blush side and the nonblush side, then average both readings.

2.2.3. Days After Full Bloom (DAFB)

DAFB should be used as a general reference to indicate when fruit might mature. There may be a 5- to 20-day spread between the average harvest date and the optimum harvest date for a particular cultivar. Record full bloom by block and cultivar each spring, since full bloom may vary from one site on your farm to another. Estimated days from full bloom to harvest for some cultivars are listed in Table 6. These dates should be used as general guides and can vary from year to year.

Table 6. Days after full bloom for apples cultivated in Pennsylvania (source: http://tfpg.cas.psu.edu)

Cultivar [a]	viability	Bloom	Vigor [b]	Harvest	DAFB [c]	S [e]	PM	CAR	FB
Akane	Good	Early to mid	V	Early Sept	105-110	H [f]	H	H	--
Ambrosia*	Good	Mid	VV	Late Sept to e. Oct	140-150	--	--	--	--
Arlet*	Good	Early to mid	MV	Mid Sept	125-130	H	H	H	--
Braeburn*	Good	Mid	MV	Late Oct	160-170	H	H	H	H
Cameo* (Carousel)	Good	Mid	VV	Mid Oct	155-165	--	--	--	--
Cortland	Good	Mid	V	Early to mid Oct	125-135	H	H	H	H
Crispin (Mutsu)	Not good	Mid	VV	Late Oct	160-170				
Cripp's Pink (P. Lady)	Good	Mid to late	VV	Mid to late Nov	180-195	--	--	--	--
Criterion	Good	Mid	VV	Late Oct	--				
Delicious	Good	Mid	MV-LV	Late Sept	135-155	L	L	L	L
Earligold*	Good	Mid	VV	Mid Aug	95-105				
Elstar	Good	Mid to late	V	Early Sept	110-125	H	H	H	--
Empire	Good	Mid	LV	Early Oct	125-140	H	H	L	M
Empress*	Good	Mid to late	MV	Late Aug	--				
Enterprise [d] *	Good	Mid to late	V	Late Sept	135-145	O	M	O	O
Freedom [d]	Good	Mid to late	V	Late Sept	140-150	O	O	H	L
Fortune	Good	Mid to late	V	Mid Oct	150-160	L	--	--	H
Fuji	Good	Mid to late	V	L. Oct to mid Nov	170-185	H	H	H	H
Gala	Good	Mid	MV	Late Aug	110-120	H	H	H	H
Gala Supreme*	Good	Mid to late	V	Early Oct	150-160	M	M	M	--
Ginger Gold*	Good	Mid	V	Early Aug	95-105	--	H	--	--
Golden Delicious	Good	Mid	V-MV	Mid Sept to e. Oct	135-150	L	L	L	M
Golden Supreme*	Good	Mid to late	MV	Early to mid Sept	125-140	M	M	L	--
GoldRush [d]	Good	Late	MV	Late Oct	165-175	O	R	H	M
Granny Smith	Good	Late	MV	Early Nov	165-180	H	H	H	M
Gravenstein	Not good	Early	VV	Early Sept	110-115	H	H	H	M
Grimes Golden	Good	Early	MV	Mid Sept	130-145	--	--	--	M
Honeycrisp*	Good	Early	MV	Mid Sept	125-140	L	M	M	M
Idared	Good	Early	MV	Early Oct	145-160	H	H	H	H
Jerseymac	Good	Early	VV	Mid Aug	90-110	H	H	L	M
Jonafree [d]	Good	Mid	MV	Late Sept	135-150	O	L	H	M
Jonagold	Not good	Mid	V	Late Sept	135-150	H	L	H	H
Jonamac	Good	Mid	MV	Mid Sept	115-130	H	H	L	M
Jonathan	Good	Mid	LV	Mid to late Sept	135-145	H	H	H	H
Liberty [d]	Good	Early	V	Late Sept	140-150	O	L	L	L
Lodi	Good	Early	V	July	65-75	H	H	H	H
McIntosh	Good	Mid	MV	Mid Sept	120-135	H	H	L	M
Macoun	Good	Mid	LV	Mid Oct	130-140	H	H	H	M
Melrose	Good	Late	V	Late Oct	140-165	H	H	H	L
Mutsu (Crispin)	Not good	Mid	VV	Late Oct	160-170	H	H	H	M
Northern Spy	Good	Late	W	Mid Oct	140-160	H	H	H	H
Northwest Greening	Good	Mid	V	Mid Oct	130-145	--	--	--	M
Novamac [d]	Good	Early	MV	Mid Sept	115-125	O	M	--	--
Orin	Not good	Mid	MV	Early Oct	145-165	H	H	M	--
Paulared	Good	Early	MV	Early Sept	95-100	L	H	L	H
Pristine [d]	Good	Early	V	Early Aug	90-100	O	L	L	--
Redfree [d]	Good	Mid	MV	Late Aug	90-100	O	L	L	L
Rome Beauty	Good	Late	V	Late Oct	165-170	H	H	H	H

Sansa	Good	Mid	LV	Late Aug	90-110	--	--	--	--
Shizuka*	Not good	Mid	V	Mid Sept	130-140	--	--	--	--
Spartan	Good	Mid	V	Late Sept	120-130	H	H	H	M
Spigold	Not good		VV	Mid Oct	140-155	H	H	H	H
Stayman	Not good	Early	MV	Late Oct	165-175	H	L	M	M
Summer Rambo	Not good	Early	VV	Late Aug	90-100	H	H	H	M
Suncrisp*	Good	Mid	V	Late Sept	140-160	--	--	--	--
Sunrise	Good	Mid	MV	Mid Aug	95 105	--	--	--	--
Sundowner*	Good	Mid to late	VV	Mid to late Nov	195-205	--	--	--	--
Tydemans Red	Good	Early	MV	Late Aug	90-100	H	L	H	H
VistaBella	Good	Early	MV	Early Aug	65-75	--	--	--	--
Williams Pride [d]	Good	Early	MV	Mid Aug	85-90	O	M	O	L
Winesap	Not Good	Late	V	Late Oct	165-175	H	L	H	L
Winter Banana	Good	Mid	MV-LV	Late Oct	160-170	H	H	H	H
Yataka	Good	Mid	V	Early Oct	145-165				
Yellow Transparent	Good	Mid	V	Mid Aug	65-75	H	H	H	H
York Imperial	Good	Mid	MV	Late Oct	170-180	H	H	H	H
Zestar *	Good	Early	V	Late Aug	95-100	M	--	--	M

[a] Asterisk denotes newest cultivars
[b] V = vigorous, MV = moderately vigorous, VV = very vigorous, LV = low vigor
[c] DAFB = Days after full bloom
[d] Scab-resistant cultivar
[e] S = scab, PM = powdery mildew, CAR = cedar apple rust, FB = fire blight, -- = Insufficient information
[f] H = high, M = moderate, L = low, O = not susceptible

(source: Pennsylvania Tree Fruit Production Guide, 2005)
http://tfpg.cas.psu.edu/introduction/intro.htm

2.2.4. PERCENT SOLUBLE SOLIDS (OR SUGAR LEVELS)

As fruit matures, starch is converted to sugars. To measure the percentage of Brix, or sugar, in a solution, a refractometer can be used. As fruit matures, refractometer readings increase, indicating fruit maturity is progressing.

Fruit from trees with a heavy crop will have lower readings than fruit from trees with a light crop under similar growing conditions. Sugar content will be higher in years of reduced moisture availability, high temperatures, and high sunlight. As with firmness, refractometer readings will also vary by fruit position within the tree and nutritional status. Fruits located in exposed areas, where considerable photosynthesis is taking place, have higher soluble solids. Fruits heavily shaded and located inside the tree or on weak spurs have the lowest soluble level of fruit on that tree (Pennsylvania Tree Fruit Production Guide, 2005).

Measurements are made by squeezing a small amount of juice from the fruit onto the prism of the refractometer. A small garlic press works well to produce the juice. Hold the instrument up to the light and read the percentage of soluble solids by looking through the lens. After each sample of juice, rinse the prism face off and wipe with a soft tissue to avoid contamination among samples. One can calibrate refractometers by zeroing with distilled water and at 10 percent with a solution of 10 grams of sucrose dissolved in 90 grams of water. Digital refractometers indicate the percent dissolved solids to the nearest 0.1 percent.

2.2.5. Acidity

As fruit mature, their acid content decreases. Malic acid is the major acid in apple juice, and it plays a major role in the flavor attribute. Table 7-3 categorizes several varieties of apples based on their sugar and acid content. Granny Smith apples have developed a well-known image based on their tart or acidic flavor. Some apple varieties, such as Pink Lady, attain acid values as high as 1.4–1.5% in juice. There are no guidelines for maturity based on acid level. The amount of acid present is related to the variety and maturity stage. A drop in acid level is an indicator of advancing maturity. Measuring acidity is somewhat cumbersome and involves the use of common laboratory instruments such as a titrator or a buret. A newly developed testing kit has just become available for slightly more than 100 EUR, one can purchase an easy-to-use colorimetric test kit to determine the acidity in fruit juice. For best use as a maturity indicator, acid level should be recorded over a number of harvests to develop patterns and guidelines (Pennsylvania Tree Fruit Production Guide, 2005).

2.2.6. Starch Levels

Stage of maturity can also be assessed by performing the starch-iodine test to document starch disappearance. Applying an iodine solution to the cut surface of fruit stains the starch a blue black. The iodine solution can be made by dissolving 10 grams of iodine crystals and 25 grams of potassium iodide in 1 liter of water. The pattern of starch disappearance is specific for each variety. Delicious loses its starch in a fairly even ring, while Golden Delicious shows an uneven pattern.

Fruit used for firmness testing and soluble solids readings can also be used for the starch-iodine test (Pennsylvania Tree Fruit Production Guide, 2005). Cut the fruit at right angles to the core, approximately halfway from the stem to the calyx end. Apply the iodine solution to the cut surface, drain away any excess, and rate the fruit after 2 minutes. The reaction of iodine and starch is temperature-dependent. Under cold conditions, the reaction will take longer. An external heating source will speed up the reaction in cold environments. Avoid contact and be cautious when mixing and applying iodine solution. Test a minimum of 10 fruits per block, preferably 20. A commonly used rating system is a scale of 1 to 6, as follows:

- full starch (all blue-black)
- clear of stain in seed cavity and halfway to vascular area
- clear through the area including vascular bundles
- half of flesh clear
- starch just under skin
- free of starch (no stain)

In Washington State, general guidelines have been established for using this scale to rate the long-term storage potential of Delicious and Golden Delicious: a 1.5-2.0 rating and a 2.0-3.0 rating, respectively. Growers should develop scales of their own for their varieties and growing conditions.

Another good reference for starch testing is "Predicting Harvest Date Windows for Apples" by G. D. Blanpied and K. J. Silsby, Information Bulletin 221, Cornell Cooperative Extension (order from Resource Center, Cornell University, 7 Business and Technology Park, Ithaca, NY 14850). This publication contains a Generic Starch-Iodine Index chart that is an excellent picture guide for making starch index determinations.

2.2.7. Seed Color and Fruit Color

Seed color can also be used in a general way to determine maturity, however, test works best for early-maturing varieties. According to the Pennsylvania Tree Fruit Production Guide (2005), cut the fruit in half and rate the seed color on the following scale:

- clear (no color)
- trace (tips brown)
- 1/4 color
- 1/2 color
- 3/4 color
- full color

Flesh color can help determine the amount of chlorophyll still present in the apple. Take a 1/16- to 1/8-inch-thick slice from the middle of the fruit. Hold the slice up to a bright light and observe the extent of green (chlorophyll) in the flesh. Again, a rating of 1 to 6 can be used:

- flesh all green
- some loss of green from center of fruit
- heavy green band 1/2 inch thick under skin
- heavy green band 1/4 inch thick
- heavy green band 1/8 inch thick
- green essentially gone from under skin

2.2.8. Fruit Texture

Texture can be evaluated by a simple taste test. If, as you chew the fruit, the flesh tends to wad up or seem cottony, the apple has not reached an ideal stage for harvest. This is a subjective test and probably no two people will always agree.

New technology is being developed for nondestructive assessment of firmness or texture by companies in Israel (Eshet Eilon), The Netherlands (Aweta), and the United Kingdom (Sinclair). The technologies work on the principle of acoustical vibration, or the amount of elasticity of the fruit following impact by nondestructive tapping of the fruit surface. With acoustics, it has been shown that consumers are able to differentiate fruit based on the acoustical properties as measured by an electronic instrument that taps the fruit and calculates an index based on the fruit's weight and vibration frequency. Bench-top models have been developed. The goal of these companies is to automate the systems for use on packing lines to assess fruit texture at a rate of up to 10 fruit per second.

2.3. Preparing the Orchard for Harvest

Wilson (2003) advice to have the orchard floor in prime condition for harvest. Eliminate groundhogs and fill all burrows. Remove any brush on the ground or any obstacles that could trip a worker. Cut the grass short. This makes it easier to walk when it is wet, and easier to pick up juice apples. Smooth off or grade all orchard roads so the picked fruit can be transported without jostling or bouncing. Many growers have constructed level loading areas, strategically located in the orchard, to facilitate the gentle handling of full bins in any type of weather.

2.3.1. Basket Versus Bag

The picking basket is becoming obsolete in Ontario orchards (Wilson, 2003). With no place to hang the basket in a modern size-controlled planting orchard, growers feel the basket encourages one-handed picking. Experience has shown picking bags are more efficient to use and, if properly handled, will not bruise the fruit as much as baskets (Fig. 3). All picking bags are adjustable in order to fit the build and strength of the picker. The picker is free to use both hands to pick and to gently set the fruit in the bag. the top of the fruit in the bin, setting the picked fruit gently on top.

If necessary this single layer can be easily inspected, with little disturbance to the fruit. If properly done, there should be minimal, if any fruit injury.

Fig. 3. First, position the full picking bag just above the fruit in the bin. Next, release the closing apparatus to open the bottom of the bag. Rest it on the fruit in the bin. Then, slowly lift the bag, while carefully drawing it over the top of the bin. The picked fruit is gently placed on top. (source: http://www.omafra.gov.on.ca)

2.3.2. Ladders

Both economic studies and first hand experience of growers attest to the added picking costs incurred when using ladders (Wilson, 2003). In orchards where ladders must be used, prune the tree in such a way as to have an opening to effectively place a ladder. Secure the ladder, allowing the picker access to the maximum amount of fruit without moving the ladder.

Wilson (2003) suggest to assure if the ladder is lightweight and strong. For convenience, avoid excessive length and train all ladder workers to safely handle a ladder before use. Ask only worker's comfortable with climbing to use a ladder. It has been said that every step a picker makes above the third rung on a ladder result in a 10% decrease in efficiency when compared to a picker standing on the ground. With this in mind, avoid excessive tree height. Similarly, hard to reach limbs might just as well not be picked; better yet, remove at pruning time. Taking the time to climb into high and difficult locations for a few apples is not economical.

2.3.3. Training Pickers

Without guidance, few people have the knack to be top quality pickers. Some people do not have the physical ability or mental awareness to be a good picker. It is best to give them jobs more suited to ability. Train pickers yearly, so they are effective and efficient with the harvesting system you use. An experienced picker trained by one grower may have habits that will not agree with another grower's system. A picker will only be as good as the grower's ability to show him or her what to do (Wilson, 2003).

2.3.3.1. PROPER DRESS

Proper footwear is important for protection and comfort (Wilson, 2003). Use rubber boots on wet and muddy days; work boots on dry days. A change of shoes for the day should be available in case of a weather change or tired feet. *(Figure 2)* Discourage the wearing of flimsy street shoes. For clothing, the layered approach works well. Clothing can be shed or added as conditions change during the day. Sweaters are a poor choice as they become easily snagged in the trees.

It is the grower's responsibility to supply rain gear. This gives you control over when the rain gear is to be worn. Rain gear is too expensive to wear continually as it will get ripped or snagged.

Remember, add Wilson (2003), worker comfort is important to productivity. If a worker is not comfortable, he or she will not work to full potential. Do not expect pickers to work in wet conditions that you would not work in. If picking must be done in the rain or other adverse conditions, a dry and warm place for lunch and breaks are well-appreciated gestures that make working conditions more tolerable.

2.3.3.2. HOW TO PICK

Never allow the pickers to just pull the fruit off the tree (Wilson, 2003). This method disturbs the tree, usually causing other fruit to fall and can lead to significant bruising. This method can also result in fruit spurs being removed with the apples, reducing next year's crop potential.

Fig. 4. A properly dressed picker should be comfortable and safe at all times. Proper footwear is a major factor in picker safety. (source: http://www.omafra.gov.on.ca)

One of the easiest picking techniques to teach is the "rolling method". Using this method the apple is gently turned upside down on the spur. If the fruit is ready to pick it usually separates easily without disturbing other apples or the fruit spur. With a hard to pick cultivar like Northern Spy, the thumb or another finger is often placed between the apple stem and the spur as the apple is rolled upwards. Set all apples carefully in the picking container. Do not drop the fruit or jostle the container. Fruit hitting other fruit, or hitting the side of the container, causes bruising. Handle apples like you would eggs. People with large hands and/or long fingers may eventually be able to remove two apples at a time per hand. Do not encourage this practice until they master picking individual fruits bruise-free.

Bins of fruit with leaves and spurs present are suspect of containing fruit of poor quality. Supervise all help by setting an example and working with them. A good grower will never ask the pickers to do something he or she cannot. Teach by example, not by lecture. Show them exactly how to do the job efficiently and effectively. All advices are included in Pennsylvania Tree Fruit Production Guide (2005).

2.3.3.4. Sorting in the Orchard

Economical growers do the absolute minimum of sorting once the fruit is in the bin. They have trained pickers to pick only marketable fruit and to avoid the inferior fruit or drop it on the ground. Sorting in the bins in the orchard is both inefficient and costly and can increase bruising tremendously (Wilson, 2003).

If sorting must be done, do so as the apples are being placed in the bin. A properly emptied picking bag will leave a single layer of apples that can be easily inspected with minimal handling. Another practice that works well is using a 1 m x 1 m sheet of plastic, air bubble packing, (the kind used to ship delicate items to prevent breakage). When spread over the fruit in a bin it serves as a cushion to sort on, reducing bruising and separates the fruit to be sorted from those already inspected. The fruit can be gently rolled off after sorting, by carefully lifting one side of the sheet. This air bubble material has the advantage over most other products because it does not absorb water from wet fruit or rain and has superior cushioning properties.

2.3.3.5. Picking Crew

Small harvest crews, made up of no more than 10-12 persons, are the most efficient (Wilson, 2003). Crews beyond this size make extra work for themselves by being in each other's way or by spreading out over a large area. Keep the distance from the point of picking on the tree to where the bins are being filled to a minimum. Time is money, and as the old adage states, "if they are walking, they are not picking". To further reduce time loss, some growers move a portable privy along with the picking crew. A small manageable crew is easier to supervise for quality and productivity. It is more efficient to have multiple, well-supervised crews backed by adequate bin handlers than a few huge crews that are difficult to service.

2.3.3.6. Piecework

Piecework does have a place in today's harvest of apples. The piecework rate is always adjustable and is commonly set so those pickers with above-average performance are rewarded for their efforts. It is common to have juice and processing apples picked up on a piecework basis. However, the successful picking of high quality fresh fruit is very difficult on a piecework basis, since piecework encourages speed that all too often increases fruit bruising. Strict supervision is needed for piecework. A grower must never allow the quality of the picked fruit to drop for the sake of speed.

2.4. Mechanical and Physiological Disorders

Bruising is the most common defect of apples. The symptoms include flattened areas with brown flesh underneath. To avoid bruising, carefully evaluate every step in your harvesting, packing, and handling operation. Pad areas of high impact and decrease drop heights. Use water dumps. Eliminate sharp corners. Immobilize the fruit during transport.

Bitter pit is a serious disorder in apples, and although it develops during fruit growth, it can be enhanced during storage by delayed cooling and high storage temperatures. Bitter pit looks like small brown spots in the flesh, usually near the surface and around the calyx end of the apple. Warm weather and moisture stress during fruit maturity, harvesting too early, heavy pruning, excessive nitrogen fertilizer application, and low fruit calcium can all contribute to the development of bitter pit. Well-timed irrigation, calcium nitrate foliar sprays (3 or 4 sprays at 1 or 2 week intervals before harvest), controlled atmosphere storage, and postharvest waxing can all help reduce the extent of bitter pit (Matzinger and Tong, 2006).

Table 7. Other disorders that are uncommon under proper storage conditions include:

Disorder	Symptoms
Sunburn scald	brown to black color on areas damaged by sunlight
Senescent breakdown	brown, mealy flesh, occurring in overmature, overstored fruit
Low temperature breakdown	cortex browning
Soft or deep scald	soft, sunken, brown to black, sharply defined areas on the surface and flesh
Jonathan spot	superficial spotting of lenticels, occurring at high temperatures
Senescent blotch	gray, superficial blotches on overstored fruit
Core flash	browning within coreline
Water core	brown, translucent areas in flesh
Brown heart	sharply defined brown areas in flesh, cavities

(source: Matzinger and Tong, 2006)

Superficial scald, a browning of the skin and flesh, is an apple defect that can develop when apples are held too long in cold storage. Skin browning begins at the calyx end of the fruit and is most severe on late harvested fruit.

2.4.1. Diseases

Postharvest diseases due to fungi, bacteria, and viruses are often due to mechanical or insect damage, followed by the invasion of infecting organisms (Matzinger and Tong, 2006). The most common diseases of apples are blue mold rot, caused by *Penicillium expansum*, and gray mold rot, caused by *Botrytis cinerea*. Blue mold rot infects fruit after harvest, and is more common where apples are moved in water at the packing shed. To control this fungus, use benzimidazole fungicides (benomyl, thiabendazole, thiophanate methyl, methyl benzimidazole carbamate) that are labeled for postharvest use. The residue tolerance for these chemicals is 0 to 10 ppm. Gray mold rot actually infects fruit in the orchard at petal fall, but the fungus does not grow until the fruit begins to mature. The fungus can grow at temperatures as low as 36 degrees F, and can infect surrounding fruit during storage (Matzinger and Tong, 2006).

Many researchers listed several mechanical and physiological disorders, however, bruising is the most common defect of apples.

2.5. Bruising

Bruising is the major reason fruit is culled from packing lines. Recent studies at harvest indicate bruising can come from a source other than rough picking. One of the most significant sources was directly related to the bulk handling of the full bins by forklift and truck.

2.5.1. Bruising in Fruit

Fresh-market fruit growers have long been concerned about bruising (Pennsylvania Tree Fruit Production Guide, 2005). Processing-fruit growers also have grown concerned, because unbruised fruit commands the best prices. The vast majority of bruising in the harvest process falls into two categories: 1) picking bruises associated with rough handling and detrimental impacts, and 2) compression bruises associated with significant vibrations during transport.

Bruising is an ever-present problem. One study showed that bruising of fruit after harvest ranged from 0.6 to 13 percent, with an average of 7.1 percent. A study conducted of packing sheds indicated that bruising caused 8.1 percent of the culls, while another study found bruising to cause only 2.7 percent of the culls. At the retail level in supermarkets, bruising was found to range from 29 to 78 percent, averaging 61 percent (Pennsylvania Tree Fruit Production Guide, 2005).

While bruising is a concern, it must be regarded as a defect that can be controlled through basic management principles. We encourage growers to determine the quality of the product being produced and to determine the dollar value of defects in the product. Good management practices then dictate that production steps be modified if the cost of correcting the problem is less than the cost incurred by defects in the product.

Damage inflicted on fruit is related to the energy available for bruising and the characteristics of the product. The energy available for bruising is in turn related to:

1. the suspension characteristics of the vehicle transporting the fruit,
2. the energy input to the system (a function of roughness of the road and vehicle speed),
3. a third engineering factor involving both the properties and the packaging of fruit.

The damage suffered by fruit is dependent on the number of individual shocks and their severity, and is directly related to the energy absorbed by the fruit.

We may think we cannot change the characteristics of the products we deal with, but this is not entirely so. Packers of Golden Delicious have learned that packing apples directly on removal from storage may produce more bruised fruit than if fruit is packed after being held at a relatively low humidity for a few days to create an outer layer of bruise-resistant cells. Reducing the amount of bruising in fruit appears to be attainable by reducing the amount of energy that fruit receives in handling.

Proper harvesting involves the following:

- Wearing proper clothing and a hat.
- Adjusting the bucket. (Picking buckets with rigid sides and of a reasonable size are recommended)
- Checking all ladders before using.
- Carefully setting ladders and setting them at the proper angle.
- Keeping your body centered on the ladder.
- Handling fruit like eggs.
- For apples, using stem-on picking methods.
- Getting your hands in the bucket to prevent bruising.
- Picking a tree from the bottom up.
- Releasing fruit carefully and slowly into the bulk bin.
- Reporting all accidents to the grower.

In practical terms, bruising can occur during any of six operations in which fruit is removed from the tree and moved into storage. In several harvest operations, some of these steps may be combined, but they are discussed here individually to show the complexity of an efficient, high-volume harvest operation.

Table 8. Fruit operations steps involved in moving the fruit from tree to storage

Fruit location	Fruit-handling operation	
Fruit on the tree	Step 1	Harvesting
Fruit in the bins	Step 2	Moving bins out of the orchard
Bins at the edge of the orchard	Step 3	Moving bins to loading area
Bins in loading area	Step 4	Loading bins on truck
Bins on truck in loading area	Step 5	Trucking bins to storage
Bins on truck at storage	Step 6	Forklift hauling bins to storage
Bins in storage		

(Source: Pennsylvania Tree Fruit Production Guide, 2005)

Listed above seven locations of fruit and the six steps involved in moving the fruit from tree to storage in detail are described on website (http://tfpg.cas.psu.edu).

In Step 1, bruising depends to the experience of picking crews. Major bruise-reducing practices include the use of three-legged aluminum stepladders. Growers do not allow pickers to set straight ladders into trees because they find the resulting damage (bruising and dropped fruits) unacceptable. Another practice is to use bubble liners in bins to absorb energy and vibrations for cultivars such as Golden Delicious and other high-value crops, such as bagged Fuji.

Step 2 involves moving the fruit within the orchard to the end of the rows. This operation is performed by tractors. Most growers prefer the use of low-profile orchard tractors with wide tires. These tires act like springs and can intercept energy to prevent it from transferring to fruit in a bin.

Most orchard tractors, in contrast, have 12- or 16-inch-wide tires on 24- or 28-inch-diameter rims. These tires are normally inflated to be fairly hard and can therefore transmit more energy to the fruit in a bin as the tractor moves over rough terrain. We recommend using tractors equipped with 18.4 by 16.1 orchard tires.

Step 3 involves moving fruit from the edge of the orchard to a loading area. If the haul distance is short it may be desirable to combine this step with Step 2. Special straddle vehicles or four-bin trailers may be useful. In some areas the trailers are operated in reverse and are attached to the front of the tractors. Using a multibin conveyance system may be more efficient than hauling bins singly on tractors. To lessen bruising, all orchard roads should be as smooth as possible to reduce the energy transferred to fruit during transport. Most loading areas should be smooth and paved, if possible, or at the very least covered with gravel. Muddy loading areas add a significant risk of spreading spores and soil-borne decay organisms. Organic material and dirt caught in bin runners can defeat sanitation procedures used at the warehouse in storing and packing fruit.

Step 4 is loading straight trucks or tractor-trailers for further bin movement. When this operation is performed on paved surfaces, using conventional rubber-tired forklifts may maximize efficiency and may be necessary for handling large volumes of fruit.

Step 5 is trucking the fruit from orchard to storage. Drivers should be instructed to follow the smoothest roads and to travel at reasonable speeds, especially over rough roads. Special trailers with “air-cushioned rides” will absorb more road shock than conventional trailers.

The final step, Step 6, is moving the fruit from the trailer to the storage itself. In this phase, loading areas should be as smooth as possible and shock-absorbing forklifts should be used, especially on rough loading areas.

Bruising may be looked upon as a profit-reducing phenomenon and a manageable problem. Bruise-producing operations can be corrected for less money than the reduction in profit caused by the bruising. Remember, bruising is usually caused by only a few procedures. Growers may want to evaluate their present practices in view of the ideas presented here.

Even the best quality bins will flex, and as they flex the fruit is disturbed and pressures the adjacent fruit. The more times a bin is moved during and after filling the greater the incidence of bruising. This type of bruising damage is further accentuated if the bins are repeatedly set on uneven surfaces. There is also an increased chance of bruising fruit with the use of flexible sleds where the bins are pulled along the ground during picking (Pennsylvania Tree Fruit Production Guide, 2005). The more uneven the orchard floor or the greater the distance the fruit sled is pulled, the greater the pressure bruising occurs.

A multiple bin carrier (Fig. 5) is a good way to reduce bruising. The bins are filled on the carrier (Fig. 6) in the orchard rows and when full, are moved carefully and set on a flat surface. From this location the bins will only be lifted once as they are moved to storage.

Fig. 5. This multiple bin carrier is in the raised transit position which offers maximum fruit protection from bruising when the fruit is moved in the orchard. (source: http://www.omafra.gov.on.ca)

Fig. 6. To reduce bruising, fill bulk bins while resting on most multiple bin carriers. The tail of the carrier has been lowered to the ground to facilitate filling. (source: http://www.omafra.gov.on.ca)

Use only the best quality bins for fresh fruit. Sort bins and use the weaker, more flexible bins for juice apples. Today's preference is for a bin made from quality exterior grade spruce or fir plywood. The 5-ply layer sides are 15 mm

(5/8 in.) thick. The bottoms made of 6 or more ply layers is 18.5 mm (3/4 in.) thick. Select grade sheeting is normally used so the interior surface of the bin does not have any knot holes.

Poor quality bins, unsatisfactory bin handling equipment, or careless operators, will result in tremendous fruit losses due to bruising. The efforts of a well-supervised picking crew to control orchard bruising can be nullified by one careless move on route to the storage.

2.5.2. Inspection of Fruit for Bruising

A bruise on an apple is not immediately evident after the bruise is made (Dobrzański and Rybczyński, 2002). It may take as long as one day before the total effect and severity can be evaluated (Wilson, 2003). To assess the amount of bruising caused at harvest by the picking crew, leave a bin undisturbed exactly where it was filled. Come back in one day and carefully inspect the fruit one layer at a time. If there is a problem, it will be evident then. If the problem is a picker, try to correct the situation with extra training. If the situation persists, that picker needs another job (Wilson, 2003).

To check for bruises that have occurred during transit, again wait one day after transit before inspecting the fruit. It's a good idea when sending fruit through commercial packing operations to request that some fruit be packed at the start of picking. The packing line will report the result of the trial and should a problem exist it can be corrected at the start of harvest. A little co-operation between grower and packer in these matters will help to maintain the high standards of apples.

2.5.3. Bruising on the Tree

Pre-harvest drop is the name given to the condition when sound fruit falls from the tree just before or during early harvest. McIntosh is a cultivar prone to pre-harvest drop. Apart from the obvious problem of good quality apples hitting the ground, these falling apples drop through the tree canopy, hit fruit hanging lower on the tree, causing heavy bruising. To reduce this type of injury, pre-harvest drop must be held to a minimum. Maintaining adequate tree nutrition and the judicious use of stop-drop sprays can substantially reduce pre-harvest drop. Similarly, when picking larger trees pick the lower limbs first so if a few fruits fall when the top limbs are picked there will be no additional losses due to bruising of lower fruit.

2.6. FROZEN APPLES

In East-Europe there is always a chance of frost during apple harvest. If frost occurs during harvest do not touch or move that fruit until the frost has left the apple. If fruit has been touched (picked), or rubbed by limbs, or other fruit while frozen, the areas of contact will be damaged under the skin (Wilson, 2003).

If frost is imminent, harvest as much fruit as possible and ensure that all harvested fruit is placed under heated cover. Apples that remain on the tree recover from freezing more completely than harvested fruit. Fruit on the tree may undergo several freezings with little injury. Harvested apples seldom recover from even one freeze. The freezing point of apples is approximately -2ºC. However, the fruit will not freeze until it is at, or below, the freezing point for some time. The greater the number of freezings, or the longer the freeze period, the more likely the fruit is to be injured and to breakdown in storage. Freezing is likely to increase the number of fruit with symptoms of senescence or old age, because freezing increases the rate of ripening. Should the fruit freeze, it will have a hard, glossy appearance, wrinkled skin, and a purplish discoloration of the red side of the apple. Frozen fruit can have a fermented off-flavour and also be considerably softer. Severely frozen areas of the fruit will be brownish, and probably mushy if a large area is affected. If a grower is not sure whether the fruit is frozen, do not begin picking until air temperatures have increased and all threat of persistent frost is gone.

Fruit subjected to frost is best packed and sold, not stored. Frozen fruit ripens more quickly and the storage life is shorter and the fruit may be subject to a higher than normal incidence of breakdown and decay. If the fruit is suspected of having been exposed to frost, at harvest, be sure to inspect the fruit periodically, by removing a few apples from storage and leaving them to age at room temperature for a week. If the fruit shows signs of breakdown when cut open, it should be marketed immediately. Wilson (2003) lay stress and warn to never risk storing frozen apples in controlled atmosphere or low oxygen storage.

2.7. PRUNING TO FACILITATE HARVEST

There are many reasons why orchards should be effectively pruned annually. One reason that receives little attention is the profound effect that pruning can have upon the ease of harvesting (Wilson, 2003). Before pruning, think of the previous harvest. What was the fruit like? What were the picking problems? Can these problems be reduced with a change in pruning practices? Pruning is the time to adjust the physical shape of the tree to ensure both quality and efficiency at harvest next year. Proper tree pruning and maintenance cannot be over emphasized. It is much easier and more economical to pick quality fruit, free of insects and disease, from well opened up trees. From the standpoint of future economic survival, all apple growers must learn to harvest efficiently, and to preserve quality (Wilson, 2003). A grower should be a keen observer and be personally aware of his/her total harvesting and handling system. Leave nothing to chance or to the judgement of others.

Most apple growers are aware of the present high marketing standards and can produce quality fruit, but the most successful growers will be those who can maintain that quality throughout the harvesting and handling period. Theirs will be the fruit that is in greatest demand.

2.8. STORAGE

2.8.1. GRADE SIZE AND PACKING

Grade Standards. U.S. grades are U.S. Extra Fancy, U.S. Fancy, and U.S. No. 1, based primarily on color requirements, but also on freedom from decay, disorders and blemishes, as well as firmness of fruit (Childers et al., 1995). These federal guidelines have been adopted by many states, but states may have additional grading and branding laws. Information pertaining to any state can be obtained from the local state department of agriculture. Washington State packers follow the grade standards of either U.S. Federal regulations or special Washington State Grade Standards promulgated by the Washington State Department of Agriculture (WSDA) in conjunction with USDA (Watkins *et al*., 2002).

Cartons. Sizing is usually carried out by weight or fruit diameter but is independent of grade. Requirements for fruit size vary greatly by market, but in general larger sizes bring greater returns (Watkins *et al*., 2002).

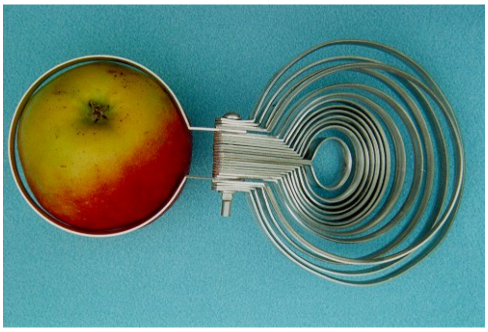

Fig. 7. Simple set used for sizing of apples by fruit diameter (multiply band rings of different circumference)

Fig. 8. Prof. Dobrzański shows equipment used in Sain-Charles International (France) for sizing fruit by diameter (photo: R. Rybczyński)*

* photo performed during the 2nd mission to the European Communities, in the frame of co-operation in the field of evaluation of fruits and vegetables quality (activity of Work Package 9)

Most fruit are packed into bushel cartons, usually 40 lb (18.2 kg), depending on variety, and sold by count (fruit per carton). Apples are most often packed on 4 to 5 soft fiberboard trays made from recycled newspaper. In some cases, the tray may be made of soft polystyrene. Cartons are often unvented. However, unvented cartons on pallet stacks will cool slowly, detrimentally affecting product longevity. Venting to improve cooling rates of fruit is becoming more common. A two-layer carton that is wider, known as the 60 x 40 pack, is becoming more common. It has the advantage of minimizing fruit handling as the cartons are placed directly onto display racks at retail.

Most apples are sold loose, although fruit are increasingly available in polyethylene bags of 3, 5, or 10 lb (1.4, 2.3, or 4.5 kg). These bags were originally used for marketing smaller fruit, but are now used for all qualities and sizes. Bags are most often sold in warehouse-type retail stores. Consumer packages in which 2 to 6 apples, or a combination of fruits, are shrink-wrapped are becoming more popular in some retail outlets (Watkins *et al*., 2002). Shrink-wrapped packages reduce the time consumers spend in the produce section, and also reduce loss caused by consumer sorting and handling of individual fruit.

2.8.2. Cooling Conditions

The rate of cooling of apple fruit affects retention of quality, but its importance varies according to variety, harvest maturity, nutritional status of the fruit and storage history. It is very important to rapidly cool apple varieties that mature in the early part of the harvest season (Summer varieties) since they will soften more rapidly than those that mature in the later part of the harvest season. Within a variety, apples tend to soften more rapidly at later stages of maturity than earlier stages. Effects of slow cooling are magnified as storage length increases. Therefore, inadequate investment of resources at harvest to ensure rapid fruit cooling may not be apparent until late in the storage period when fruit may not meet minimum firmness standards for marketing. For example, a 1-day delay at 21°C (69.8°C) before cooling results in a 7 to 10 day loss of storage-life for ‘McIntosh.’ The effects of delays before cooling of fruit, irrespective of timing of CA conditions, are illustrated for ‘Empire’ apples in Table 9.

Table 9. Effect of cooling rate on firmness of rapid CA Empire apples.

Days to cool to 0 °C	Days from harvest to 3% O_2	Flesh firmness (N) at removal from CA
1	4	63
7	4	58
14	4	52

(Source: Watkins *et al*., 2002 modified from Blanpied, 1986)

Apple fruit can be cooled by room cooling, forced-air cooling, or hydro-cooling. Forced-air cooling and hydro-cooling systems can be used to rapidly reduce fruit temperatures, but they are not widely used for apples in the U.S. Room-cooling, in which normal air flow within the storage room cools the fruit, is the predominant method in most regions. However, air flows around rather than through bins of fruit, and therefore this method is slow and inefficient. Rapid cooling is often difficult to accomplish when rooms are filled rapidly and refrigeration capacity was not designed for a large fruit load. This problem can be overcome in two ways. First, fruit can be separated and loaded into a number of rooms for pre-cooling before being moved into long-term storage. A second option is to load only the quantity that can be handled by the existing refrigeration system.

When refrigeration capacity is a limiting factor, no more than two stacks of bins should be placed across the width of the storage room each day, and that should be reduced to one stack if the air temperature in the room is not down to 0°C (32°F) by the next morning (Bartsch and Blanpied, 1990). Faster cooling will be obtained if bins are placed in the downstream discharge of the evaporator with pallet runners oriented in the same direction as the air flow. Additional bins of fruit should be stacked, no more than two high, in unfilled refrigeration rooms to cool overnight before loading into the CA room the next morning. These stacks should be placed randomly throughout the unfilled room to maximize air exchange with the fruit. Capacity to cool fruit is dependent on refrigeration capacity and room design. A qualified refrigeration engineer should assist in the development of a cooling program.

Maximizing quality maintenance of fruit requires attention not only to temperature immediately after harvest, and during storage, but also during packing, transport, and retail display. This combination of events is sometimes described as the "cold chain," highlighting the importance of maintaining the links from harvest to consumer (Bartsch and Blanpied, 1990).

2.8.3. Optimum Storage Conditions

Apple producers have learned that apple fruit respond dramatically to both temperature and atmosphere modification (Watkins *et al*., 2002). Rapid temperature reduction and the exacting maintenance of low temperatures close to the chilling point of the variety can provide good to medium quality product following 3 to 6 months of storage and in some cases longer. However, modern commercial warehouses couple temperature management with CA for long-term storage of apples.

Regular air storage. The recommended conditions for commercial storage of apples are -1°C to 4°C (30.2 to 39.2°F) and 90 to 95% RH, depending upon variety. Typical storage periods for a number of varieties in air are shown in Table 10. The acceptable duration of air storage has become shorter over the last several years as quality standards in the market have increased (Watkins *et al*., 2002). Also, short-term CA storage is becoming more common as the period available for sale of air-stored fruit has decreased.

Table 10. Potential months of storage (storage characteristics of several apple varieties)

Variety	0ºC air	CA*	Superficial scald susceptibility	Comments
Braeburn	3-4	8-10	Slight	Sensitive to CO_2.
Cortland	2-3	4-6	Very high	Temperature sensitive; McIntosh conditions preferred; Scald inhibitor essential.
Delicious	3	12	Moderate to very high	Sensitive to CO_2 > 2%; Scald inhibitor essential.
Empire	2-3	5-10	Slight	Avoid late harvest; Temperature sensitive; Scald inhibitor not required. CO_2 sensitive.
Fuji	4	12	Slight	Late harvested fruit may be CO_2 sensitive.
Gala	2-3	5-6	Slight	Loses flavor during storage.
Golden Delicious	3-4	8-10	Slight	Susceptible to skin shrivel.
Granny Smith	3-4	10-11	Very high	Sensitive to CO_2.
Idared	3-4	7-9	Slight	Temperature sensitive; Tolerant to orchard freezing damage.
Jonagold	2	5-7	Moderate	Avoid late harvest; May develop scald.
Jonamac	2	3	Moderate	Loses flavor during storage.
Law Rome	3-4	7-9	Very high	Scald inhibitor essential.
Macoun	3	5-7	Slight	Can be stored with McIntosh.
McIntosh	2-3	5-7	Moderate	CO_2 sensitive; Normal storage is sometimes shortened by excessive flesh softening; Scald inhibitors recommended.
Mutsu	3-4	6-8	Slight	Green apples have low eating quality.
Spartan	3-4	6-8	Slight	Can be susceptible to high CO_2. Susceptible to skin shrivel at 36 to 38 °F.
Stayman	2-3	5-7	High	Will tolerate CO_2 up to 5% but usually stored in 2 to 3% CO_2. Scald inhibitor essential. Susceptible to skin shrivel.

* The potential months storage are for rapid CA and range from those obtained with standard CA to those obtained with low O_2 and low ethylene CA. Growing region affects storage periods obtained even under optimal CA conditions. (Source: Agriculture Handbook 66 on the website of the USDA)

Temperatures for air-stored fruit are affected by sensitivity of the variety to low temperature disorders. While lower temperatures usually result in firmer and greener fruit, some varieties such as 'McIntosh' can develop core browning, soft scald and internal browning when held at temperatures below 3°C (37.4°F). However, these disorders typically develop only in fruit kept for more than several months, so risks of low-temperature injury are low for fruit kept in short-term storage (2 to 3 months). An additional factor to consider in selecting storage temperatures, is the impact of temperature on RH requirements. It is easier to maintain RH > 90% at 1 °C (33.8°F) than 0°C (32°F). Final decisions should be based on experience with a variety and advice of extension personnel.

Most apple varieties are not sensitive to chilling temperatures and should be stored as close to 0°C (32°F) as possible. However, varieties that are susceptible to low temperature disorders should be stored at 2 to 3°C (35.6 to 337.4°F). Temperatures also should be increased for fruit stored in low O_2 CA, since lower temperatures increase risk of low O_2 injury.

Temperature in storage rooms should be monitored throughout the storage period using thermocouples throughout the room (Bartsch and Blanpied, 1990). It is dangerous to rely on a single thermometer at the door, as temperatures within stacks and throughout the room may be lower or higher than indicated by such readings. Faster fruit ripening and greater refrigeration usage result when fruit temperatures are too high (Table 11). Excessive temperatures after packing due to lack of cooling or developing during transport to market can negatively impact quality at the consumer level. Fruit temperatures can increase during packing; failure to remove heat may result in subsequent loss of firmness during transport (Kupferman, 1994; Watkins, 1999).

Table 11. Rates of heat evolution (BTU ton^{-1} day^{-1}) by ten apple varieties at different temperatures. Adapted from Tolle (1962). To convert BTU ton^{-1} day^{-1} to kJ ton^{-1} day^{-1}, multiply by 1.055.

	Temperature				
Cultivar	-1 °C	0 °C	2.2 °C	3.3 °C	4.4 °C
Delicious	690	760	910	1,010	1,110
Golden Delicious	730	800	970	1,070	1,180
Jonathan	800	880	1,060	1,170	1,290
McIntosh	730	800	970	1,070	1,180
Northern Spy	820	900	1,090	1,200	1,320
Rome Beauty	530	580	700	780	850
Stayman Winesap	820	910	1,100	1,210	1,330
Winesap	530	590	710	780	860
Yellow Newton	510	570	690	760	840
York Imperial	610	670	810	900	990
Mean	680	750	900	1,000	1,100

(source: Agriculture Handbook 66 on the website of the USDA)

Controlled Atmosphere (CA) Considerations: Apples are the predominant horticultural commodity stored under CA conditions, but the gas composition and storage temperature conditions are specific to variety, growing region, and sophistication of the equipment available for monitoring and controlling the atmospheres. Interactions occur between O_2, CO_2 and temperature. For example, low storage temperatures increase fruit susceptibility to low O_2 injury. Also when very low O_2 levels are utilized, levels of CO_2 should be reduced to prevent CO_2 damage.

Until the mid 1970's, 8 to 10 days were often required to load a CA room and a further 15 to 20 days were needed for fruit respiration to lower O_2 to 2.5 to 3%. Fruit quality resulting from these conditions gradually became unacceptable in the marketplace. Rapid CA is now standard practice in many apple industries. Nitrogen flushing equipment enables O_2 in CA rooms to be reduced to less than 5% within a day or two of harvest, although 4 to 7 days from the harvest of the first fruit and placing into the storage room with CA conditions is considered "rapid CA." For certain varieties, fruit core temperatures must be reduced to predetermined thresholds before application of CA. Even when rooms are filled over extended periods, O_2 concentrations are usually lowered by flushing with N_2, and it is becoming more common to use N_2 flushing for re-sealing rooms that are opened briefly to remove some of the fruit required for marketing (Watkins *et al*., 2002). Nitrogen used for flushing is either purchased in tanks or generated on site.

An RH of 90 to 95% is recommended for apples to prevent shrivel. The major causes of dehydration are small coil surface areas and/or frequent defrosting. When CA rooms are designed, the refrigeration engineer should demand the largest coil size feasible for the room. Operators have been reducing the number of defrost cycles to an absolute minimum to optimize RH in the room. Some operators reduce the O_2 to the minimum safe level and then raise the temperature to 1 to 2°C (33.8 to 35.6°F) to minimize the need to defrost. Some storage rooms are outfitted with high pressure water vapor systems that add moisture to the room and are suited for operation at around 0 °C (32°F). The air distribution system should be designed to prevent condensation of water droplets on fruit to prevent decay. The use of plastic rather than wooden bins, or poly tubes (bin liners) inside wooden bins, has also helped minimize shrivel of 'Golden Delicious' (Watkins *et al*., 2002).

Once fruit have been cooled and CA conditions established, CA storage regimes fall into one of three categories, depending on level of equipment and technology involved.

Standard CA involves conservative atmosphere conditions used with minimum risk of gas-related injuries. Control of these atmospheres may be manual by daily reading and adjustment, or via computer controlled equipment. The margin of safety is large enough so that fluctuations in gas concentrations in manually adjusted storages should not cause fruit injury.

Low O_2 CA storage requires that fruit be kept at $O_2 < 2\%$, but above the concentration at which fermentation will occur. Non-descriptive terms such as 'ultralow' are sometimes used but should be avoided in favor of describing specific O_2 percentages. The safe O_2 concentration varies by variety (Table 12) and region. 'Delicious' apples from some regions, for example, can be stored safely at 0.7% (Lau, 1997) allowing control of superficial scald without use of diphenylamine (DPA). Fruit of the same cultivar from other growing regions may show injury when stored at these low O_2 levels (Lau et al., 1998). Strains within a variety can also vary in sensitivity (Lau, 1997). An extreme case is the Marshall strain of 'McIntosh' where O_2 < 4 to 4.5% are not safe whereas 2 to 3% O_2 is acceptable for other 'McIntosh' strains (Park et al., 1993). In general, it is necessary to increase storage temperature when low O_2 CA storage is used. A number of guidelines have been developed for safe operation of long-term CA storage.

Table 12. Atmospheric and temperature requirements for standard CA storage of apples.

Variety	CO_2 (%)	O_2 (%)	Temperature °C	Low O_2 (1.5 to 1.8%) storage potential
Braeburn	0.5	1.5-2	1	yes
Cortland	2-3 2-3 (for 1 mo) then 5	2-3 2-3	0 2	no
Delicious	2	0.7-2	0	yes
Empire	2-3*	2	2	yes
Fuji	0.5 *	1.5-2	0-1	yes
Gala	2-3	1-2	0-1	yes
Golden Delicious	2-3	1-2	0-1	yes
Granny Smith	0.5	1.5-2	1	yes
Idared	2-3	2	1	yes
Jonagold	2-3	2-3	0	yes
Jonamac	2-3 2-3 (for 1 mo) then 5	2-3 2-3	0 2	no
Law Rome	2-3	2	0	yes
Macoun	5	2-3	2	no
McIntosh	2-3 (for 1 mo) then 5 2-3 (for 1 mo) then 5	3 2	2 3	no
Marshall McIntosh	2-3 (for 1 mo) then 5	4-4.5	2	no
Mutsu	2-3	2	0	yes
Spartan	2-3	2-3	0	yes
Stayman	2-5	2-3	0	yes

* CO_2 sensitive, keep CO_2 well below the O_2 level. If not treated with DPA, use 1.5 to 2% CO_2 during the first 30 days. (Source: Watkins *et al*., 2002 modified from Kupferman (1997)

Low ethylene CA storage. Apple fruit are climacteric, with autocatalytic ethylene production often beginning close to harvest. However, rates of ethylene production can vary greatly among apple varieties. An important physiological effect of CA storage is inhibition of either ethylene production or its action due to lowered O_2 or increased CO_2.

Low ethylene CA storage has been evaluated as a method for reducing superficial scald, as a safe substitute for low O_2 CA storage, and for retarding flesh softening and other forms of senescence (Blanpied, 1990). Low ethylene CA storage (< 1 ppm or 1 µL L^{-1}) was used successfully in New York for storage of the naturally low ethylene-producing 'Empire' apple, but it has been replaced by low O_2 storage. In general, low ethylene CA storage has not proven successful for maintenance of fruit quality if levels of ethylene gas within the fruit cannot be controlled, and generally the return on investment in this technology has been poor.

Other methods used in conjunction with CA storage to maintain quality of apple fruit include treatments using short-term stress levels of low O_2 or high CO_2. In varieties including 'Granny Smith,' 'Delicious,' and 'Law Rome,' O_2 of 0.25 to 0.5% for up to 2 weeks has resulted in control of superficial scald (Little et al., 1982; Wang and Dilley, 2000). High CO_2 (15 to 20%) treatments before application of CA storage were used for maintenance of firmness of 'Golden Delicious' apples in northwestern North America, but generally are no longer recommended due to fruit damage (Blanpied, 1990; Watkins *et al*., 2002).

Under commercial conditions, fruit from CA rooms should be sampled at monthly intervals to detect development of any storage problems and therefore reduce the chances of major fruit losses. Sampling should be carried out by placing representative samples of fruit near a sampling port in the door of the CA room. Samples should be kept in mesh bags rather than plastic bags to prevent false positive readings for scald (Watkins *et al*., 2002).

2.8.4. CA AND APPLE VARIETIES

The selection of CA atmospheres and temperature must take into consideration the variety and in some cases, as mentioned above, the strain of a particular variety, in addition to where it was grown. Experience has shown that varieties can be divided into two types: those tolerant of high CO_2 and those that are not.

'Gala' and 'Golden Delicious' are CO_2-tolerant varieties which also benefit from rapid reduction of atmosphere. In Washington, fruit with moderate pulp temperatures can be placed into a low O_2 environment without danger of CO_2 damage (Watkins *et al*., 2002). Rapid CA is valuable because it helps retain fruit firmness and acidity better than slowly established CA on these varieties. Washington grown 'Gala' and 'Golden Delicious' can be stored as low as 1.0% O_2

with CO_2 levels up to 2.5% at 1°C (33.8°F). If the temperature is lowered below this point, O_2 is raised. Regular storage is 0°C (32°F).

'Fuji,' 'Braeburn' and 'Granny Smith' are varieties in the CO_2-intolerant category. Their cells are densely packed and air exchange within the fruit is therefore reduced. In Washington, these apples must have the flesh temperature close to the storage temperature before the O_2 is reduced (Watkins *et al*., 2002). These varieties have a tendency to develop internal browning, a CO_2 damage symptom that is associated with a natural predisposition of the variety (and pre-harvest factors as well as storage regime). CO_2 should remain well below the O_2 level at all times, and temperatures should be slightly elevated. For example, fruit stored at 1.5% O_2 are stored with CO_2 below 0.5% at 1°C (33.8°F) if fruit are appropriately mature at harvest. It is not advisable to store waxed fruit in boxes with polyliners in CA, as this can hinder air exchange within fruit.

Watkins *et al*. (2002) indicate 'Red Delicious' which is somewhat CO_2-tolerant and is also tolerant of rapid CA. However, producers have not seen the dramatic positive effects of rapid CA on 'Delicious' that have been noted on 'Golden Delicious' or 'Gala.' 'Delicious' fruit soften more rapidly in a bin than on the tree, so CA should not be delayed after harvest. Typical regimes for CA of non-watercored 'Delicious' are 1.5% O_2 and up to 2.0% CO_2 at 0 to 1°C (32 to 33.8°F).

Regulations on CA storage cover both the safe operation and use of the legal definition of "Controlled atmosphere" for stored apples. Regulations include the rate of establishment of CA conditions, the maximum level of O_2 permitted and the length of time fruit are in CA, however, some regulations vary from country to country.

Many precautions must be taken to assure the safe operation of CA storage rooms (Watkins *et al*., 2002). Operators must be aware of the risks of working with O_2 levels below those needed for survival. Death can be almost instantaneous. Additional precautions must be taken when working with CA generators to avoid implosion or explosion hazards.

Chapter 3

TRANSPORT VEHICLES IN HANDLING APPLES

3.1. CHARACTERIZATION OF THE TRANSPORT TECHNIQUES AND VEHICLES USED IN ORCHARD

3.1.1. TRACTOR

All the transport means under study (Table 13) were tested in combination with most popular in Poland - a 9 kN class tractor, Ursus C-360 3P, with a gross weight of 2421 kg. The tractor is powered by a Perkins diesel engine with a power output of 35 kW at 2250 r.p.m.

3.1.2. TECHNICAL SPECIFICATION OF TRAILERS AND FORKLIFTS

Table 13. Technical specification of the transport means studied

Transport Vehicle	Producer	box pallet capacity [No.]	Weight [kg]	Outline size [m]
forklift PWC-701	HERCO	2	280	-
forklift PWC-703/TN	HERCO	2	60	-
self-unloading trailer	ZDMO	4	1000	6,0 x 1,9 x 0,6
Pyro-s trailer	MEPROZET	8	2100	6,4 x 2,4 x 2,1
Universal trailer D44B	SAN	6	1550	5,5 x 2,4 x 1,1*

* - trailer height, sideboards removed

3.1.3. Front and Rear Forklifts

The tractor was equipped with two forklifts with lifting capacity of 7.5 kN (Fig.9):

– front forklift, PWC-701, mounted on the front axle support of the tractor, with lifting height of 1.35 m,
– rear forklift, PWC-703/TN, mounted on the three-point rear attachment of the tractor, with lifting height of 0.3 m.

Fig. 9. Tractor with forklifts during work in orchard (source: Rabcewicz, 2001)

For the tractor to transport four box pallets at a time, the operator uses the front forklift to pile the box pallets two to a stack. Then the tractor transports such two-box pallet stacks on each forklift.

3.1.4. Self-Unloading Trailer for Orchard Use

The self-unloading trailer with a capacity of 4 box pallets (Fig. 10) was designed and made at the Institute of Mechanization, ISK, Skierniewice.

Fig. 10. Self-unloading trailer with 4 pallets (source: Rabcewicz, 2001)

Fig. 11. Sliding of pallets from self-unloading trailer (source: Rabcewicz, 2001)

Unloading is performed by the operator who releases the towbar lock by means of a cable-operated link and slowly moves the tractor forward. Inertia causes the trailer platform to tilt rearwards, and the box pallets slowly slide to the ground (Fig. 11). When the unloading is completed, the platform – under its own weight – returns to its horizontal position and the trailer is ready for another transport cycle.

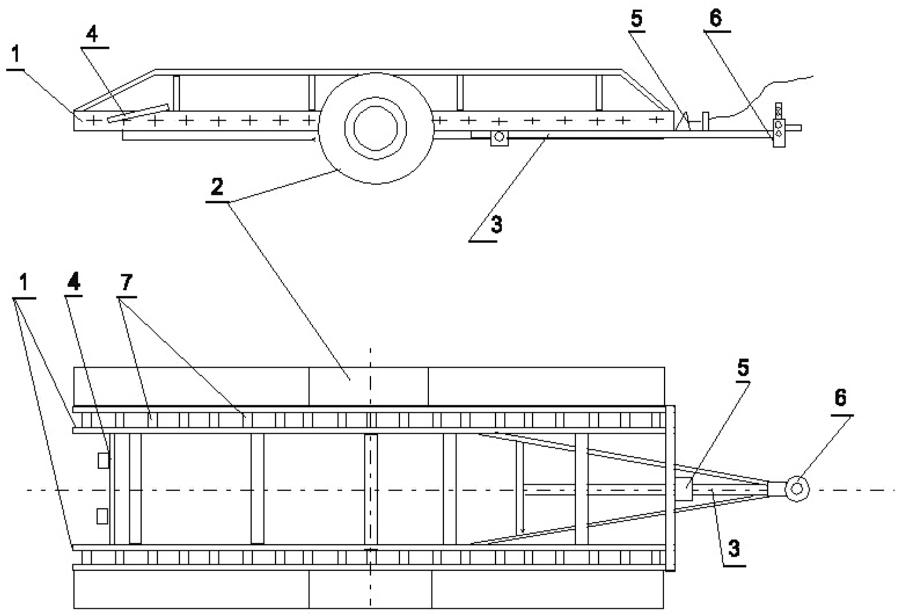

Fig. 12. Schematic of self-unloading trailer. 1 – roller platform, 2 - wheels, 3 - towbar, 4 – pallet stopper, 5 – towbar-platform lock mechanism, 6 – coupling, 7 – platform rollers

It is made up of a platform supported on a single-axle undercarriage, the platform being a roller conveyor with two rows of rollers (Fig. 12). In the front there is a swivel-mounted towbar equipped with a latch for locking it to the platform. At the rear of the platform there is a manually operated stopper blocking box pallets placed on the platform.

The trailer, with box pallets loaded on by hand, is rolled along the interrows of the orchard after the pickers. When the box pallets are filled, they are moved to the storage facility or to a reloading area within the orchard.

3.1.5. Pyro-S Self Loading/Unloading Trailer

The single-axle Pyro-s trailer with a loading capacity of 8 box pallets (Fig. 13) has a two-frame structure. The outer (main) frame is supported on a drive system made up of twin wheels located on a common axle, one behind the other. This design ensures good shock absorbing characteristics for the transported loads. On the front part of the outer frame there is a coupling permitting the trailer to be hooked up to a tractor. The inner frame is attached to the outer frame in a manner allowing its raising and lowering.

Fig. 13. Pyro-s trailer: general view

Fig. 14. Pyro-s trailer: grips securing box pallets

The lower part of the frame is provided with moving grips which, when the trailer is loaded, are lid into the gap of the box pallet base (Fig. 14). Raising of the inner frame and the in and out movement of the grips are effected by means of hydraulic servos powered from the hydraulic pressure system of the tractor.

Before loading onto the trailer, box pallets to be transported are piled two-high and arranged in a straight row. Such a prearrangement of the load is usually made when full box pallets are to be taken out from the innerrows with the help of a tractor equipped with a forklift. Loading the trailer proceeds then in the following manner. The tractor operator approaches the row of pallets with the rear of the trailer and keeps reversing the tractor until eight box pallets are located within the trailer frame – Fig. 15. When the tractor-trailer aggregate stops the operator lowers the trailer frame, activates the hydraulic servos sliding the grips in position to secure the box pallets, and then raises the frame to its transport position. Unloading of the trailer is effected by reversing the procedure.

Fig. 15. Pyro-s trailer: loading of box pallets

3.1.6. Agricultural Universal Trailers

The transport aggregate used in the study was composed of two two-axle box-type trailers, D44B, with a loading capacity of 3.0 t (Fig. 16). The sideboards were removed from the trailers, and the tractor was equipped with a front forklift. The front forklift of the tractor was used to load full box pallets onto the trailers. In the loading area the tractor was unhooked from the trailers and six box pallets were loaded on each trailer, without piling up.

Fig. 16. Two-axle box-type trailers, D44B, with a loading capacity of 3.0 t

3.2. TRANSPORT VEHICLES USED IN STORAGE

Forklifts equipped with large jaws, allows to keep very gently a bounding packages at all operations; including lifting up and down as well during transport in the internal space of storage facilities (Fig. 17).

Fig. 17. Prof. Dobrzański in a battery charged forklift frequently used in large storage facility (photo: R. Rybczyński - Saint-Charles International, Perpignan, France)*

* photo performed during the 2nd mission to the European Communities, in the frame of co-operation in the field of evaluation of fruits and vegetables quality (activity of Work Package 9)

Chapter 4

EFFICIENCY OF TRANSPORT

4.1. EFFICIENCY OF THE TRANSPORT TECHNIQUES AND VEHICLES USED IN ORCHARD

The harvest and transport of fruits are responsible for 60-70% of the labour expenditure involved in the production of seed fruits (Ostrowski, 1977). Improvement of the efficiency of transport operations permits notable savings, but requires the application of technologies specific to particular production conditions. The choice of technical means for the transport of fruits from the orchard to the storage facility is related primarily to their efficiency, and that in turn depends on the type of containers in which the fruits are to be transported, on the distance between the orchard and the storage area or facility, on driving speed, load capacity of the means of transport used, and on the time of loading and unloading. It has been shown that under identical conditions transportation of fruits in small containers (crates) yields lower levels of transport efficiency than when box pallets are used. According to Cegłowski (1970), time required to transport 1 ton of apples from the orchard to the storage facility was 34 minutes in the case of box pallets, and as much as 99 minutes when 20 kg crates were used. This is supported by the results obtained by Rosenberg (1973), who found that the use of box pallets with a capacity of 300 kg caused an increase in harvest efficiency by 20% and transport efficiency by 32% when compared to the technology based on the use of crates.

It is assumed that transport means with lower load capacity should be employed over shorter distances, while specialized means of transport are recommended for use in orchards with higher crop yields and longer transport distances (Czetwiertakow, 1986). Cąderek (1976) formulated the opinion that transport of fruits using low-capacity means of transport, e.g. tractors with forklifts, is profitable when the duration of the transport cycle does not exceed 20 minutes. Likewise, according to Blanpied et al. (1962), Cąderek (1979), and Wilkus (1989), the use of tractors equipped with front and rear forklifts for transport of box pallets is justified only in the case of short distances between the orchard and the storage facility. One of the advantages of the method is the elimination of the operation of loading and unloading onto/from other means of transport. When the distance from the orchard to the storage facility is greater, the authors suggest the use of specialized trailers and vehicles with minimum loading capacity of 6-8 box pallets. Also according to Sikora (1972) the best vehicle for fruit transport over distances of up to 0.3 km is a tractor equipped with front and rear forklifts. In his study the efficiency of such tractor transport was over 6 t h^{-1}. For fruit transport in box pallets over distances of 0.3-1.0 km the agricultural trailer proved to be more efficient (also 6 t h^{-1}). To reduce the cost of transportation over longer distances, it is recommended to designate – within orchards - reloading areas that will permit the utilization of specialized means of transport with high loading capacity (Kenzie, 1971).

Cianciara (1974) estimates the efficiency per day of a tractor equipped with forklifts and transporting fruits over distances of 1-2 km to be 20 tons. The time required for a tractor equipped with two forklifts to transport 1 ton of fruits from the orchard – according to Karasek (1974) – is about 21 minutes. According to Cąderek (1974), transport of 1 ton of apples in box pallets by means of a tractor with one forklift takes about 3 minutes. Orzechowski (1976) determined the parameters of work of an Ursus C-330 tractor equipped with two forklifts, used for apple transport over an average distance of 750 m. The mean time of loading of 1 ton of fruits was 1.3 min; the mean time of unloading was 4.5 min. Without load, average speed of the tractor was 25.4 km $h^{-1}$and the speed when transporting fruit on tarmac roads was 15.4-20.5 km/h (average speed of 18.4 km h^{-1}). The duration of operations involved in the transport of 1 ton of fruits by means of a tractor with two forklifts are as follows (Cąderek 1979, 1980): transport of empty box pallets – 4.9 min., transport of full pallets from orchard to storage area – 17.5 min., loading of box pallets – 3.0-7.8 min., time losses – 1.5-2.6 min.

The average efficiency of Rabo 240 self-unloading trailer with load capacity of 24 box pallets with a capacity of 360 kg was estimated by Lange (1980) to be 26-30 crates (9-11 t h^{-1}). That level of efficiency was obtained in experiments on a transport distance of 1.5 km. The efficiency of the trailer used only for the transport of full crates (without transporting empty crates) was 40-50 crates (14.4-21.6 t h^{-1}). Under the same conditions a tractor equipped with a forklift transported 15-18 crates (5.4-6.5 t h^{-1}). Lange and Weiding (1983) performed a study on the transport of apples from the working alleys of an orchard by means of a Rabo 180 self-propelled transport vehicle with a load capacity of 19 box pallets. The efficiency obtained in the study was 41-47 box pallets per hour (15-17 t h^{-1}).

In a comparative study involving a specialized self-unloading trailer with a capacity of 8 box pallets and a tractor equipped with two forklifts, speeds with load, obtained by Hołownicki (1977), were as follows: for the trailer – 17.2 km h^{-1}, for the tractor – 18.7 km h^{-1}. The time of loading and unloading of the trailer was 5'48". Two indexes characterizing transport efficiency were used in the determinations: Wq [t h^{-1}] and Wp [t km h^{-1}]. The former index is a quotient of the load capacity of the vehicle and of the duration of the transport cycle; the latter takes into account the distance covered and is the product of the distance and the value of Wq. With increasing transport distance, the efficiency of the trailer increased in comparison to that of the tractor: on a distance of 0.5 km the efficiency of the trailer was twice that of the tractor and on a distance of 3.0 km - fourfold. According to Gautier (1980), the combined time of empty and filled box pallets transport per 1 ton of apples was 24 minutes for a tractor and 19 minutes for a specialized transport trailer. The mean time of unloading 1 ton of fruits transported on a trailer was 3.9 min, and that of loading – 3.4 min. Assessment of the transport efficiency of the ÖP-4,5 specialized orchard trailer (Hungary) with a capacity of 9 box pallets, in comparison to a tractor with two forklifts, was performed by Karasek (1973). The mean time of arranging 9 box pallets into a load adapted to the trailer was 14.8 min t^{-1}. The combined time of transporting apples over a distance of 2200 m was 32.2 min/t for the trailer and 20.8 min t^{-1} for the tractor. The low efficiency of the trailer is attributed by the author to loading time losses resulting from the necessity of placing logs or sills beneath the piled box pallets every time a load was prepared.

According to McMechan and Morton (1959), a tractor equipped with one forklift can transport 8-12 box pallets from the orchard to the loading area within an hour. The loading of 16 pallets one by one onto a trailer took on average 12 minutes, and when the pallets where piled two high – 7 minutes. Over a distance of 800 - 1200 m, a tractor carrying three box pallets (two on the rear and one on the front forklift) transported 14 pallets within an hour. The time of loading 12 pallets onto a specialized transport vehicle was determined by the authors as 5 minutes, and the time of transporting the load on a distance of about 4.8 km as 23 minutes. Mean travel speeds of a self-propelled transport vehicle with a load capacity of 10 box pallets, of a tractor equipped with two forklifts (4 pallets), and of a tractor trailer (8 pallets) in studies by Bult and Holt (1968) were, respectively: 19-40 km/h, 13-19 km/h and 16-26 km/h. The tractor drivers chose the travel speeds so as to - in their opinion – avoid vibrations that could cause damage or bruising to the transported fruits. Achieved levels of transport efficiency on a distance of about 900 m (including the transport of empty pallets) were approx. 7.2 t h^{-1} for the self-unloading vehicle, 4.14 t h^{-1} for the tractor and 2.5 t h^{-1} for the trailer. It was observed that with increasing transport distance, above 3 km, the tractor with forklifts – due to its low loading capacity – became less efficient than the trailer. In a study by Rabcewicz et al. (1997), a tractor with one forklift transported within one hour 3.8 t of apples over distances of 360 – 720 m. Average speeds were as follows: without load – 12.1 km h^{-1}, with load – 10.2 km h^{-1}. Under those conditions an aggregate of orchard trolleys transporting four pallets achieved an average transport efficiency of 4.1 t h^{-1} even though its mean speed with load was under 7 km h^{-1}. An analysis of the efficiency of methods utilizing loading and transport equipment with high load capacity was made by Klimpl (1988). He compared the following types of transport means: the "Rabo 240" trailer with a load capacity of 24 box pallets, and self-propelled transport vehicles - "Rabo 180" with a load capacity of 19 box pallets, "ND9-021" with a load capacity of 13 box pallets, and "VBP-09" with a load capacity of 9 box pallets. Average transport speeds achieved in the experiment were 15 km h^{-1} for "Rabo 240" and "VBP- 09", and 20 km h^{-1} for "Rabo 180" and "ND9-21". Efficiency per hour in real work time was as follows: " Rabo 240" – 27.09 t h^{-1}; "Rabo 180" – 24.61 t h^{-1}; "ND9-021" (transport distance - 500 m) – 12.72 t h^{-1}; "VBP-09" (transp. dis. - 500 m) – 10.5 t h^{-1}.

On the basis of questionnaires filled in by users of the Pyro-s trailer, Walków (1985) determined the mean efficiency of the Pyro-s as 4 t h^{-1}, and the mean annual utilization of the trailer was determined at the level of 200 h. The author emphasized the relation of the transport efficiency per hour to such factors as work organization, transport distance, type of road surface, etc. Fuel consumption by tractors with forklifts was approximately 5 l h^{-1}, and that of tractors working with the Pyro-s trailer - 7 l h^{-1}. On the basis of data given by that author one can conclude that there are not more than 100 trailers of the type in operation in Poland.

4.2. THE METHODS OF EFFICIENCY ESTIMATION IN TRANSPORT TECHNIQUES

The fundamental objective of using specialized transport vehicles in fruit transport is the improvement of transport efficiency through reduction of loading and unloading times. The results of our own studies confirmed a considerable reduction of the time of those operations as a result of application of the Pyro-s and self-unloading trailers with relation to forklifts and general-purpose trailers. The time of loading 1 ton of fruits by means of a tractor with forklifts (approx. 2 min t^{-1}) is similar to results of earlier studies (Orzechowski, 1976; Cąderek, 1980). Clearly in favour of the Pyro-s trailer is its comparison with specialized vehicles for box pallet transport tested by other authors (Gautier, 1980; Karasek, 1973) which were characterized by loading and unloading times several times longer. Therefore, the Pyro-s trailer should be considered as a transport vehicle whose application results in considerable savings of time used for the loading and unloading operations.

Due to the possibility of damage to the fruits, the speed of vehicles transporting apples from the orchard to the storage facility should be adapted to the road surface over which they have to travel (Armstrong et al., 1991; O'Brien et al., 1983, Schulte-Passon et al., 1990; Brown et al., 1993, Slaughter et al., 1993, Burton et al., 1989, Timm et al., 1995). In practice, travel speed is controlled by the driver who observes load vibrations and movements resulting from the uneven road surface. No special care is required when empty transport vehicles to the loading area, so higher driving speeds can be used. Average speeds attained by the transport means tested in our own study were lower that those obtained by other authors - Bult and Holt (1968), Orzechowski (1976), Hołownicki (1977). Even when not loaded, the vehicles had a lower speed, which suggests that the road used in the tests enforced speed reduction more often than in studies by those authors. Average speed without load was similar for all the vehicles testes, and was not related to the type of road surface. According to expectations, all the vehicles transporting fruit moved more slowly than when driving without load, and the average speeds attained did not differ. Driving speed with load is significantly affected by the mass of the load and by the type of suspension used in a particular type of vehicle, as this determines the level of vibrations resulting from uneven road surface. Lower speed was used for those vehicles in which vibrations generated at the wheel-road surface contact could be observed on the transported fruits. In our own study, the slowest vehicle was the tractor with forklifts. It responded the most strongly to poorer road surface, which enforced a reduction of driving speed.

As has been mentioned, transport efficiency is related to the time used for vehicle loading/ unloading operations and for travel from the orchard to the storage facility. As a rule, loading and unloading operations are performed under similar conditions, and the times achieved depend primarily on the mode of operation of the vehicle involved. Possible differences may result from lower efficiency of the driver/operator, or by varied condition of the bins or pallets used. Greater differentiation is characteristics of the travel times, as these are related to driving speed, affected by the road surface, and, to a greater extent, to the distance on which the transport operations are performed. Since studies on transport efficiency are made for different transport distances, comparison of the values obtained is difficult. The method introduced in our study, based on a theoretical value of efficiency, determined for a transport distance close to the mean from the experiments, was not applied in studies presented in the literature. The method is more effective than direct comparison of obtained values of effective efficiency and it may prove to be useful in studies on transport of produce other than fruits. The necessary condition is that studies are conducted on roads of similar character and surface condition.

Comparison of the efficiency of transport means under varied conditions is even more difficult. The only way is to estimate the parameters attained by identical transport means, provided they are included in the study. The efficiency obtained in our own study for the tractor equipped with forklifts did not differ much from the results of earlier studies (Lange, 1980; Bult and Holt, 1968; Cianciara, 1974).

High efficiency of specialized transport vehicles similar to the Pyro-s trailer in terms of load capacity and operating principle finds confirmation in other sources (Lange, 1980; Klimpl, 1988). The results of our own study showed a considerable advantage of the trailer over other means of transport. The high efficiency of the trailer results from its relatively high load capacity, short loading and unloading times, and high speed when travelling with load.

Transport means with a capacity of 4 box pallets – tractor with forklifts and the self-unloading orchard-use trailer – attained similar levels of effective efficiency. However, differences were observed in their efficiency, related to the particular times of loading and unloading. These concerned mainly the tractor with forklifts, whose minimum loading time (78 s) was several times shorter from its maximum (383 s). The most frequent reason for long loading of the tractor is problems with correct piling up of box pallets due to their poor technical condition. The advantage, in terms of transport efficiency, of the self-unloading trailer over the tractor with forklifts was shown by comparing their mean theoretical levels of efficiency. On both types of road surface the mean values achieved for the trailer were significantly higher than those for the tractor with forklifts. The lower efficiency of the tractor seems to be due mainly by the more time-consuming loading/unloading operations.

The time of loading and unloading was also the reason for the low efficiency of the aggregate of general-purpose trailers, characterized by the highest load capacity. The trailers attained low levels of effective transport efficiency, and the time required to load and unload 1 ton of fruits was several times longer than that recorded in the other transport technologies. At the same time, the theoretical efficiency of the trailer aggregate was similar to that of the tractor with forklifts. One can conclude, therefore, that at that transport distance the much longer time of reloading operations of the trailer aggregate begins to be compensated for by its three-fold greater load capacity.

4.2.1. Distances and Road Surfaces

The study was conducted under production conditions, during the transport of fruits from the orchard to the storage facility in three seasons. All the vehicles were operated by the same driver. Apples were transported over roads with two kinds of surface:
- mostly gravel (70-80%), remaining part was tarmac,
- mostly tarmac (75-85%), remaining part was gravel.

4.2.2. Parameters for Efficiency Estimation

Estimation of transport efficiency on each type of road was made in 12 replications. Each transport cycle includes trip to the orchard, loading the fruits, back way from the orchard to the storage, and unloading. The measuring set electronically equipped supplied from the electrical system of the tractor (Fig. 18) allows on determination the following values:
- distance covered by the tractor [m],
- total time of travel from start to stopping the tractor [s],
- time of actual travel [s],
- sum of time spent by the tractor when stopped [s].

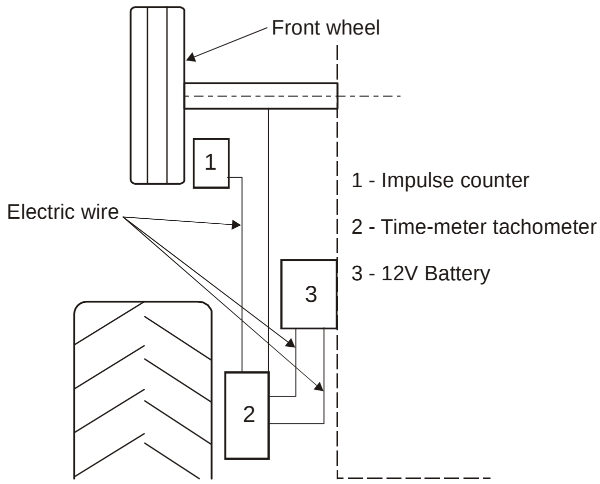

Fig. 18. Schematic of apparatus for measurement of distance covered and tractor work time

The transport trip was measured with accuracy of 1 meter, while 1 second was accuracy of time. During the study the following times were recorded: loading time (T_{lo}), unloading time (T_{unl}), empty travel (T_{tlo}), travel with load (T_{te}) - Table 18.

Table 18. Times recorded during the study on transport means efficiency

Time	Descriptions
T_{lo}	Time measured from the coming of vehicle with empty trailer to until the moment when loaded trailer with fruits left the orchard. The measurement covers time of all operations connected with loading including uncorrected setting boxes and pallets. For universal trailer the time necessary for connecting tractor is added.
T_{unl}	The measurement of time started when the vehicle loaded with fruits stopped in storage and is finished departure after unloading. Unloading of universal trailers is done with the help of battery forklift.
T_{tlo}	Trip time of loaded vehicle from orchard to storage.
T_{te}	Trip time of empty vehicle in a back way from storage to orchard.

The efficiency of transport means was determined as:
- effective transport efficiency, obtained in effective work time; that value takes into account the distance covered, on which the level of efficiency was achieved, and it is useful for the determination of transport means requirements with relation to the level of crop yields obtained and to the distance from the orchard to the storage;
- standardized efficiency, determined for a transport distance of 1000 m.

4.2.3. Effective Transport Efficiency

The effective efficiency is related to the work (Q × L) that is performed during the transport of load (Q) over distance (L) is a specific time T. Its value is defined by the formula (1):

$$W_1[tkm/h] = 3{,}6 \times \frac{Q \times L}{T_{zw} + T_{jp} + T_{jz}} \tag{1}$$

where:

Q [t] – load capacity of the transport vehicle,
L [m] –transport distance covering trip with load and empty vehicle,
T_{zw} [s] – combined time of loading and unloading: $T_{zał} + T_{wył}$,
T_{jp} [s] – time of travel without load,
T_{jz} [s] – time of travel with load.

4.2.4. Standardized Efficiency

Statistical comparison of the efficiency of transport means for average values of effective efficiency is not possible due to the fact that they were achieved over different, though similar, transport distances. Therefore, it is necessary to apply a method that will permit referencing the results obtained in the experimental replications to one transport distance. For this purpose standardized efficiency of transport vehicles was determined, adopting 1000 m as the reference transport distance.

The theoretical hourly efficiency achieved in the individual transport passes was determined from the formula (2):

$$W_{t1000}[t/h] = 3600 \times \frac{Q}{T_{zw} + T_{jp1000} + T_{jz1000}} \tag{2}$$

where:

Q [t] – load capacity of the transport vehicle,
T_{zw} [s] - combined time of loading and unloading: $T_{zał} + T_{wył}$,
T_{jp1000} [s] – time of travel without load on a distance of 1000 m,
T_{jz1000} [s] – time of travel with load on a distance of 1000 m,

Travel times of vehicles with and without load were determined from the formula (3):

$$T_{j1000}[s] = 1000 \times V_n^{-1} \tag{3}$$

where:

V_n [m/s] – average speed of unloaded or loaded vehicle achieved in a given replication.

4.3. ECONOMIC EVALUATION OF TRANSPORT TECHNOLOGIES

Higher hourly fuel consumption in technologies utilizing transport means with greater load capacities compared to those transporting 4 box pallets is due to greater engine power requirements. Hourly fuel consumption obtained in our own study for the tractor with forklifts and the Pyro-s trailer (4.8 and 5.3 l h^{-1}) was slightly lower than that determined by Walkow (1985): 5 and 7 l h^{-1}, respectively. The differences may be related to different test conditions. Comparing the fuel consumption level per one ton of transported fruits one can observe a close relation between the fuel consumption and the attained level of transport efficiency. The least amounts of fuel are required for transport by means of the Pyro-s trailer, i.e. using the vehicle of the best efficiency. Fuel costs related to the other transport technologies are several times higher. The fundamental importance of transport efficiency for fuel consumption can also be noted analysing the effect of transport distance on the theoretical fuel costs per 1 ton of transported fruits. On the other hand, variations in the share of times of particular operations in the whole transport cycle have only a negligible effect on the hourly fuel consumption.

The costs of fruit transport increase with increasing distance between the orchard and the storage facility. This is due to a decrease in the efficiency of transport means. In turn, a decrease in expenditure with increasing amounts of apples transported during a season is a result of better utilization of transport means and of spreading the costs of their purchase and operation onto a greater quantity of transported load. Graphs illustrating the relation of the costs of transporting 1 ton of fruits to the travel distance and the quantity of fruits transported during the season may be helpful in the selection of optimum – from the viewpoint of a given fruit farm – transport means.

The profitability of using transport means with load capacity of 4 box pallets for transport over short distances has already been pointed out (Blanpied et al., 1962; Cąderek, 1979; Czetwiertakow, 1986; Wilkus, 1989). However, there are differences in the definition of conditions under which transport technologies with their use are cheaper than those involving transport means with greater load capacities. A much shorter limit distance, in terms of profitability, of apple transport by means of a tractor with forklifts than that determined in our own study was obtained by Sikora (1972). According to that author, over distances above 0.3 km that method of transport ceases to be competitive with relation to the agricultural trailer. The reason for this, apart from the lower purchase costs of the transport means (trailer only) is the difference in the manner of loading. The tractor working with the trailer was not equipped with a forklift (which additionally reduced the costs of the transport aggregate), and loading was performed with the help of the tractor that carried apples out of the orchard interrows. This had an effect on the efficiency, as it permitted time losses for tractor coupling to and decoupling from the trailer to be avoided. Such a solution, under conditions of high crop yields obtained and good efficiency of workers may, however, seriously interfere with the organisation of harvest. Highly similar to our own results are the recommendations stating that box pallet transport on tractor forklifts is profitable only when the duration of transport cycle does not exceed 20 minutes (Cąderek, 1976). This found a confirmation in our own study, where a tractor with forklifts achieves the same times when the distance from the orchard to the storage facility is approximately 1.5 km. At greater distances, the application of transport means with load capacity of 4 box pallets is less economical than using the Pyro-s trailer when the amount of apples transported during a season is 400 tons or more.

Among the transport technologies under estimation, the highest expenditure is related to transport by means of general-purpose trailers. Within the range of transport distances of 0.5-6 km, the cost of transporting 1 ton of fruits is considerably higher (at distances of up to do 2 km – twice as high) than the costs of transport by means of the Pyro-s trailer. The primary reason for this is the low efficiency of aggregate and high costs of purchase. These considerations determine the low competitiveness of such aggregates with relation to transport means with load capacity of 4 box pallets. Equalization of costs for transport distances of 2-2.5 km takes place only when the volume of fruits transported during a season reaches the level of 1000 tons. Transport of apples by means of an aggregate of general-purpose trailers seems economically justified in situations where the distance between the orchard and the storage facility is considerable. For example, for 400 tons and above of fruits transported during a season the distance is more than 3 km.

In large farms, where the quantity of apples harvested during a day exceeds the transport capacity of a single transport vehicle, it is necessary to use transport aggregates. From the economic point of view, the optimum choice is the Pyro-s trailer – the cost of transporting fruits with the help of the trailer is notably lower than is the case with other transport technologies. If there is no possibility of a specialized vehicle and forklifts and general-purpose agricultural trailers are used, their selection should be related to the distance between the orchard and the storage facility. If the distance is less than 2 km, fruits should be transported using transport means with load capacity of 4 box pallets. If the distance is greater, it is recommended to establish a reloading area in the orchard and to reload box pallets on aggregates of general-purpose trailers.

4.3.1. Time of Operations and Real Range of Transport

Experiments on transport efficiency were planned in a two-factor system: transport means x type of road surface. The experiments were performed in 12 replications (transport trips). The measurements included times of loading and unloading, and travel time of transport means with and without loads.

To compare the time spent on operations of loading and unloading, the times obtained in the experiments were referenced to the corresponding quantities of fruits. The particular values were divided by the load capacity of the particular vehicles, thus obtaining the times of loading and unloading 1 ton of fruits [s t^{-1}]. The speeds attained by the vehicles with and without load were determined on the basis of 12 trips (replications) for each type of road surface. The values of effective transport efficiency obtained in the particular replications were plotted on individual graphs for each type of road surface. In view of the fact that the results were obtained for different transport distances (Table 19), the efficiency was standardized by converting the results obtained for the distance of 1000 m.

Table 19. Range on a road at efficiency study of apple transport techniques

Road type	Gravel			Tarmac		
vehicle	Distance range [m]					
	Min.	Max.	Mean	Min.	Max.	Mean
tractor with forklift PWC	853	1189	1003	908	1245	1021
Pyro-s trailer	533	778	683	987	1377	1096
Self-unloading trailer	741	1273	1082	750	1232	1032
Universal trailer	645	764	704	629	716	676

Experiments on fruit damage assessment were planned in a three-factor system: transport means x driving speeds x number of layers in a box pallet. The experiments were performed in two replications (transport trips). Measurements were made for three layers of apples in box pallets. From every layer a sample of 100 apples was taken according to a method described earlier.

Mean values and coefficient of variation V(%) were calculated for the obtained values of apple firmness. Moreover, the firmness of particular fruits was related to the value characterizing the harvest ripeness of a given variety and the percentage share was determined for fruits with firmness lower than the recommended value. Fruit size distribution in the sample was determined by their percentage share in particular size classes. Statistical estimation of the effect of type of transport means, driving speed, and fruit arrangement in box pallets on the extent and kind of damage to the fruits was performed on mean values, individually for class I, combined classes II and III, and for class IV. Damage levels obtained in the particular combinations were also compared in the particular classes to those observed in apples in control box pallets.

4.3.2. TIMES OF LOADING AND UNLOADING

Minimum, maximum and mean values of the times of operations of transport means loading and unloading, as well as values of the coefficient of variation, are given in Table 20. The shortest times of loading were obtained for the self-unloading trailer and the tractor with forklifts (125 and 168 seconds, respectively). Slightly longer was the loading time of the Pyro-s trailer (193 s), and the longest was that of the aggregate of agricultural trailers (1414 s). The shortest times of unloading were obtained for the Pyro-s and the self-unloading trailers (below 80 s). Fairly stable times of unloading (V% = 6.6%) characterized the aggregate of agricultural trailers, but their unloading time was as much as 695 s.

Table 20. Time of loading and unloading operations for techniques tested

	Time of operation [s]								
operation	loading			unloading			loading & unloading		
vehicle	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
tractor with forklift PWC	78	383	168.4	56	170	100.8	157	461	269.2
Pyro-s trailer	102	262	192.5	47	117	73.3	158	352	265.8
Self-unloading trailer	90	219	125.1	44	195	77.5	142	340	202.6
Universal trailer	1065	1712	1414.1	578	760	694.7	1678	2465	2108.8

The results of the experiments were processed statistically using R.A. Fisher's analysis of variance. The analysis was performed for percentage values, on values transformed in accordance with the Bliss function. For the estimation of the significance of differences between the mean values, Duncan or Student's t-tests were used, assuming a 5% level of significance.

From among the transport means under testing, the shortest time of loading and unloading 1 ton of apples was required for the Pyro-s trailer (73 and 28 s t^{-1}, respectively) which also had the shortest combined time of the two operations (Table 21). In terms of the speed of loading and unloading, the self-unloading trailer, for which the combined time of both operations was about 154 s t^{-1}, was second. Even longer was the loading (128 s) and unloading (76 s) of 1 ton of load transported by means of the tractor with forklifts. The most time-consuming, however, were the loading and unloading operations for the aggregate of general-purpose trailers. The combined time of both operations (533 s t^{-1}) exceeded that for the other transport means several timed.

Table 21. Time of operation at loading and unloading of 1 ton apples [s]

vehicle	loading	unloading	Both operations
tractor with forklift PWC	127.6 b	76.3 c	203.9 c
Pyro-s trailer	73.0 a	27.9 a	100.9 a
Self-unloading trailer	94.8 a	58.8 b	153.6 b
Universal trailer	357.1 c	175.4 d	532.5 d

values marked with the same letter do not differ significantly (5%) acc. to Duncan's t-test; assessment of significance within the columns

4.3.3. VEHICLE DRIVING SPEED

Driving speeds of the transport means over roads with different surfaces are illustrated by the data in Table 22. Differences in driving speeds without load attained by the transport means tested on each of the types of road surface were insignificant. Also, no effect of the type of road surface on the driving speed was proven, even though all the transport means moved much faster on tarmac.

Table 22. Speed of the transport vehicles on two types of road [m/s]

vehicle	empty			loaded		
	surface		Diff.	surface		Diff.
	gravel	tarmac		gravel	tarmac	
tractor with forklift PWC	4.11 a	4.29 a	0.18	2.62 a	3.24 b	0.62 *
Pyro-s trailer	4.22 a	4.35 a	0.13	3.43 bc	3.66 c	0.23
Self-unloading trailer	4.30 a	4.48 a	0.18	3.17 b	3.37 bc	0.20
Universal trailer	3.99 a	4.26 a	0.27	3.21 b	3.45 bc	0.24

- mean values marked with the same letter do not differ significantly (5%) acc. to Duncan's t-test; assessment of significance separately for driving with and without load
* - significant difference (5%)

The lowest speed was attained by the aggregate of two orchard-use trailers on gravel – 3.99 m s^{-1}, on which the highest speed (4.30 m s^{-1}) was achieved by the self-unloading orchard-use trailer. The self-unloading trailer also reached the highest speed on tarmac – 4.48 m s^{-1}. The greatest difference between driving speeds on gravel and on tarmac (0.27 m s^{-1}) characterized the aggregate of agricultural trailers. For all the transport means tested, driving speed with load was lower than without.

Comparison of mean speeds showed that on both the types of road surface the slowest vehicle was the tractor with forklifts. On gravel, on which it reached the mean speed of 2.62 m s^{-1}, the difference between the tractor and the other vehicles tested was statistically significant. The mean speeds of the other vehicles on gravel did not differ significantly, though the fastest, at 3.43 m/s, was the Pyro-s trailer. Also on tarmac the aggregate with Pyro-s proved to be the fastest, and its mean speed (3.66 m s^{-1}) was significantly different from the mean speed of the tractor with forklifts (3.24 m s^{-1}).

For all the transport means, comparison of speeds attained on both types of road surface showed a drop in speed on gravel, though only in the case of the tractor with forklifts the differences in mean speed values were statistically proven.

4.3.4. Effect of Distance Range on The Efficiency of Transport Vehicles

Increasing distance between the location of fruit harvesting and the storage facility causes an extension of the time transport means need for travel and, as a consequence, a decrease in their efficiency. Its rate, different for the particular vehicles, depends o their load capacity, time of reloading operations, and driving speed. Determination of changes in the theoretical efficiency with relation to the transport distance permits the determination of distances above which the application of a given transport technology becomes unjustified.

The levels of efficiency attained by the Pyro-s specialized trailer over the whole range of distances between orchard and storage facility assessed in the study (250-6000 m), considerably exceeding those attained by the other transport vehicles, indicate that the transport technology involving that trailer permits the most efficient transportation of harvested fruits under the conditions of virtually any fruit farm. Also favourable for the Pyro-s trailer is its comparison with other known designs. Lower levels of efficiency of specialized transport means with similar load capacity were obtained in their studies by Bult and Holt (1968), Karasek (1973), and Klimpl (1988). Transport means with notably greater load capacity (19-24 box pallets) were characterized by levels of transport efficiency similar to those attained by the Pyro-s trailer (Lange and Weiding, 1983), or only slightly higher (Lange, 1980).

Higher levels of efficiency attained on shorter distances by transport means with load capacity of 4 box pallets with relation to vehicles with greater load capacities were observed in earlier studies (Hołownicki, 1977; Cąderek, 1979; Czetwiertakow, 1986; Wilkus, 1989). According to Sikora (1972) a tractor with two forklifts, on distances of up to 300 m, is more efficient than an agricultural trailer; Bult and Holt (1968), for similar transport means, estimate that distance at 3000 m. Our own study has shown that on gravel, over distances up to 1000 and 1400 m respectively, a tractor with forklifts and a self-unloading trailer can transport more fruits in an hour than an aggregate of agricultural trailers with three-fold the load capacity. On tarmac the distances are slightly longer – 1200 and 1450 m. In view of the small differences in the speeds of the transport means mentioned, the primary reason of the lower efficiency of the agricultural trailers appears to be the much longer time of their unloading. Over greater transport distances the mass of fruits transported at a time becomes more important; hence the trailer aggregate becomes more effective.

The mutual relationships of the efficiency of the studied transport means in combination with the distance between the storage facility and the harvest area indicate that the Pyro-s trailer is the most efficient under the conditions of a vast majority of fruit farms. The use of the trailer permits better utilization of tractors, and on larger farms may help reduce their number. This prompts the reminder that until recently the number of tractors needed on a fruit farm was determined on the basis of requirements related to protective measures, while now the determining factor is possibility of efficient harvest. On smaller farms, not equipped with specialized transport means, up to the distance of 1000 - 1400 m, it is justified to use vehicles with load capacity of 4 box pallets, out of which better levels of efficiency are obtained using the self-unloading orchard-use trailer. Its advantage over a tractor with forklifts is more pronounced on roads with poorer surface, over which the tractor with forklifts has to travel more slowly due to the risk of damage to the fruits. For distances above 1400 m it is recommended to replace transport means with a load capacity of 4 box pallets with available vehicles of greater load capacity. They are then more efficient, even though, like in the case of the aggregate of agricultural trailers, their loading time is exceptionally long.

4.3.5. Efficiency Level of Vehicles over Different Transport Distances

The objective of that stage of the study was the determination and comparison of efficiency levels attained by the vehicles over different transport distances between the location of fruit harvest and the storage facility. For distances of 250 - 6000m, with increase step of 250m (250; 500; 750; .... 6000 m) the values of the effective transport efficiency were calculated. For the calculations average times of loading and unloading were taken, determined on the basis of all 24 replications. Times of travel with and without load were determined separately for each road surface as a product of average speeds achieved in the experiments and the transport distance assumed in the calculations.

For all the transport techniques, the results indicate a decrease of efficiency with increasing distance of fruit transport. The decrease is the most rapid for distance changes within the range of 250 - 1000 m, where the efficiency of the tractor with forklifts and of the Pyro-s and the self-unloading trailers drops by almost a half. A relatively slight decrease in efficiency (by about 16%) at those distances is observed in the case of the aggregate of general-purpose trailers. For a better illustration the effect of distance on transport efficiency within the range of 250-5000 m are presented in Table 23.

Table 23. Efficiency of transport vehicle on selected distances of gravel road

	Distance of transport [km]													
	0,25		1		1,5		2		3		4		5	
vehicle	[t/h]	[%]*	[t/h]	[%]*	[t/h]	[%]*	[t/h]	[%]*	[t/h]	[%]*	[t/h]	[%]*	[t/h]	[%]*
tractor with forklift	23.83	100	11.91	100	8.93	100	7.15	100	5.11	100	3.97	100	3.25	100
Pyro-s trailer	11.17	46.9	5.31	44.6	3.91	43.8	3.10	43.3	2.20	43.1	1.70	42.8	1.39	42.8
Self-unloading	13.91	58.4	6.26	52.6	4.58	51.3	3.61	50.5	2.54	49.7	1.96	49.4	1.59	48.9
Universal trailer	6.33	26.6	5.33	44.8	4.82	54.0	4.39	61.4	3.74	73.2	3.25	81.9	2.88	88.6

* efficiency have been referenced to the Pyro-s trailer on given distance [%]

For both types of road surface, the highest efficiency over the whole range of transport distances is achieved by the Pyro-s trailer. Over the distance of 250 m it can transport approximately 24 tons of fruits within one hour. When the distance is 2000 m, the efficiency of the trailer exceeds 7 t h^{-1} and is higher than the efficiency of the aggregate of general-purpose trailers on the distance of 250 m. The efficiency of the self-unloading orchard-use trailer on distances up to 2000 m slightly exceeds a half (250 m - 58%, 2000 m - 50%), and at greater distances decreases below 50% of the efficiency of the Pyro-s trailer (3000 m – 49.7%, 5000 m – 48.9%). Still lower values of efficiency are characteristic of the tractor with forklifts. Over the whole range of transport distances they do not reach even a half of the efficiency of the Pyro-s (250 m – 44.5 %, 5000 m – 42.8 %). Up to the distance of 1000 m, the least efficient is the aggregate of general-purpose trailers. On the distance of 250 m its efficiency value of about 6.3 t h^{-1} is almost three-fold lower than that of the Pyro-s trailer, and 50% lower than that of the remaining two types of transport means. With increasing transport distance, however, the efficiency of the trailer aggregate improves in relation to that of the tractor with forklifts and of the self-unloading trailer. On gravel, the efficiency of the general-purpose trailers equals that of the tractor on the distance of 991 m (W = 5.35 t h^{-1}), and that of the self-unloading trailer on the distance of 1338 m (W = 4.94 t h^{-1}). On tarmac, the distances are slightly longer - 1183 and 1450 m (corresponding values of efficiency are then 5.22 and 4.97 t h^{-1}).

4.3.5. Efficiency of the Transport Techniques on the Road

The levels of efficiency of the transport means achieved on two types of road surface are presented in the Table 24. The distances covered in the particular trips include trips with and without load; hence the corresponding transport distance constitutes one half of the value shown on the axis.

Table 24. Efficiency of transport technique on gravel and tarmac [tkm/h]

vehicle	gravel				tarmac			
	Min.	Max.	Mean	%	Min.	Max.	Mean	%
tractor with forklift PWC	9.71	12.81	11.07	9.09	8.72	13.77	11.35	15.03
Pyro-s trailer	15.96	23.14	20.18	9.87	23.34	27.94	25.91	6.16
Self-unloading trailer	11.84	15.94	13.08	8.96	11.00	15.02	12.90	7.46
Universal trailer	6.87	8.42	7.72	5.51	7.03	9.51	8.23	9.02

For each of the vehicles testes the minimum, maximum and mean values of efficiency were determined, as well as the coefficient of variation (V%) - Table 24.

Values of efficiency obtained over distances of 1200-2400 m were relatively constant for both types of road surface, and coefficients of variation (V%) assumed values below 10%. The exception were the results obtained by the tractor with forklifts on tarmac ((V%) = 15%). On gravel, the Pyro-s trailer was the most efficient. On distances of 1200-1500 m, its efficiency – 18.9-21.3 t km h^{-1} – was more than twice as high as that of the general-purpose trailers (6.9-8.4 t km h^{-1}). Under similar conditions (distance: 1450 and 1496 m) the efficiency of the self-unloading trailer was 12.9 and 13.2 t km h^{-1}, respectively. The mean efficiency of that last vehicle (13.1 t km h^{-1}) was slightly higher than the mean efficiency of the tractor with forklifts (11.1 t km h^{-1}).

High efficiency of the Pyro-s trailer was confirmed in tests on tarmac roads. On distances of 2000-2400 m it was almost 26 t km h^{-1}, while on similar transport distances the efficiency of the self-unloading trailer and of the tractor with forklifts was a half of that value. The least efficient vehicle, like in the case of tests on gravel roads, was the aggregate of general-purpose trailers whose mean efficiency only slightly exceeded the value of 8 t km h^{-1}.

4.3.6. Standardized Efficiency of Transport Vehicles on the Road

The highest mean efficiency was achieved by the Pyro-s trailer which transported, within an hour, 11.72 t of fruits on gravel and 12.62 t of fruits on tarmac. Almost 50% less apples were transported by means of the self-unloading trailer – 6.48 and 6.41 t h^{-1}, respectively. Still less efficient, with the differences of mean values with relation to those for the vehicles mentioned above being statistically proven, was transport by means of the tractor with forklifts (mean values of efficiency on both road surfaces of 5.57 and 5.65 t h^{-1}) and the general-purpose trailers (5.13 and 5.65 t h^{-1}). The mean values of efficiency of the last two transport means did not differ statistically, though the times of their transport cycles were notably different: tractor with forklifts - 861 and 853 s, trailers - 2782 and 2531 s.

The standardized efficiency, recalculated for the transport distance of 1000 m, was higher on tarmac than on gravel for all the transport techniques, though the differences were statistically significant only in the case of the Pyro-s trailer and of the aggregate of universal trailers (Table 25).

Table 25. Roundtrip times and efficiency of transport technique on tarmac and gravel at 1000 m

vehicle	mean time of roundtrip [s]		mean efficiency [t/h]		
	gravel	tarmac	gravel	tarmac	both surfaces
tractor with forklift PWC	861 b	853 b	5.57 ab	5.65 b	5.61 a *
Pyro-s trailer	813 ab	755 a	11.72 d	12.62e	12.17 c *
Self-unloading trailer	739 a	747 a	6.48 c	6.41 c	6.45 b *
Universal trailer	2782 d	2531 c	5.13 a	5.65 b	5.39 a *

mean values of transport efficiency on different road surfaces marked with different letters are statistically different (analysis of variance, Duncan's t-test, P ` 0.05)
* - comparison concerns this column only

4.4. COSTS AND FUEL CONSUMPTION

4.4.1. FUEL CONSUMPTION

The amount of fuel consumed was determined by means of the "full tank" method, consisting in topping up the fuel tanks after the completion of transport work performed during a given day. The work time per day, after which the measurements were taken, varied for the particular transport means and was related to their levels of transport efficiency. The amounts of fruits transported per day were similar, at 10-12 t. Fuel consumption was measured with an accuracy of 0.01 kg, and five measurements were made for each of the vehicles tested.

4.4.2. INSTANT FUEL CONSUMPTION

The least amounts of fuel were consumed by the transport means with the lowest load capacity (Table 26). Average fuel consumption by the tractor towing the self-unloading trailer was 4.21 kg h^{-1}, and that of the tractor with forklifts was only slightly higher (4.78 kg h^{-1}). According to expectations, the highest fuel consumption was observed for the aggregate with general-purpose trailers (5.93 kg h^{-1}).

Table 26. Fuel consumption of tractor coupled with vehicles used for apple transport [kg h^{-1}]

Vehicle	forklift		Pyro-s trailer		Self-unloading trailer		Universal trailer	
No.	$G_e\ h^{-1}$ [kg h^{-1}]	$G_e\ t^{-1}$ [kg t^{-1}]	$G_e\ h^{-1}$ [kg h^{-1}]	$G_e\ t^{-1}$ [kg t^{-1}]	$G_e\ h^{-1}$ [kg h^{-1}]	$G_e\ t^{-1}$ [kg t^{-1}]	$G_e\ h^{-1}$ [kg h^{-1}]	$G_e\ t^{-1}$ [kg t^{-1}]
1	4.54	1.09	5.55	0.33	4.20	0.83	5.80	1.05
2	4.76	0.69	5.23	0.32	3.92	0.44	6.21	1.07
3	4.90	0.88	5.29	0.37	4.23	0.48	6.10	1.10
4	4.59	0.91	5.47	0.44	4.39	0.74	5.53	0.79
5	5.09	0.89	5.17	0.44	4.29	0.63	5.99	1.02
mean	4.78	0.89	5.34	0.38	4.21	0.62	5.93	1.01

$G_e\ h^{-1}$–fuel consumption per hour
$G_e\ t^{-1}$– fuel consumption per ton of transported apples

The lowest fuel consumption per 1 ton of transported fruits was recorded for transport by means of the Pyro-s trailer – 0.38 kg t^{-1}. Much higher fuel expenditure was required in the application of the tractor with forklifts (0.89 kg t^{-1}), and the aggregate with general-purpose trailers (1.1 kg t^{-1}).

4.4.3. EFFECT OF TRANSPORT DISTANCE ON FUEL CONSUMPTION

The length of the transport distance affects the times of the particular stages in the total transport cycle, and therefore also the requirement for power that is different for the particular operations. The determination of the theoretical power requirement for an operation, and of the fuel consumption on the basis of that, permits a more universal approach to the determination of changes in fuel consumption with relation to changes in the transport distance than can be achieved in direct tests (concerned with a specific tractor).

In the calculations, mean times of loading and unloading obtained in the efficiency study were used, and constant values were assumed for rolling resistance irrespective of rod surface, and for power consumption for the loading and unloading operations. On the basis of the assumptions adopted, and using standard methods for the calculation of power requirements and of coefficients of rolling resistance and tractor efficiency (Dajniak 1979, Nowacki 1978), the following were determined:

- percentage time-share of particular operations in the whole transport cycle,
- power consumption [kW/h] (power require in all transport operations cycle),
- fuel consumption [kg h^{-1}],
- fuel consumption per 1 ton of transported apples [kg t^{-1}].

The calculations were made for transport distances of from 0.5 to 6.0 km, with a step of 0.5 km.

Fuel consumption was determined with the use of the relation between the hourly fuel consumption G_e and the engine power on the basis of equation (4) described by Dąbkowski et al., (1989):

$$G_e = 3.24e^{0.0325N_e} \quad (4)$$

where: G_e[kg h^{-1}] – hourly fuel consumption,
N_e [kW] – effective power calculated for a given load.
(coefficient of correlation R = 0.999)

The dynamics of increase in fuel consumption with increasing transport distance differs for the particular transport means (Fig. 19). Within the range of distances of 0.5-6 km a slight decrease in fuel consumption was observed for transport means with lower load capacity (e.g. for the tractor with forklifts - from 3.76 to 3.87 kg h^{-1}), while the greatest increase (from 3.72 to 4.42 kg h^{-1}) concerned the aggregate with general-purpose trailers.

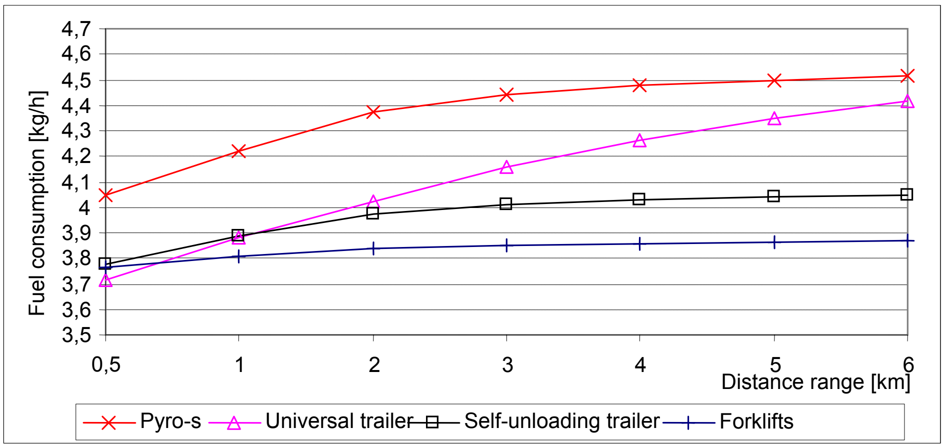

Fig. 19. Fuel consumption determined for studied transport techniques at different transport range

The quantity of fuel necessary for transporting 1 ton of fruits (Fig. 20) increases proportionally to transport distance, for all the transport means tested, but the rate of increase is especially significant in the case of transport means with load capacity of 4 box pallets. Over the whole range of distances under assessment, the least quantity of fuel is required for transport by means of the Pyro-s trailer (from 0.23 kg t^{-1} for 0.5 km to 1.64 kg t^{-1} for 6 km). The least favourable indexes at distances up to 1 km are observed with the application of the general-purpose trailers (twice as much fuel as in the case of the Pyro-s), but increasing transport distance results in equalization of fuel consumption in both the transport technologies.

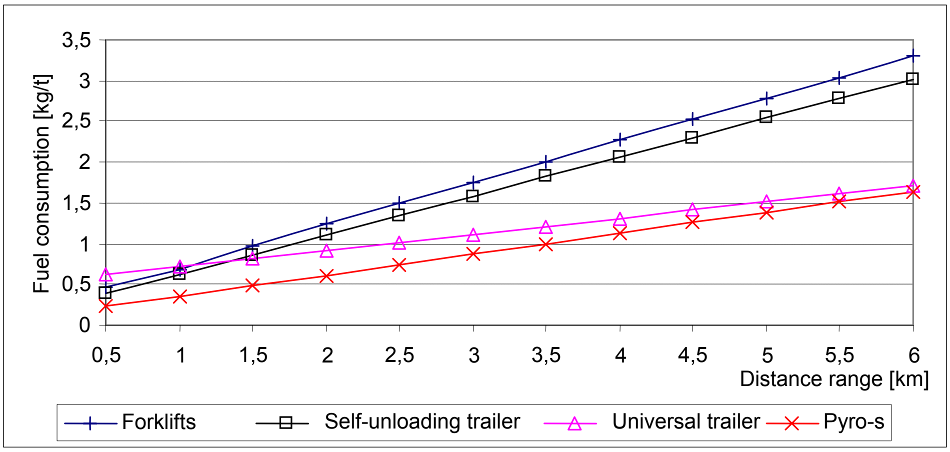

Fig. 20. Effect of transport distance on fuel consumption in transporting 1 ton of apples

4.4.4. Costs of Apple Transport

Economic evaluation of apple transport was performed by comparing the levels of expenditure related to transporting 1 ton of fruit in the various transport technologies. For the purpose the total costs of transport were determined, including the cost of tractor work, costs of work of transport equipment, and human labour (Wójcicki et al., 1992). The adopted data and assumptions are presented in Table 27. The hourly costs of tractor operation were calculated for the whole period of its operation during a year, due to the fact that it is used also outside of the harvest period. At this stage fuel costs were left out, as they were included in further calculations as related to the hourly values of efficiency attained by transport means over different transport distances. The purchase cost of the obsolete Ursus C-360-3P tractor was substituted by the price of the Ursus U 3512.

The prices of series-produced transport means were adopted on the basis of manufacturers' data; those of specialized vehicles on the basis of calculations. In the costs of the aggregate of two general-purpose trailers a provision was made for the cost of the tractor front forklift that was used for performing loading and unloading operations. No provision was made for capital costs not for costs of keeping the trailers in a garage.

Table 27. Data and assumptions adopted in the calculations of fruit transport costs

Annual costs	Ursus tractor U 3512	forklift PWC		Pyro-s trailer	Self-unloading trailer	Universal trailer D44B
		701	703/TN			
price [PLN]	40000	4000	620	20000	8500	12500
Depreciation time [years]	15	15	15	15	15	15
Work time [h]	440*	Related to annual cargo of fruits				
Amortization charges	rate = price divided by number of years of depreciation time					
Costs of repairs [%] of price	9%	5%	5 %	5 %	5 %	5%
Garage charges [%]	5% of price	None available				
Prime costs	20% of fuel	-	-	-	-	-
insurance [PLN]	100	-	-	-	-	-
fuel [PLN/kg]	2.6	-	-	-	-	-
maintains C_r [PLN/h]	6,5 **					

* - *acc. to Department of Economics,ISK*
** - *acc. to Institute of Economics of Agriculture*
(prices and rated as of May, 2001)

The costs of transport of 1 ton of fruits were calculated for levels of efficiency attained by the transport means over transport distances of from 0.5 to 5.0 km, with 0.5 km increment. As the unit costs are related to the amount of fruits transported during the season, the calculations were performed for different amounts of fruits transported during the harvest – from 200 to 1500 tons (with a step of 100 tons).
The cost of transport of 1 ton of fruits was calculated according to the formula (5):

$$K_t = \frac{K_c + K_{pal} + C_r}{W_t} + \frac{K_m}{Q_r} \quad (5)$$

where:

K_t [PLN t^{-1}] – cost of transport,
K_c [PLN h^{-1}] – cost of 1 hour of tractor work (sum of costs of amortization, overhauls, garage, lubricants and engine oil, mandatory insurance, divided by the assumed number of work hours in a year),
K_{pal} [PLN h^{-1}] – hourly cost of fuel (product of mean hourly fuel consumption from operation experiments and of the price of fuel),
C_r [PLN h^{-1}] – cost of 1 man-hour of labour,
K_m [PLN/year] – annual cost of transport vehicle work,
W_t [t h^{-1}] – efficiency attained over given transport distance,
Q_r [t/year] – amount of fruits transported during the harvest season.

In the case of large fruit farms, in which high apple crop yields are achieved, the quantity of apples harvested during a day may exceed the transport capacity of a single transport aggregate. In such a case it is necessary to use several transport means working in parallel. Under such conditions the daily rate of utilization of the vehicles increases, and vehicles of different levels of efficiency transport different amounts of apples during the season. To determine the costs that have to be borne in such a situation, it was assumed that the transport vehicles work daily for 80% of the total time of an 8-hour shift (6.4 h) and fruit harvest continues for 35 work days.

The cost of transport of 1 ton of apples during the 35-day period of harvest was calculated from the formula below (6):

$$K_{tn} = \frac{L_g\left(K_p + K_c\right) + K_m + K_r}{L_g W_t} \qquad (6)$$

where:
K_{tn} [PLN t^{-1}] – cost of transporting one ton of apples,
L_g [h] – number of hours of tractor work during the harvest period (35 x 6.4 h),
K_{pal} [PLN h^{-1}] – hourly cost of fuel from operation tests ands of fuel price,
K_m [PLN/year] – cost of transport vehicle work per year,
K_r [PLN/year] – costs of labour during the harvest period: product of the number of man-hours and of the cost of 1 man-hour (35 x 8 h x 6.5 PLN).

The rate of decrease of the cost of transporting 1 ton of load with increasing volume of transported fruits and of increase of the cost due to increasing transport distance is different for the particular transport means under study. The results obtained indicate that for 200 ÷ 600 t of fruits transported over shorter distances the cheapest solution is the application of tractor with forklifts and of the self-unloading trailer. On the distance of 0.5 km the costs of transport with those transport means are as follows: for a crop of 200 t – 7.8 and 9.0 PLN t^{-1}, for a crop of 600 t – 6.0 and 5.7 PLN t^{-1}, respectively. Costs of transport with the other transport means are higher: for 200 t of fruits - with Pyro-s 14.0 PLN t^{-1}, with the aggregate of general-purpose trailers 24.3 PLN t^{-1}, for 600 t of fruits – 6.3 PLN t^{-1} and 13.0 PLN t^{-1}, respectively. As the volume of transported fruits increases, the transport distance at which those transport means become more economical than the Pyro-s trailer decrease: for 200 t of fruits the distance is about 2.6 km, but for 600 t only 1.0 km. Differences in the cost of transporting 400 t of fruits over distances of 1-1.5 km are already slight – transport costs on a distance of 1 km: tractor with forklifts – 8.7 PLN t^{-1}, self-unloading trailer – 8.8 PLN t^{-1}, Pyro-s trailer – 9.4 PLN t^{-1}. Under the same conditions the transport of 1 ton of fruit using the general-purpose trailers costs 15.9 PLN t^{-1}. The costs of transport with the use of that last technology are generally high in relation to the other transport means.

This is especially true in comparison with the Pyro-s trailer: for all the assumed transport distances and volumes of transported fruits transport with the Pyro-s is cheaper, and on distances up to 1 km the difference is two-fold. The use of general-purpose trailers is more economical with relation to transport means with load capacity of 4 box pallets on longer transport distances: for 300 t of fruits - above 4 km, for 500 t - above 3 km, and for 1000 t - above 2.5 km.

In a situation where the volume of fruits transported in a day exceeds the transport capacity of a single aggregate and several transport means are used for the full shift time, over the whole range of transport distances up to 5 km transporting fruits with the help of the specialized Pyro-s trailer is the least expensive (Fig. 21). On the transport distance of 0.5 km the cost of transporting 1 ton is approx. 3 PLN, while in the case of the second-ranking transport vehicle – the self-unloading trailer – the cost is over 4.6 PLN. The most expensive on that distance is transport with the general-purpose trailers - 10 PLN t^{-1}. With increasing transport distance the costs of transport grow, and there is a shift in the relation between the expense involved in transporting apples by means of the tractor with forklifts and the orchard-use trailer and that of apple transport by means of general-purpose trailers. The costs of those transport technologies equalize at transport distances of about 2 km, when the respective cost levels are 14.5 PLN, 12.6 PLN and 13.8 PLN t^{-1} (for comparison - approx 7.6 PLN in the case of the Pyro-s). Above that distance the application of general-purpose trailers is cheaper than the use of the tractor and the self-unloading trailer.

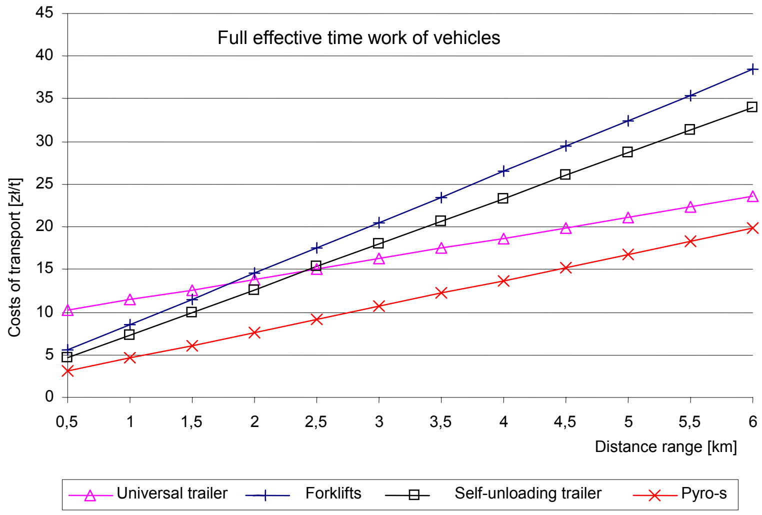

Fig. 21. Effect of transport distance on unit costs of apple transport (PLN/t)

Chapter 5

APPLE DAMAGE AND BRUISING IN TRANSPORT

5.1. FACTORS AFFECTING DAMAGES IN TRANSPORT OF APPLES

The transport methods applied should ensure possibly low level of damage to apples, both during transport and in the course of loading-unloading operations. Research results indicate that transport is the production stage when fruits are most exposed to damage (Hanna and Mohsenin, 1972; Meli and Krebs, 1984). Bruising occurring in the course of harvest and transport affect the storage of fruits. Cąderek (1982), in his study on the effect of mechanical damage on the storage of apples of three varieties: Cortland, Spartan and Bancroft, observed a significantly lower percentage of healthy apples after storing fruits with mechanical damage. The strongest effect on the health of the fruits was that of skin cuts and punctures; e.g. apples of the Cortland variety with damage of that type remained healthy in storage in 58% only, while the corresponding percentage Figure for undamaged fruits was 96%.

The occurrence of damage to apples in transport is related to a number of factors, out of which the most important include the fruit resistance to mechanical damage, related to variety and harvest ripeness, type of packing and transport means used, number of reloading operations, road surface condition, and proper choice of transport speed. To minimize the damage occurring during that production stage it was even suggested to collect harvested apples in containers with water and to transport them to special storage silos (Tennes et al., 1977; Burton et al., 1978). Also with the aim of reducing damage to fruit, producers decide even to apply fairly outdated technologies. For transporting apples out of the orchard interrows, Stanek (1992) recommends to replace forklift-equipped tractors with orchard sledges made of hardwood. According to that author, this should significantly reduce the level of damage to fruits.

The resistance of apples to mechanical damage and the methods of avoiding such damage at particular stages of production and handling are the subject of numerous research works. The studies attempt to define the factors that affect the character and extent of damage to fruit: the mechanical properties of fruit skin and meat, temperature, permissible heights of drop onto various surfaces (Holt et al., 1981; Hyde et al. 1993; Schulte et al., 1993; Barreiro and Altisent, 1993). A study on damage resulting from impact of two apples of the Granny Smith variety showed a close relationship between the damage to the two fruits and the energy transmitted between as a result of the impact (Pang et al., 1992). According to those authors, the extent of the damage may be related primarily to the forces acting between fruits inside a bin or box.

Insufficient firmness of apples resulting from premature or delayed harvest (incorrect stage of ripeness) may fundamentally affect the extent of damage occurring in transport. According to Ostrowski (1966), apples with firmness below 89.0 N can be transported only with the application of the best technical means, and when their firmness is less than 66.7 N they should not be transported at all. From among the many methods for the determination of harvest ripeness of apples, measurement of firmness as represented by the value of force necessary to penetrate the fruit meat with a cylindrical plunger is one of the most thoroughly tested and most commonly available to fruit farms (Wilkus, 1980; Dobrzański et al., 1995). Model mechanical tests for relating the firmness of fruits to their harvest ripeness indicate that the values of apple firmness in the harvest ripeness of the McIntosh and Idared varieties are 71.6-75.5 and 82.4-89.3 N, respectively. Some authors (Kubiak et al.,1980; Cąderek, 1986; Lange and Ostrowski, 1992;) give the harvest ripeness of McIntosh as not less than 71.2 and that of Idared as not less than 80.1 N. According to the most up-to-date data the ranges of fruit firmness values are 65.7 – 75.5 N (McIntosh) and 74.6 – 89.3 N (Idared) - Rutkowski (2001).

Estimating the mechanical strength of fruits of 10 varieties of apple, three classes of skin resistance and three classes of meat resistance to destructive damage were defined (Dobrzański et al., 1995). In terms of skin strength, the Idared variety was classified in Class I (resistant fruits), and McIntosh was classified in Class II (medium resistant fruits). Apple meat compression tests and the obtained values of destructive stress permitted the classification of Idared apples in the class of the most resistant fruits, and those of McIntosh variety in the class of fruits with the lowest resistance. Strong susceptibility of McIntosh apples to mechanical damage during harvest was confirmed by Cianciara and Zbroszczyk (1983), who classified the fruits of that variety in the group of the lowest resistance. In turn, confirmation of considerable resistance to damage of apples of Idared variety was obtained by Meli and Krebs (1984) in their study on two apple harvest and transport technologies.

Damage to fruits is strongly related to the container into which they are collected during harvest. It depends on the following properties of the container: type of design and material used, capacity, and height. A study comparing the extent of mechanical damage to transported fruits showed that apples collected and transported in box pallets get damaged to lesser extent than those in 20 kg crates (Cąderek, 1979; Ben and Kropp, 1980; O'Brien et al., 1980). Improvements of design and materials for box pallets help reduce the level of damage to transported fruits (Timm et al., 1995). According to Burton et al., (1989), the use of boxes with special foam coating reduced the level of damage in several tested transport methods by 35-40%. Likewise, replacement of box pallets made of sawn wood with box pallets made of plywood resulted in a considerable reduction in the number of damaged apples (Armstrong et al., 1991).

An important indicator of the suitability of a packing container for fruit transport is the ratio of the area of fruit contact with the walls to the volume of the container. The higher value of index greater the probability of the occurrence of damage to the transported fruit (Moser, 1982). Also, an important factor is the weight of load in box: the weight increase the decrease the values of accelerations to which the fruits are subjected during transport Jourdain et al., (1993) found that in the course of apple harvest and transport to the storage facility fruits in layers adjacent to the wooden walls of box pallets are about 33% more exposed to damage. A doubling in the rate of fruit damage in layers adjacent to bin walls was recorded in their study by McBirney and Van Doren (1959). To eliminate the effect of fruit position in the bin on the damage occurring in transport it is recommended that assessments should be based on percentage values referencing the amount of fruits damaged in transport to the overall mass of fruits transported (O'Brien et al. 1983).

The literature does not provide a clear-cut definition of the effect of the depth of the bin or box on the extent of fruit damage occurring in transport. According to Blanpied and Ludington (1960) and Blanpied et al. (1961) increase in the height of boxes in which McIntosh apples were transported on a tractor trailer – from 500 to 610 mm – had no effect on the level of mechanical damage to the apples. In turn, McBirney and Van Doren (1959) observed an increase in the rate of damage of Golden Delicious apples in the lower layers with increasing bin depth. According to those authors, the rate of damage in bottom layer of apples in a bin 760 mm high was twice as high as that in the bottom layer in a bin with a height of 380 mm. Nelson and Mohsenin (1968) estimated the mean static load of fruits in the bottom layer in a bin with 280 kg capacity as 20 N, and according to Timm et al. (1998) an individual apple in the bottom layer is affected by a force with mean value of 21 N. Apple limit of plasticity depends on the variety, temperature, and ripeness of the fruits, and falls within the range of 70 - 80 N (Shahabasi et al., 1995; Timm et al., 1998). In the course of fruit transport from the orchard to the storage facility the maximum load values were above 73 N (Timm et al., 1998). In a model study on layer loading in boxes filled with metal balls of different sizes, Geyer et al. (2000) found that the load force is related to the position of a given ball, and the load value sometimes exceeded 70 N, which could cause mechanical damage to fruits even if the box was not moving or vibrating.

The effect of the road surface condition on the occurrence of mechanical damage to fruits is serious enough for roads over which transport is conducted are subject to classification in this respect. At the Department of Transport of the State of Michigan, USA (Timm and Brown, 1992; Brown et al., 1993) a road map has been prepared for three regions with the largest apple production, with roads classified into three classes of surface quality. There is a recommendation to avoid the roads with the worst surface, or – if there is no such possibility – to use only vehicles and trailers with pneumatic suspension for fruit transport. Cegłowski (1974) and Ostrowski (1984) emphasize the necessity of maintaining in very good condition those road surfaces over which fruits are transported. The also recommend the exclusive use of well-sprung transport means as well as correct selection of transport speeds.

Mechanical damage to transported agricultural produce is a derivative of the reaction of the transport vehicle to road surface unevenness (O'Brien et al., 1983; Burton et al., 1989; Schulte-Pason et al., 1990; Armstrong et al., 1991; Brown et al., 1993; Slaughter et al., 1993). Vibrations and shocks caused by road surface unevenness are transmitted through the suspension of the transport vehicle onto its frame and then, through the packing bins or boxes, onto the produce transported. Studies on the effect of the type of packing containers and of vehicle suspension on the extent of damage to apples in transport showed that improvement in fruit quality resulting from the application of pneumatic suspension gave a profit of about 3 USD per transport bin with relation to conventional suspension systems (Timm et al., 1995).

The results of studies on damage to transported fruits do not provide clear-cut answers concerning the mechanisms of occurrence of such damage with relation to the character of vibrations, road surface unevenness, or depth of layers in a transport bin. One can encounter opinions that damage occurring to fruits in transport is less significant than that occurring during harvest. Serious damage to apples of the Granny Smith variety occurring in the course of harvest were attributed by Schoorl and Holt (1982) to the energy absorbed by the fruits during their pouring from containers used by the harvest workers into box pallets. The lowest rate of damage (11-13%) was recorded in the upper layers of fruit in containers, and the highest in the bottom layer - 25-27 %. Studies by McMechan et al. (1962) showed a relatively low damage rate occurring during transport over a distance of about 100 m compared to that occurring in harvest, during box pallet filling. Strong effect of the force of impact on fruit meat crushing and must weaker of surface abrasion and indentations occurring inside packing containers were proved by O'Brien et al. (1984) in a study on the determination of apple sensitivity to bruising caused by a drop onto a wooden surface or another fruit. The fruits were dropped from heights of 50, 30 and 20 cm.

There have been different interpretations of the effect of the depth at which fruits are located in the box on the rate and extent of the occurring damage. According to some opinions damage to fruits occurs mainly as a result of vibrations, in several top layers of fruits in the container (O'Brien et al., 1963; O'Brien et al., 1969; O'Brien and Fridley, 1970; Slaughter et al., 1993; Hinsch et al., 1993). Of key importance are the frequency, amplitude, and duration of the vibrations, amplitude of shifts on the container base, depth of fruit mass in the container, compactness of packing, and the physical properties of the transported fruits. More extensive damage is caused by vibrations with higher acceleration values, even is their duration is relatively short. It has been observed that when the combination of amplitude and frequency in the surface layers of fruits is sufficient to generate vibrations close to 1 g (g – gravitational acceleration), the fruits in those layers can move freely as they receive sufficient energy from the lower layers (O'Brien and Guillon, 1969; Chesson and O'Brien, 1971; O'Brien et al., 1983). Cyclic states of zero gravity permit fruits to rotate and impact against one another, which – according to those authors – explains the occurrence of the highest rates of damage in the top (above 2/3 of the container depth) layers of fruits in containers. The rate of damage decreased with increasing depth in the container, and the least extensive damage was observed in the bottom fruit layers, where the values of acceleration did not exceed 0.36 g (O'Brien et al. 1983).

Another factor accepted as a main cause of in-transport mechanical damage to apples is load forces acting inside the transport container (Cąderek, 1979). Green (1965) attributes the occurrence of much more extensive damage to fruits in the bottom layers in box pallets transported by means of four different transport means to the effect of static forces resulting from the mass of the load. Vibrations recorded in his study had the highest acceleration values in the top layers of fruits. According to Brown et al. (1993), even sporadic occurrence of strong vibrations in the load, with acceleration values of up to 7.0 g, can generate load forces that create a hazard for the middle and bottom layers of fruits. Also Brusewitz and Bartsch (1989) appreciated their importance, enumerating them next to vibrations and impact as a primary factor causing damage to fruits at the particular stages of their turnover. According to Holt and Schoorl (1983, 1985), the main source of energy causing damage to fruits is shocks due to road surface unevenness, while vibrations and static loads are of minor importance. In the opinion of authors conducting test-stand studies simulating the conditions occurring in apple transport by means of vehicles with different suspension systems, the character of road surface irregularities and unevenness is also important, humps and ridges across the road being more dangerous than potholes. Soft suspension dissipates more energy generated by bumps on road surface irregularities, which reduced apple damage by 40% compared to hard suspension.

No effect of position of fruits of five apple varieties in layers in transport box on the extent of damage was found in studies by Emilson and Castberg (1965). A certain randomness in the occurrence of damage was observed by McLaughlin and Pitt (1984) who studied the response of apple tissue to cyclic loads with variable peak values (205-324 kPa) and to static loads with the same values. The characteristics of damage under the cyclic and static loads were not significantly different. The static model showed that damage to apple tissue occurred randomly, irrespectively from the number of loading cycles. Cell walls were subjected to the highest pressures in the initial stage of the action of loads of both types.

The relationship between vibrations to which apples are subjected in transport and damage to the fruits seems obvious irrespective of the interpretation. What is important is to determine the conditions that have to be met to minimize the risk of damage to the fruits. Holt (1967) found a distinct relationship between damage to apples and the speed of transport means. Transport speed at which no visible movement of the upper layers of fruits can be observed permits the avoidance of major mechanical damage to the fruits. The choice of speed suitable for given road conditions depends on the type of vehicle suspension system (Green, 1966). The author compared damage to apples transported by means of a tractor with forklifts, an orchard-use trailer with a load capacity of 3 box pallets, and self-loading vehicle (S.L.V.) with a load capacity of 4 pallets. Average speed of the first two transport means was 6.4 km h^{-1} (4 mph), and of the third – 8 and 16 km h^{-1} (5 and 10 mph). Vibrations were measured by means of sensors located on the sideboards of the box pallets and on pieces of wood placed in the top layers of fruits. Mean values of acceleration for all the transport means were 0.20-0.25 g. Peak values of sporadic accelerations recorded by the sensor located on the sideboards of box pallets were 4.5 g for the tractor and 1.5 g for the self-loading vehicle. Hen and Sun (1981) showed that shocks causing accelerations in the range of 0.9-2.5 m s^{-1} (0.09-0.25 g) had no effect on bruising of transported apples of the Golden Delicious variety. The limit value of acceleration determined under laboratory conditions by Sober et al. (1990), below which no visible or sub-skin bruising occurred, was 40 g for the Paula Red variety and 30g for Golden Delicious. The authors also observed a notable effect of the mass of fruits on the extent of occurring damage.

O'Brien and Fridley (1970) compared the values of acceleration of vibrations occurring enroot in transport means with different suspension systems. Acceleration sensors were mounted on the chassis of the vehicles and in the top layers of fruits. The greatest chassis vibrations (about 0.4 g) were recorded for vehicles with coil and leaf spring suspension, on which fruits in the top layers were subjected to accelerations of up to 1.0 g. The safest for the transported fruits was the vehicle with pneumatic suspension whose chassis had accelerations below 0.2 g and fruits in the top layers about 0.4 g. Brown et al. (1993) found that the values of the most common vibrations of the chassis of transport means in motion fell within the range of 0.25-0.50 g. In a study involving transport means differing in suspension systems and load capacity, brand new box pallets were used as it was found that the degree of deflection of box pallet bottom increased with age of the box pallets, especially if piled on top of one another with no support in the middle. Apples with punctured skin constituted from 0 to 2% of the total volume of transported fruits, and apples with no damage, depending on the type of vehicle, from 70 to 91%. Transport means with spring suspension caused greater damage (both in terms of rate and extent) than vehicles with pneumatic suspension. In a study by Green (1965), the number of vibrations with accelerations of 1.0 g was the greatest in the top layers if fruits for all four transport means tested. For two – a self-propelled vehicle with a load capacity of 6 tons and a two-wheeler (with no springs) with a load capacity of 1 ton – no accelerations of that value were recorded in the middle and bottom layers. Herregods (1994) is of the opinion that mechanical damage to apples transported in unit packing is caused by vibrations with acceleration values exceeding 0.75 g. Most extensive damage in fruit transport by truck occurred in the rear part of the platform, in top-layer crates.

Some studies on damage to fruits are concerned with the effect of transport means as such, without going deep into the mechanisms of its occurrence. Kossowski (1979) recommends the avoidance of transporting apples by means of forklifts due to mechanical damage to fruits in the top layers in box pallets. Comparing the extent of damage to fruits of the Gloster apple variety transported on tractor forklift and by means of a train of orchard trolleys with load capacity of 1 box pallet, greater damage was observed in fruits transported by means of the tractor (Rabcewicz et al., 1997). In a study by Burton (1989), the least damage was caused by a transport technology based on the use of tractor forklift in the orchard and a special three-axle trailer on the way to the storage facility. Damage greater by about 60% was observed in transporting apples in the rear of a specialized bin carrier and then to a cold storage plant using a truck. Maindonald and Finch (1986) compared the levels of damage to apples of the Granny Smith variety transported in box pallets by means of two transport vehicles – with conventional leaf spring suspension and with pneumatic suspension. A slightly lower level of mechanical damage was observed in fruits transported by means of the pneumatically suspended vehicle. A distinct advantage of pneumatic suspension over spring suspension was noted by Armstrong et al. (1991) in a study involving simulations of transport for 15 minutes over 2nd category roads.

Cąderek (1976) estimated the percentage of damaged fruits for McIntosh apples transported on the forklift of a tractor over a distance of 250 m as 8.7%. Most of the damaged fruits (8.1%) had bruising with diameters below 15 mm, while fruits punctured or with longitudinal cuts constituted 0.2%. Apples of the Bankroft variety, transported in the same type of packing on a distance of 350 m, got damaged in 7.1%. There were no punctures, and longitudinal cuts constituted 0.05%. Also Cąderek (1974) observed the following damage in apples of the McIntosh variety transported in box pallets by means of a tractor with forklifts: bruising up to 15 mm – 9.5%, bruising above 15 mm – 0.7%, cuts and punctures – a total of 0.5%. In a simulation study on an artificial track, Wilkus (1989) observed a relation between the occurrence of mechanical damage to fruits and the duration of transport, with the major share of the damage occurring in the initial stage of transport. The author compared also the rates of damage to apples in transport on distances of 500 - 1500 m by means of an orchard-use trailer and a forklift travelling with speeds of 5-15 km h^{-1}. For the Jonathan and McIntosh varieties, less extensive damage (differences in mean values were statistically proven) was observed in fruits transported on the trailer. Using the damage scale proposed by the author, 82% McIntosh apples transported on the trailer and 80% of those transported on the forklift were classified as „consumption apples".

In the prediction of the extent of in-transport damage to fruits also the processes of mathematical modelling are employed (Holt and Schoorl, 1985; Jones et al., 1991). The models include the following variables: road surface, type of tyres used, type of suspension system, type of undercarriage, kind of load and manner of its arrangement. The energy absorbed by fruits was determined by defining the characteristics of forces acting on the fruits in transport. The values of predicted damage to apples transported in box pallets placed at various locations on transporting vehicles were verified in measurements implemented in practice. Peleg (1984) was involved in the development of a mathematical model of mechanisms causing damage to fruits. The model allowed the prediction of the extent and depth of damage to the fruit meat, and considered two contact systems – fruit to fruit and fruit to hard surface. The parameters used in the model were determined experimentally for various fruit species. For the development of mathematical models for the prediction of damage to apples, Srivastawa et al. (1992) tested the behaviour of apples of three varieties under static loads, in free drop, and under enforced vibrations. The area and depth of damage were determined with relation of the vibration parameters.

In studies on in-transport damage to fruits various methods are used for the assessment and classification of the damage. Occasionally authors develop their own classifications of damage (Cąderek, 1982; Wilkus, 1977; 1978), frequently different for different studies (Cąderek, 1980; Cąderek 1982). This makes it difficult to compare the results obtained. Classifying the degrees of mechanical damage to apples according to the USDA (United States Department of Agriculture) scale, Mohsenin (1968) divided them into four quality groups (described in the work methodology). Fruits in classes I, II, III are cleared for commercial turnover as consumption fruits, while apples in the last class are used for processing. Also in accordance with the Polish standard PN-77R-75024:1977, apples with punctured or cut skin cannot be stored or used for direct consumption. Cianciara (1981; 1986), Cianciara et al. (1988), Hołownicki (1985), used the scale adopted by Mohsenin in their studies on damage to apples at various stages in their turnover. When the process to which the fruits were subjected did not affect one of the classes, a modification was made to the classification, combining classes of the USDA classification (Cianciara and Hołownicki, 1986) or dividing into several subclasses a class in which an especially strong effect of a factor was observed (Kossowski, 1979).

Various methods are used for the assessment of transport means. The most popular are simulations on vibration test stands and artificial tracks, as well as driving on actual transport roads. Under real conditions, particular technical and methodological difficulties are encountered in obtaining repeatable results and in measuring vibrations on the vehicles. This is especially difficult when low frequency vibrations are concerned. The most commonly used measurement technique is the application of magnetic recorders for recording voltage signals transmitted from accelerometers installed at selected locations on the vehicle tested. The recorded vibration characteristics are processed under laboratory conditions using stationary processing and analysing apparatus (Zalewski and Pleszczyński, 1979).

Accelerometers are usually installed on the chassis frame of the vehicle tested, in layers of fruits (O'Brien and Friedley, 1970; O'Brien et al., 1983), or on bin walls (Green, 1966). In fruit layers accelerometers can be placed directly, on pieces of wood, or built into mockup fruits placed in between real fruits (Rider et al., 1973; O'Brien et al., 1973, Burton 1989). Another method for the measurement of energy absorbed by damaged apples is the use of a mockup fruit in the form of a vinyl sphere filled with water (Jenkins and Humphries, 1982). As a result of impacts, momentary pressure increases occur inside the sphere, forcing out a certain amount of water through valves in the sphere vinyl skin. The resultant decrease in the sphere weight indicates in a linear fashion the amount of absorbed energy and the extent of damage. The most modern methods for vibration measurement involve the use of mockup fruits known as IS (Instrumented Sphere), equipped with sensors and recorders of the value and duration of vibrations. The devices have their own memory, which allows for several hours of autonomous, unattended operation (Schulte-Pason et al., 1990; Sober et al., 1990). But even though Herold et al. (1993), comparing the technical characteristics of mockup fruits, credited those devices with a high level of suitability for the determination of loads to which fruits are subjected in the course of their turnover, one should keep in mind that they are not capable of representing accurately the particular varieties of apples (Tennes et al., 1990). An additional shortcoming of the device is its high cost, limiting its availability to larger research centres only.

Mechanical damage to fruits is most frequently assessed through sensory examination of fruit surface and through measurements of fruit diameters. Contemporary highly accurate thermal (Bennedsen and Qu, 1996) or ultrasonographic (Upchurch et al., 1990; Bellon, 1993, Molto et al., 1996; Crowe, 1996; Galili et al., 1993) methods are not used in evaluations of transport means.

5.2. PROCEDURES OF STUDY THE EFFECT OF TRANSPORT ON APPLE DAMAGE

Damage to apples was assessed on fruits of the McIntosh and Idared varieties, the choice of which was based on their fundamentally different resistance to mechanical damage: McIntosh is considered to be especially susceptible to damage, and Idared exceptionally resistant (see – Review of Literature). Moreover, both of these apple varieties, in spite of the ongoing changes, still retain their position as major varieties in the Polish apple production. In the years 1997-1998, in terms of the volume of fruits produced in Poland, Idared (400,000 tons) rated first and McIntosh (120,000 tons) - fifth (Mika 1999).

Harvested fruits were collected in metal bins with removable canvas bottoms, all the bins being filled with fruits by the same six-person team. Immediately after the harvest, the apples were transported to the storage facility. Transport of apples of each variety took place on two consecutive days. Damage to apples was assessed for three driving speeds for each of the transport means used, on fruits from individual bins selected at random during harvest in the same orchard quarter.

As the assessed damage to apples originated both in transit and during the loading and unloading operations, there was no possibility of formulating conclusions on the suitability of particular transport means for transporting fruits at various speeds directly on the basis of the damage. To determine the response of the transport means to road surface irregularities, in all transport trips measurements were taken of the values of acceleration of vibrations acting on one of the transported bins.

5.2.1. FIRMNESS, FRUIT SIZE AND WEIGHT

Prior to the harvest, on random-selected trees in the orchard quarter the firmness, size, and weight of fruits were determined. Firmness was tested according to standard methodology (Lange, Ostrowski 1992) using the Magness-Taylor firmness tester with a 10 mm diameter plunger; the depth of penetration was 8mm. The measurements were taken on the test day, on 30 fruits from 8 trees, with two replications on each apple: on the side with the basic colouring and on the blush side. The areas where the plunger was pressed in were uncovered by cutting in the fruit skin a circle with a diameter of about 20 mm. Apple size was determined on the same fruit sample on which the firmness tests were performed. The apples were classified in size classes with a step of 5 mm, and mean weights of the apples were also determined.

Values of firmness of the McIntosh apples, determined on the days when damage assessment was performed, did not differ significantly. The obtained values of 78.3 and

81.2 N, respectively, (Table 29), exceeded the recommended level for fruits of that variety for the phase of harvest ripeness (65.7-75.5 N, Rutkowski, 2001).

Table 29. Firmness of apples on the days of damage assessment

days	variety					
	Mc Intosh			Idared		
	Firmness		Firmness < 65.7 N * [%]	Firmness		Firmness < 74.6 N *[%]
	[N]	V(%)		[N]	V(%)	
1	78.3	11.6	16.7	75.7	8.4	63.3
2	81.2	12.7	10.0	76.4	9.6	70.0

* - firmness of one or two sides of the fruit

Irrespective of the men values, firmness of one side of about 13% of the apples was lower than the recommended value. Firmness of individual fruits of the Idared variety, compared to McIntosh, was more uniform and the mean values determined for the two test days – 75.7 N and 76.4 N – classified the fruits tested in the lower ranges of the interval recommended for harvest ripeness (74.6-89.3 N, Rutkowski 2001). However, the share of fruits with firmness value of at least one side (one or both) below the minimum allowed, was relatively high (63 and 70%).

The diameters of all the fruits of the McIntosh variety fell within the range of 60-90 mm. On the first test day 87% of the fruits and 90% on the second were classified in the 65-80% size class. The diameters of the fruits of the Idared variety were above 65 mm and did not exceed 90mm. 96,6 % of the apples on day one fell in the range of 70-90 mm. On the second test day that size range included 93.3% of the fruits in the sample.

5.2.2. Vehicles Speed and Transport Range

The fruits were transported over the same road, with transport distance identical for all replications. For the McIntosh variety, 55% of the transport distance was a tarmac-surfaced public road, the remaining 45% being a gravel road in the orchard. Orchard quarters with the Idared variety were located along the same road, but closer to the storage facility, hence the orchard road constituted only about 35% of the total transport distance. The condition of the road was estimated as very good. The apples came from the same part of the quarter. In each single transport trip only one bin filled with apples was transported. All other bins, filling up the total load capacity of a given vehicle, contained concrete ballast with weight identical to that of a binfull of apples.

The tests were made with three driving speeds. The speeds were maintained so that the vehicle did not exceed an assumed maximum speed level that the tractor driver kept over predetermined sections of the road. The road sections, identical for all the vehicles tested, comprised most of the whole transport distance with the exception of areas where the speed had to be reduced due to traffic requirements (road bends, intersections). A replication of the experiment was a single transport trip of a vehicle at one of the assumed speeds. Two replications were made for every combination, each on a different test day.

Maximum speed values were chosen in accordance to the following assumptions:
$V_1 = 3.87$ m s^{-1} (13.9 km h^{-1}) – speed equal to average speed achieved at efficiency study,
$V_2 = 5.49$ m s^{-1} (19.8 km h^{-1}) – single fruits vibrating on top layer of 4 bins load,
$V_3 = 7.27$ m s^{-1} (26.2 km h^{-1}) – fruits vibrating on top layer of fruits on all of tested vehicle.

Assessment of damage to the fruits was made three days after harvest, i.e. after a period when mechanical damage becomes clearly visible (Cianciara, 1981). The transported bins were stored in a room at ambient temperature. Damage to non-transported apples provided reference for the assessment of damage sustained in transport. Damage observed in the control sample was due to careless picking and transfer from the pickers' containers to the bins. The control sample was made up of apples in two bins left in the orchard, at the location from which transport originated.

Damage assessment for the two apple varieties was made by the same team of three persons. The assessment was performed visually, on fruits selected from three fruit layers in the bin: surface layer, middle, and bottom layer. From each layer 100 fruits were taken at random, according to the following procedure: 50 apples from the bin perimeter (area of contact with bin wall), 20 from the centre of the layer, 30 from intermediate locations in the layer. The determinations included the number of undamaged apples, the extent of damage to particular fruits, and the number of apples with skin cuts. The diameter (or the length and width, depending on the shape) of bruising was measured with an accuracy of 1 mm.

5.2.3. VIBRATIONS

Although logic suggests that vibrations are the primary source of damage to transported apples, it is not easy to determine the mutual relationships between apple bruising and the magnitude of vibrations. The occurrence of damage to fruits is burdened with a certain degree of randomness, even under laboratory conditions (McLaughlin and Pitt, 1984). Limit values of acceleration posing a threat to fruits are different for various varieties and stages of ripeness (Sober et al., 1990). And then, the type of suspension system and the condition of transport bins may cause damage that is incidental in character and therefore unpredictable (Brown et al., 1993).

In our study, damage to apples occurred over the whole transport cycle, also during the loading and unloading operations. Therefore, there is no possibility of directly relating the damage to fruits with the magnitude of vibrations recorded on the bins during transport. Nevertheless, the values of acceleration recorded are useful for comparison of the responses of vehicles to increasing speed or worsening road surface condition.

Making such a comparison for the transport means tested, one can observe that the recorded accelerations of vibrations are distinctly higher for the tractor with forklifts and the self-unloading trailer. This is especially true of the tractor with forklifts, for which even at the lowest speed, seemingly safe for the transported fruits, the recorded accelerations had values above 2.5 g, exceeding by a factor of ten the value of 0.25 g accepted by Chen and Sun (1981) as safe for apples of Golden Delicious variety. Any increase in the speed of that vehicle results in the occurrence of strong jolts, not observed in other transport means, with values exceeding 5.0 g, even sporadic occurrence of which can generate load forces dangerous to the middle and bottom layers of fruits in bins (Brown et al., 1993). The above confirms the conclusion – following from the assessment of damage to fruits – that the use of tractor forklifts is a transport method that is the least safe for the transported apples. This is supported by studies by Green (1966), in which bins transported by means of a tractor were subjected to accelerations of 4.5 g, while the maximum values of acceleration recorded on other vehicles were several times lower (1.5 g).

5.2.3.1. Bin Vibrations Monitoring

The level of vibrations transmitted onto the transported bins was determined on the basis of measurements of the values of acceleration to which the bins were subjected during transport. Schematic of the measurement apparatus is presented below (Fig. 22).

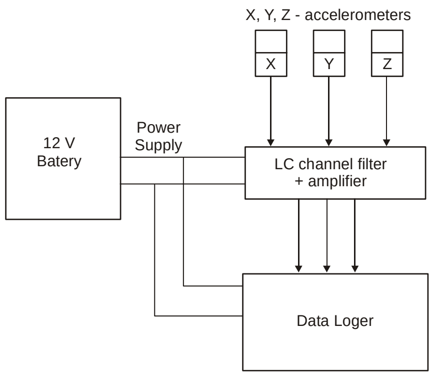

Fig. 22. Schematic of accelerometer connections with recording apparatus

Fig. 23. Accelerometers installed on the bin wall

The courses of vibrations were recorded during each transport trip of the bin containing apples subjected to damage assessment. To the bin wall three piezoelectric sensors were attached (type KD-42), converting the values of acceleration into electric signals (Fig. 23). Each sensor measured acceleration values in one plane – X, Y, Z. The measure of acceleration is a multiple of gravitational acceleration g (g = 9.81m s^{-2}). The signals obtained were recorded on the tape of a sixteen-channel magnetic recorder (Honeywell, Model 2206) – Figure 24.

Fig. 24. View of apparatus recording bin acceleration values

Bins with fruits were placed on the transport means in places with vibrations of the highest values of acceleration, as determined in preliminary observations (Fig. 25). The recording apparatus, supplied from the electrical system of the tractor, was placed in one of the bins on the vehicle.

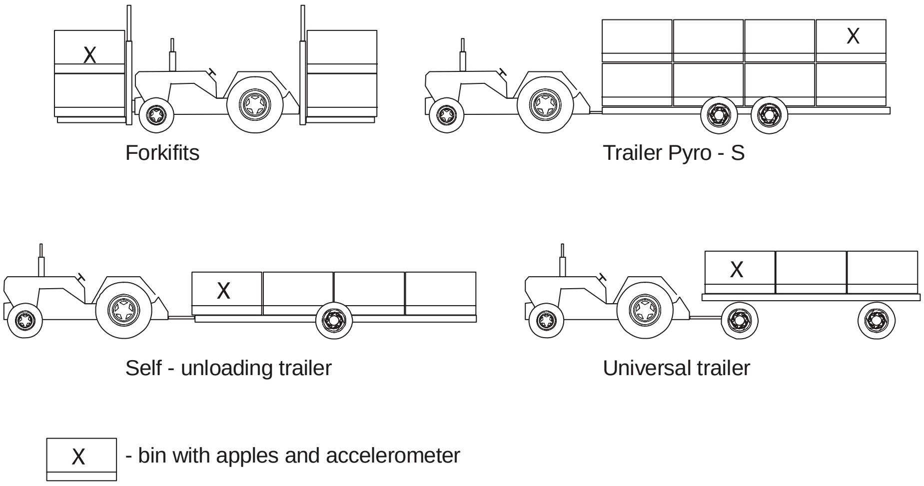

Fig. 25. Schematic of accelerometer location on the bins

Analysis of acceleration values was made in the measurements laboratory of the Department of Mechanization, ISK. The measurements provided a considerable amount of recorded courses of vibrations. Each vibration was described by three component values related to accelerations in the three planes - X,Y,Z. A special computer program was developed that calculated the resultant values of vibrations on the basis of the component values. As a result of the analysis, histograms of the resultant acceleration values were determined for the whole distance of every transport trip, with increments of 0.1 g.

Values obtained for the particular transport trips were grouped into value intervals of every 0.5 g, and the results were compiled in tables, separately for the two varieties of transported apples.

5.2.3.2. Fruit Accelerations in Bin as a Consequence of Vehicle Vibrations

The accelerations of over 95% of vibrations recorded on the transported bins had values below 1.5 g – Tables 30, 31. Vibrations with accelerations exceeding 2.5 g were recorded mainly on bins transported on the tractor with forklifts and on the self-unloading trailer – the exception was a single transport trip with the Pyro-s trailer, when the maximum recorded value of acceleration was 2.81 g.

Table 30. Appearance of vibration recorded in the bin during McIntosh apples transport [%]

Vehicle	Speed	No.	range of acceleration [g]						Value max.
			< 0.5 g	0.5 - 1.0 g	1.0 - 1.5 g	1.5 - 2.0 g	2.0 - 2.5 g	> 2.5 g	
Forklifts	V_{min}	1	64.45	31.99	3.53	0.03			
		2	74.88	24.2	0.88	0.03			
	V_{mean}	1	48.74	41.87	8.26	1.1	0.03		
		2	46.01	40.91	9.13	3.63	0.27	0.01	2.59
	V_{max}	1	38.9	46.44	12.99	1.63	0.05		
		2	49.05	33.43	13.9	3.06	0.46	0.11	5.22
Pyro-S trailer	V_{min}	1	96.52	3.48					
		2	95.62	4.32					
	V_{mean}	1	91.41	8.28	0.27	0.04			
		2	87.86	12.12	0.02				
	V_{max}	1	89.49	9.93	0.46	0.12			
		2	87.46	11.67	0.74	0.1	0.01	0.02	2.81
Self-unloading trailer	V_{min}	1	75.79	20.65	2.69	0.74	0.11	0.02	2.82
		2	74.86	22.86	2	0.24	0.05		
	V_{mean}	1	56.84	34.57	6.78	1.6	0.17	0.04	2.82
		2	60.68	32.18	5.82	1.2	0.1	0.01	2.68
	V_{max}	1	74.62	22.65	2.42	0.3	0.01	0.01	2.81
		2	76.33	20.12	3.14	0.4	0.02		
Universal trailer	V_{min}	1	96.29	3.7	0.01				
		2	96.34	3.66					
	V_{mean}	1	94.57	5.4	0.03				
		2	94.62	5.32	0.06				
	V_{max}	1	96.07	3.86	0.06	0.01			
		2	93.88	6.1	0.02				

The maximum value of acceleration recorded for the tractor with forklifts at the highest speed was 5.22 g. Vibrations with acceleration values above 2.5 g were recorded during 6 transport trips, and only at the lowest speed the values of acceleration did not exceed 2.0 g. No clear relationship was found between the level of vibrations and the tractor speed – during the transport of apples of the Idared variety the highest accelerations were recorded when driving at the intermediate speed (8.7% of accelerations above 2.5 g). Bins transported on the self-unloading trailer were subjected to vibrations in the range of 2.0-2.5 g at all the speeds used in the tests. In 6 replications the value of a small number of vibrations (0.01-0.27%) exceeded 2.5 g, however – as opposed to the tractor with forklifts – the value of 2.9 g was never exceeded.

Table 31. Appearance of vibration recorded in the bin during Idared apples transport [%]

Vehicle	Speed	No.	range of acceleration [g]						Value max.
			< 0.5 g	0.5 - 1.0 g	1.0 - 1.5 g	1.5 - 2.0 g	2.0 - 2.5 g	> 2.5 g	
Forklifts	V_{min}	1	57.57	33.06	5.79	2.73	0.57	0.28	< 2.83
		2	71.75	24.9	2.59	0.75	0.02	-	
	V_{mean}	1	37.72	22.52	11.87	8.41	10.79	8.7	< 2.83
		2	60.75	32.72	5.56	0.93	0.03	-	
	V_{max}	1	45.56	33.78	14.09	5.56	0.97	0.04	< 2.83
		2	63.29	27.9	6.97	1.41	0.24	0.19	< 2.83
Pyro-S trailer	V_{min}	1	88.86	11.14					
		2	87.23	12.77					
	V_{mean}	1	87.3	12.19	0.45	0.06	0.01		
		2	89.59	10.41					
	V_{max}	1	80.84	17.77	1.17	0.21			
		2	91.88	7.69	0.32	0.1	0.02		
Self-unloading trailer	V_{min}	1	73.59	22.3	3.28	0.8	0.02		
		2	74.32	22.74	2.73	0.19	0.02		
	V_{mean}	1	50	37.62	9.62	2.68	0.09		
		2	47.76	39.68	10.05	2.17	0.25	0.09	< 2.83
	V_{max}	1	37.79	42.99	13.85	3.83	1.28	0.27	< 2.83
		2	49.62	36.08	11.57	1.52	1.21		
Universal trailer	V_{min}	1	93.16	6.62	0.22				
		2	91.14	8.23	0.63				
	V_{mean}	1	84.47	14.45	1.06	0.01			
		2	86.53	13.11	0.35	0.01			
	V_{max}	1	80.18	18.77	1.03	0.02			
		2	83.78	15.68	0.52	0.02			

The accelerations recorded for the Pyro-s trailer at the lowest and, middle speed did not exceed 1.0 g. for the higher speeds 2.0-2.5 g accelerations were observed, but their share was negligible – 0.01-0.02%. Irrespective of the speed, vibrations of bins transported by universal trailer were characterized by lower acceleration values than those for the other vehicles. Accelerations with values below 1.5 g constituted over 99.9% of the total number recorded. During five transport trips with the intermediate and highest speeds only a slight share of the vibrations recorded (0.01-0.02%) had values within the range of 1.5-2.0 g.

The substitution of tractors with self-unloading trailers for orchard use reduces the risk of the occurrence of strong jolts to transported bins, but does not eliminate vibrations with acceleration values exceeding 2.5 g. A distinct reduction in the magnitude of vibrations can be achieved through the application of transport means with greater load capacity – specialized trailers (Pyro-s) or general-purpose trailers. The accelerations of a massive majority of vibrations on those transport means (99-100%) never reach the value of 1.0 g. Values above 2,0 g are never encountered in the case of the general-purpose trailer, for which, moreover, transport speed does not affect the magnitude of occurring vibrations. At the same time the least extensive damage to Idared apples was observed when the trailer was used at the highest speed, and the most extensive – at the intermediate speed. It can be supposed that the bruising occurring in transport is less significant, while the important source of damage lies in the operations of loading and unloading. It can be stated with a high degree of conviction that bin vibrations with acceleration values below 2.0 g do not cause notable damage to apples of Idared variety.
The limit value of bin vibration accelerations, below which no damage to McIntosh apples occurs, is lower than for the Idared variety and equals 1.5 g. Accelerations below that limit value were recorded in transport trips at the lowest speed, in the Pyro-s and the general-purpose trailers. In both cases the extent of damage to transported fruits did not differ from the levels recorded in the control sample in each of the adopted classes.

5.2.4. DAMAGE CLASSIFICATION

The damage was classified in four classes in accordance with the USDA scale (Mohsenin 1968) − Table 32.

Table 32. Apple damage classes according to USDA scale

class of damage	Size of damages
I (Extra Fancy)	Apples without bruising, apples with small bruises less than 12.7 mm of diameter or several bruising of total area equal or less than circle of 19 mm
II (Fancy)	Apples with single bruising or several bruising o area less 19 mm or several bruising o area less 25.4 mm
III (Utility)	Apples with single bruising of diameter less than 25.4 mm or several bruising o area less than circle of 31.7 mm in diameter
IV (Cull)	Apples with injuries, dent of skin or with single bruising or several bruising o area less 25.4 mm or several bruising of total area over the circle of 31.7 mm

The number of apples of both varieties with each class of damage was expressed in percentage values. Due to the low amount of damage in class III, for comparisons the numbers of apples with damage class II and III were combined.

5.2.5. Effect of Vehicle Type and Driving Speed on Fruit Damage

Among the apples in the bins left in the orchard as control, the percentage share of fruits with particular damage classes was as follows: McIntosh: class I – 95.1%, combined classes II and III – 2.5%, class IV – 2.2%; Idared (respectively) – 96.7%, 1.4%, 1.7% - Tables 33, 34.

Table 33. Percentage values for McIntosh apples damaged in transport: mean values from three layers

a. Damage of class I

Harvested Apples	Vehicle	Vehicle speed		
		V_1 (min.)	V_2 (mean)	V_3 (max.)
95.1	Forklifts	**87.7** b	**89.5** bc	**72.6** a
	Pyro-S trailer	94.1 c	90.4 bc	**87.5** b
	Self-unloading trailer.	91.0 bc	**87.6** b	**86.9** b
	Universal trailer	90.1 bc	**83.8** b	**84.9** b

b. Damage of classes II and III

Harvested Apples	Vehicle	Vehicle speed		
		V_1 (min.)	V_2 (mean)	V_3 (max.)
2.5	Forklifts	**10.9** b-e	**8.3** bcd	**15.5** e
	Pyro-S trailer	3.2 a	**6.3** abc	**9.5** b-e
	Self-unloading trailer.	**7.6** a-d	**8.8** b-e	**6.4** abc
	Universal trailer	5.6 ab	**13.3** de	**12.4** cde

c. Damage of class IV

Harvested Apples	Vehicle	Vehicle speed		
		V_1 (min.)	V_2 (mean)	V_3 (max.)
2.2	Forklifts	0.8 a	1.6 a	**11.3** c
	Pyro-S trailer	2.4 ab	2.4 ab	2.5 ab
	Self-unloading trailer.	1.2 a	3.5 ab	**6.5** bc
	Universal trailer	3.3 ab	1.9 a	2.0 a

1) numbers in bold – significant difference (5%) with relation to the control acc. to Student's t-test
2) mean values marked with the same letter do not differ significantly (5%) acc. to Duncan's t-test. Comparison of significance of differences with damage classes.

Table 34. Percentage values for Idared apples damaged in transport: mean values from three layers

a. Damage of class I

Harvested Apples	Vehicle	Vehicle speed		
		V_1 (min.)	V_2 (mean)	V_3 (max.)
96.7	Forklifts	**88.2** abc	**85.7** ab	**79.8** a
	Pyro-S trailer	90.3 bc	90.9 bc	**85.7** ab
	Self-unloading trailer.	**89.7** bc	**83.7** ab	**84.5** ab
	Universal trailer	91.6 bc	**87.5** abc	94.2 c

b. Damage of classes II and III

Harvested Apples	Vehicle	Vehicle speed		
		V_1 (min.)	V_2 (mean)	V_3 (max.)
1.4	Forklifts	**8.6** abc	**8.3** abc	**17.7** c
	Pyro-S trailer	**6.9** ab	5.2 ab	**11.7** bc
	Self-unloading trailer.	**7.9** ab	**12.7** bc	**10.6** abc
	Universal trailer	**7.0** ab	**8.2** abc	3.6 a

c. Damage of class IV

Harvested Apples	Vehicle	Vehicle speed		
		V_1 (min.)	V_2 (mean)	V_3 (max.)
1.7	Forklifts	2.7 abc	**5.7** c	2.3 ab
	Pyro-S trailer	2.7 abc	3.8 bc	1.7 ab
	Self-unloading trailer.	2.0 ab	2.5 ab	3.7 bc
	Universal trailer	1.1 a	3.7 bc	2.1 ab

1) numbers in bold – significant difference (5%) with relation to the control acc. to Student's t-test
2) mean values marked with the same letter do not differ significantly (5%) acc. to Duncan's t-test. Comparison of significance of differences with damage classes.

The share of fruits with damage of class I in bins transported by means of the tractor with forklifts was from 72.6 to 89.5% and was lower than in the control bins irrespective of the driving speed. For both the transported apple varieties, the differences between mean values for the driving speeds and the control were statistically proven. The lowest share of fruits with damage of that class (McIntosh) was observed in transport trips at the highest speed of the tractor, and the obtained mean value – 72.6% – was significantly lower than in transport of that variety at the other speeds. At the same time, for all the speeds applied, there was an increase in the share of fruits with damage of classes II and III. In two cases there was a significant increase, with relation to control, in the share of fruits with most extensive damage (class IV): for the McIntosh variety at the highest speed – to 11.3%, and for Idared at the intermediate speed – to 5.7%. Slightly better results, compared to the forklifts, were obtained in fruit transport by means of the self-unloading trailer. The share of class I apples of McIntosh variety in bins transported on the trailer at the lowest speed was 91% and did not differ from the control. For the other speeds the differences were statistically proved, but the mean values obtained (McIntosh – 87.5 and 86.9%; Idared – 83.7 and 89.7%) were higher than in the case of transport on the forklifts. Irrespective of the driving speeds, significantly higher – than in control – share of fruits with damage of classes II and III was observed, and for the transport of McIntosh apples at the highest speed – also of those with damage of class IV (6.5%).

Relatively slight, compared to the other vehicles, damage to apples occurred in transport by means of the specialized Pyro-s trailer. A significant decrease in the share of class I apples, with relation to the control, was observed only for the highest transport speed: the share of McIntosh apples decreased to 87.5%, and of Idared – to 85.7%. Mean values determined for the trailer on the basis of all the speeds were approximately 90% (McIntosh – 90.8%, Idared – 89.1%). No increase was observed in damage of class IV, though there was an increase in the share of fruits with damage of classes II and III.

Somewhat ambiguous was the effect of increase in speed in the case of the general-purpose trailer. The lowest share of Idared apples in class I of damage (87.5%) was observed for the intermediate speed. Higher values, similar to those for the control, were observed for that class at the remaining speeds. The highest value (94.%) was that obtained at the highest speed, at which the share of fruits in classes II and III remained at the level of the values for the control. In the transport of McIntosh apples, at the intermediate and highest speeds the share of apples with damage in class I (83.8 and 84.9%, respectively) was significantly lower. At the same time for those speeds there was an increase in the share of fruits with damage of classes II and III. For both the apple varieties, irrespective of the speed, there was no increase in the share of apples with damage of class IV with relation to the control.

5.2.6. Effect of Fruit Position in the Bin on the Extent of Damage

The extent of damage to apples transported to the storage facility increased with increasing depth in the bins – Table 35. The mean share of class I fruits for the McIntosh variety was 93.7% in the surface layers, 88.1% in the middle layers, and 79.1% in the bottom layers, and for the Idared variety the corresponding values were 93.7%, 88.1% and 80.4%, respectively. At the same time, with increasing depth in the bins there was a significant increase in the share of fruits in the other damage classes, particularly classes II and III.

Table 35. Percentage share of bruised apples in transported bins: values averaged for the speeds and transport vehicles

Variety	Layer in bin	Damage classes		
		I	II i III	IV
Mc Intosh	top	93.7 c	4.2 a	1.4 a
	middle	88.1 b	7.8 b	3.3 b
	bottom	79.2 a	15.7 c	4.3 b
Idared	top	93.7 c	4.6 a	1.1 a
	middle	88.1 b	8.3 b	3.2 b
	bottom	80.4 a	14.6 c	4.4 b

- mean values marked with the same letter do not differ significantly (5%) acc. to Duncan's t-test; assessment of significance within columns for one variety

No significant differences in damage to apples of the two varieties were noted between the estimated layers in the control bins. A slight decrease in the share of fruits in class I and an increase in the share of the other classes in the lower layers in the bins were observed for the Idared variety. Apples in the bottom layers of the McIntosh variety were slightly less bruised than in the surface and middle layers (Tables 36, 37).

A notable effect of the depth of fruits location in the bin on the extent of damage was observed when comparing the mean extent of damage in the bottom layers of Idared apples (Table 36). Significant differences were observed between the shares of fruits of class I in the surface and middle layers (self-unloading trailer, intermediate and highest speeds), and in the middle and bottom layers (forklifts and self-unloading trailer, lowest speed). Most differences in the share of class I fruits were observed between the surface and bottom layers. Statistical significance was proven in 8 combinations, 6 of which involved the forklifts and the self-unloading trailer. A significant increase in the bruising of apples of the McIntosh variety in the bottom layer of fruits compared to the surface layer was observed in bins transported at the highest speed on the forklift and by means of the general-purpose trailer. For the first of the vehicles the share of class I fruits decreased from 86 to 54%, and the for the second – from 92.6 to 70%.

Table 36. Percentage of bruised apples of McIntosh variety with relation to type of vehicle and fruit layer in the bin

a. Damage of class I

Vehicle	Layer in bin	Harvested Apples	Vehicle speed		
			V_1 (min.)	V_2 (mean)	V_3 (max.)
Forklifts	top	94.5 a	93.0 a	93.5 a	86.0 b
	middle	94.5 a	91.1 a	91.5 a	75.0 b
.	bottom	96.1 a	76.8 a	82.1 a	54.0 a
Pyro-S trailer	top	94.5 a	97.5 a	94.0 a	91.0 a
	middle	94.5 a	93.5 a	91.0 a	86.0 a
	bottom	96.1 a	90.0 a	85.4 a	85.1 a
Self-unloading trailer.	top	94.5 a	97.0 a	92.9 a	94.8 a
	middle	94.5 a	90.1 a	88.6 a	84.7 a
	bottom	96.1 a	83.4 a	79.7 a	78.7 a
Universal trailer	top	94.5 a	95.5 a	92.9 a	92.6 b
	middle	94.5 a	91.0 a	82.0 a	88.7 ab
	bottom	96.1 a	84.2 a	74.0 a	70.0 a

b. Damage of classes II and III

Vehicle	Layer in bin	Harvested Apples	Vehicle speed		
			V_1 (min.)	V_2 (mean)	V_3 (max.)
Forklifts	top	2.6 a	6.4 a	5.4 a	6.0 a
	middle	3.5 a	8.3 a	6.0 a	14.5 ab
.	bottom	1.5 a	11.1 a	15.0 a	29.7 b
Pyro-S trailer	top	2.6 a	1.0 a	3.0 a	6.4 a
	middle	3.5 a	2.6 a	6.4 a	10.5 a
	bottom	1.5 a	14.6 a	10.7 a	12.0 a
Self-unloading trailer.	top	2.6 a	2.5 a	5.2 a	2.3 a
	middle	3.5 a	7.9 a	7.3 a	7.3 a
	bottom	1.5 a	7.5 a	15.2 a	11.3 a
Universal trailer	top	2.6 a	3.5 a	5.3 a	6.0 a
	middle	3.5 a	3.5 a	13.9 a	9.6 a
	bottom	1.5 a	19.5 a	23.5 a	24.5 a

c. Damage of class IV

Vehicle	Layer in bin	Harvested Apples	Vehicle speed		
			V_1 (min.)	V_2 (mean)	V_3 (max.)
Forklifts	top	2.3 a	0.3 a	0.5 a	8.0 a
	middle	1.9 a	0.3 a	2.3 a	10.5 a
.	bottom	2.5 a	2.6 a	2.6 a	16.0 a
Pyro-S trailer	top	2.3 a	1.5 a	1.3 a	1.9 a
	middle	1.9 a	3.3 a	2.3 a	3.0 a
	bottom	2.5 a	2.5 a	3.9 a	2.6 a
Self-unloading trailer.	top	2.3 a	0.3 a	1.9 a	2.9 a
	middle	1.9 a	2.0 a	4.0 a	7.9 a
	bottom	2.5 a	1.9 a	5.0 a	9.8 a
Universal trailer	top	2.3 a	1.0 a	1.3 a	0.8 a
	middle	1.9 a	5.5 a	3.4 a	1.0 a
	bottom	2.5 a	4.5 a	1.3 a	5.5 a

- mean values marked with the same letter do not differ significantly (5%) acc. to Duncan's t-test; assessment of significance of differences between mean values made separately for each type of vehicle and for each transport speed

Table 37. Percentage of bruised apples of Idared variety with relation to type of vehicle and fruit layer in the bin

a. Damage of class I

Vehicle	Layer in bin	Harvested Apples	Vehicle speed		
			V_1 (min.)	V_2 (mean)	V_3 (max.)
Forklifts	top	98.5 a	92.0 b	93.1 b	87.4 b
	middle	96.7 a	92.1 b	83.5 ab	80.8 ab
.	bottom	94.0 a	78.6 a	78.8 a	69.9 a
Pyro-S trailer	top	98.5 a	93.0 a	97.1 b	91.0 a
	middle	96.7 a	92.9 a	89.8 ab	85.2 a
	bottom	94.0 a	84.1 a	83.0 a	80.0 a
Self-unloading trailer.	top	98.5 a	94.5 b	94.6 b	93.6 b
	middle	96.7 a	92.7 b	78.9 a	80.7 a
	bottom	94.0 a	79.6 a	74.1 a	76.9 a
Universal trailer	top	98.5 a	95.6 a	93.1 b	97.0 a
	middle	96.7 a	91.7 a	88.5 ab	94.2 a
	bottom	94.0 a	86.5 a	79.3 a	90.5 a

b. Damage of classes II and III

Vehicle	Layer in bin	Harvested Apples	Vehicle speed		
			V_1 (min.)	V_2 (mean)	V_3 (max.)
Forklifts	top	0.3 a	6.0 a	3.5 a	10.6 a
	middle	2.3 a	4.1 a	9.5 a	16.0 a
.	bottom	2.5 a	18.3 a	13.4 a	28.0 a
Pyro-S trailer	top	0.3 a	4.5 a	1.9 a	9.0 a
	middle	2.3 a	5.2 a	4.5 a	11.5 a
	bottom	2.5 a	11.9 a	11.0 a	15.1 a
Self-unloading trailer.	top	0.3 a	4.5 a	3.4 a	3.7 a
	middle	2.3 a	5.4 a	16.6 a	14.9 a
	bottom	2.5 a	15.8 a	22.2 a	15.4 a
Universal trailer	top	0.3 a	3.7 a	5.4 a	2.0 a
	middle	2.3 a	6.7 a	7.7 a	3.9 a
	bottom	2.5 a	11.5 a	12.2 a	5.4 a

c. Damage of class IV

Vehicle	Layer in bin	Harvested Apples	Vehicle speed		
			V_1 (min.)	V_2 (mean)	V_3 (max.)
Forklifts	top	1.0 a	1.9 a	3.3 a	1.9a
	middle	1.0 a	3.5 a	6.9 a	3.0a
.	bottom	3.5 a	2.9 a	7.5 a	3.5a
Pyro-S trailer	top	1.0 a	2.5 a	1.0 a	0.0 a
	middle	1.0 a	1.9 a	5.6 a	3.0 a
	bottom	3.5 a	4.0 a	6.0 a	2.0 a
Self-unloading trailer.	top	1.0 a	0.5 a	0.8 a	1.0 a
	middle	1.0 a	1.9 a	4.0 a	4.4 a
	bottom	3.5 a	4.5 a	3.3 a	4.5 a
Universal trailer	top	1.0 a	0.3 a	1.5 a	1.0 a
	middle	1.0 a	1.5 a	3.3 a	1.9 a
	bottom	3.5 a	2.0 a	7.3 a	7.2 a

- mean values marked with the same letter do not differ significantly (5%) acc. to Duncan’s t-test; assessment of significance of differences between mean values made separately for each type of vehicle and for each transport speed

Evaluation of the fruits left in the orchard indicated a low level of damage to the fruits during the harvest. Over 95% of apples of both varieties were classified in class I which includes fruits with no or only slight damage. These findings did not support the opinion that the harvest, as related to the transport of fruits from the orchard, is the main source of the occurrence of mechanical damage to apples - McMechan *et al.* (1962), Schoorl and Holt (1982), and O'Brien *et al.* (1984). Moreover, in the control bins no increase of apple bruising was observed with increasing depth in the bin, which suggests that the opinion that such damage results from absorption of energy by fruits during bin filling is incorrect – Schoorl and Holt (1982). At the same time, approximately 2% of the apples in the control bins sustained the most extensive damage (class IV). Most of those cases were skin punctures caused by shanks of other fruits or by protruding elements of the bin during pouring the fruits into the bins. It can be accepted, therefore, that if the process of harvesting is a source of damage to fruits, it causes mainly relatively infrequent (though the most serious) skin punctures. Damage of classes I, II and III recorded on fruits delivered to the storage facility, therefore, is caused in the course of the loading/unloading operations and in transit.

In the bins brought to the storage facility, most of the damaged fruits were located in the bottom layers of the load. With increasing depth in the bins, there was a decrease in the share of undamaged fruits (or with slight damage only), classified in class I. Especially notable differences occurred between the surface and the bottom layers and concerned mainly vehicles with load capacity of 4 box pallets. Decrease in the share of fruits in class I was accompanied by an increase in their share in classes II and III (from about 5% to 15%). Our study does not support the opinion that in transport it is the apples that are located above 2/3 of the bin height that get damaged most frequently and that the damage is caused by shocks and vibrations in the surface layers of the fruits – O'Brien *et al.* (1963), O'Brien and Guillon (1969), O'Brien *et al.* (1969), O'Brien and Fridley (1970), Chesson and O'Brien (1971), Hinsch et al. (1993), Slaughter *et al.* (1993). The main source of damage appears to be the load forces exerted by fruits in the bin, as indicated in earlier publications: Green (1965), Cąderek (1979), Brusewitz and Bartsch (1989), Brown *et al.* (1993). The load forces are especially dangerous for the lower layers of fruits during more violent shocks caused by bumps in the road surface (Holt and Schoorl, 1983 and 1985), and damage to the transported fruits can occur even during sporadic shocks with acceleration values exceeding 7.0 g (Brown *et al.*, 1993). The increase in the level of damage in apples located in the deeper layers of transported bins, observed in our own study, did not depend on the properties of the transported fruits. The average numbers of fruits in the assumed classes of damage, determined for the particular fruit layers in the bins for all the transport trips, were very similar for both apple varieties, although occasionally there were considerable differences in the values obtained in individual transport trips. The differences are understandable in that the response of fruit tissue to static and cyclic loads is burdened with a certain level of randomness (McLaughlin and Pitt, 1984) which sometimes makes it totally impossible to relate the extent of damage to the location of fruits in the transport bin (Emilson and Castberg, 1965).

On the basis of the results of our own study we can firmly state that among the transport technologies tested transporting apples by means of a tractor with forklifts is the most conducive to the occurrence of mechanical damage to the fruits. Irrespective of apple variety and driving speed, significantly lower – with relation to the control – amounts of fruits in class I were observed. With increasing speed there was an increase in the share of fruits with more extensive bruising, including those classified in class IV. Fruits with this class of bruising should be excluded from further turnover and from storage. In our study, conducted on a road good surface condition, a significant increase in the rate of class IV damage was noted also for the intermediate speed of the tractor. This indicates an inherent instability of that vehicle and difficulty of determining a safe level of speed at which it should travel while transporting fruits. The method recommended by Holt (1967), consisting in the observation of the top layer of fruits, may prove unreliable, especially on roads with poor surface where strong jolts may occur. A lowering of the quality of fruits transported on tractor forklifts, with relation to other transport means, was also observed in earlier studies (Kossowski, 1979; Wilkus, 1989; Rabcewicz *et al.*, 1997). It appears, therefore, that in order to minimize the level of damage to apples transported by that method the speed of tractors with forklifts must be greatly reduced with relation to the speed of other transport vehicles. This is in agreement with the views of Green (1966), who recommended that the speed of tractors with forklifts should be a half of that of other specialized transport vehicles for orchard use. This assumes a special significance in view of the fact that the method involving the use of forklifts is at present one of the most commonly used in the country.

The risk of damage to transported apples can be slightly reduced – with relation to the technology based on the use of tractors with forklifts – through the application of self-unloading orchard-use trailers. The use of the trailers with the lowest transport speed did not result in any significant reduction in the amount of the least bruised McIntosh apples with relation to the control sample. Also, no decrease in the quantity of class I apples was observed in transport trips at the highest speed, for which, however, there was a significant increase in the share of apples with the most serious damage of class IV. As increase in the rate of damage of that class was observed only on transport means with load capacity of 4 box pallets and did not concern fruits transported on vehicles with greater load capacity, one could accept the opinion, indicated earlier, that there is a relationship between the occurrence of damage and the volume of transported fruits (Sober *et al.*, 1990). An especially notable advantage of transport means with greater load capacity became apparent in our study during the transport of apples of the Idared variety. The tractor with forklifts and the self-unloading trailer caused more damage to the fruits than did the remaining, much heavier vehicles. It should be emphasized that in the technology involving the use of the self-unloading trailer box pallets are not subjected to any reloading operations – all the damage to the fruits occurs on the trailer.

Comparing the transport technologies under study, one can observe that the lowest level of damage to apples transported from the orchard to the storage facility is obtained when using the specialized Pyro-s trailer. As opposed to the other transport means, the trailer ensures an unchanged – in relation to the control – share of undamaged or only slightly damaged fruits. Also in favour of the method is its level of class IV of damage to transported fruits, almost identical to the control. The number of apples with this class of damage did not increase even when driving at the highest speed. Therefore, we have to observe with regret that for a variety of reasons (mainly of economic nature) the scale of application of specialized transport means which fundamentally improve the level of transport safety is at present limited. With increasing requirements for improved quality of fruits, the introduction of safer technologies of apple transport appears to be indispensable, even if it involves greater expenditure related to the purchase of specialized transport means.

A lack of clear effect of speed on the level of apple bruising was observed in transport by means of the general-purpose trailer. Although fruits of the McIntosh variety were more bruised when higher speeds were used, but for apples of Idared variety the least changes in fruit quality after transport were recorded for the highest speed. The average share of fruits in class I determined for that speed did not differ from the control and was the highest of all the values obtained, both in transport by means of the trailer and in comparison with the other vehicles. It appears, therefore, that the primary source of damage in that transport technology lies in the loading/unloading operations, and transport speed is of lesser significance to the safety of fruits in transport. This conviction seems to be supported by the analysis of vibrations caused by trailer jolting on the transport road – the lowest values of acceleration were recorded in the bins transported on the universal trailer.

CHAPTER 6

FRUIT QUALITY AND TEXTURE*

Quality evaluation of horticultural products has been a subject of interest to many researchers for many years. There are many different factors that can be included in any discussion of quality. Quality of agricultural products is an important factor to both the producers and consumers. In this context the consumer is the person or organization receiving the product at every point in the production chain. This is important because quality will be perceived differently depending on the needs of the particular consumer: a packing shed operator will have a very different idea of quality to the ultimate eater of the fruit (Studman, 1994). However, there is no clear definition of quality for agricultural products. Quality factors for fresh fruit and vegetables adapted from Kader, 1983 are: hygiene and quarantine factors (parasites larvae, pupae, natural toxicants, contaminants, spray residues, heavy metals etc.), cosmetic appearance (size; weight, volume, dimensions, shape, regularity, surface texture, smoothness, waxiness, gloss, colour, uniformity, intensity, spectral, physical defects, splits, cuts, dents, bruises), texture and flavour factors (firmness, hardness/softness, crispness, mealiness-grittiness, fibrousnesses toughness), flavour (sweetness, sourness, astringency, bitterness, aroma, off-flavours, off-odours) and nutritional (dietary fibre, cancer inhibitors, carbohydrates proteins, lipids, vitamins, minerals).

Texture is a quality attribute that is critical in determining the acceptability of fruits and vegetables. It is convenient to define *quality* as the composite of intrinsic characteristics that differentiate units of the commodity – individual pieces of the product – and to think of *acceptability* as people's perceptions of and reactions to those characteristics. Although the term is widely used, *texture* is not a single, well-defined attribute. It is a collective term that encompasses the structural and mechanical properties of a food and their sensory perception in the hand or mouth. Although some definitions of texture restrict its use to only sensory attributes or to

* Some parts of this chapter concerning on texture based on the article prepared by Judith A. Abbott from Produce Quality and Safety Laboratory, USDA, ARS, Beltsville, Maryland and F. Roger Harker from The Horticulture and Food Research Institute of New Zealand Ltd. Mt. Albert Research Centre, Auckland, New Zealand

sensory attributes and the mechanical properties directly related to them, the term texture is sometimes extended to include some mechanical properties of commercial interest that may not be of direct interest to consumers, such as resistance to mechanical damage. In this review, we will use the term *texture* in the broadest sense. A few of the many terms used to describe sensory texture of fruits or vegetables are hard, firm, soft, crisp, limp, mealy, tough, leathery, melting, gritty, wooly, stringy, dry, and juicy. There are no accepted instrumental methods for measuring each of these attributes. In fact, there is some disagreement among sensory, horticultural, and engineering uses of certain terms, particularly firmness which is discussed later. Textural attributes of fruits and vegetables are related to the structural, physiological, and biochemical characteristics of the living cells; their changes over time; and their alteration by processes such as cooking or freezing. The continuous physiological changes in living cells plus the inherent variability among individual units of the commodity make the assessment of fruit or vegetable texture difficult. Because of their continuous change, textural measurements are often relevant only at the time of evaluation; that is, they usually cannot be used to predict condition much later in the storage period or marketing chain.

Firstly, quality standards are affected by international and cultural preferences (Amos et al, 1994). Secondly, standards can be affected by cultural changes or by strong marketing in the media. Quality standards may involve appearance, feel, taste, consistency, handling characteristics, ability to retain properties for long periods of time, or the absence of undesirable impurities (Kader, 1983). Clearly for each factor, some objective means of measurement is required (Watada, 1993). Several methods are available for quality detection in horticultural commodities according to external and internal properties. The challenges are to make these techniques affordable in the market place and especially to relate the measurement parameters to the very subjective, sensory evaluation of quality by consumers. As a result, several nondestructive techniques for quality evaluation of horticultural products have been developed. These methods are based on the detection of various physical properties that correlate well with certain quality factors of the products (Chen, 1996).

6.1. PHYSICAL METHODS FOR FRUIT QUALITY EVALUATION

Chen (1996) presents an overview of various quality evaluation techniques that are based on one of the following properties: density, firmness, vibration characteristics, X-ray and gamma ray transmission, optical reflectance and transmission, electrical properties, aromatic volatile emission, and nuclear magnetic (NMR).

Zachriah (1976) reported that a number of researchers have investigated the electrical properties of fruits and vegetables, however, the results were not conclusive enough to permit development of a practical method for quality sorting of fruits and vegetables.

Norris, 1989 studied NIR reflectance and transmittance characteristics of many agricultural products and have found that radiation in the near-infrared region of the spectrum can provide information related to many quality factors of agricultural products. Bellon and Sevila (1993) developed an NIR system, which combined a CCD spectrophotometric camera and bifurcated fiber optics, for determining soluble solids in apples.

Short wave radiations such as X-rays and gamma rays can penetrate through most agricultural products. The level of transmission of these rays depends mainly on the mass density and mass absorption coefficient of the material. Tollner *et al.*, (1994) gave a comprehensive overview of ongoing research and commercial development of X-ray sensors for nondestructive detection of interior voids and foreign inclusions in fruits and vegetables.

Nuclear magnetic resonance (NMR) is a technique that detects the concentration of hydrogen nuclei (protons) and is sensitive to variations in the concentration of liquid in the material. Although NMR imaging (MRI) has been used frequently in the medical field and other quality factors in fruits and vegetables has not been fully explored. Wang et al. (1988) used MRI methods to obtain images of watercore and its distribution in Red Delicious apples. Chen *et al.* (1989) used MRI to evaluate various quality factors of fruit and vegetables.

One of the most practical and successful techniques for nondestructive quality evaluation and sorting of agricultural products is the electro-optical technique, based on the optical properties of the product. Thus, determining such optical characteristics of an agricultural product can provide information related to quality factors of the product.

6.2. NON-DESTRUCTIVE MEASUREMENTS FOR ON-LINE SORTING

Most force/deformation measurements are destructive, for example the familiar Magness-Taylor fruit firmness test and the Kramer shear test, or are too slow for on-line use, such as the Cornell firmness tester. However, remember that eating is destructive! Rupture forces usually provide the best correlation with sensory texture evaluations of foods. Unfortunately destructive tests cannot be used to sort fruits and vegetables for subsequent sale, so a great deal of research has gone into developing nondestructive methods to estimate the mechanical properties and the textural quality of fruits and vegetables (Chen and Sun, 1991; Abbott *et al.*, 1997; Hung *et al.*, 2001). None of these nondestructive methods has attained wide commercial acceptance to date. During development, new instrumental texture measurements are most often initially calibrated against existing instruments. If they are to be used to predict sensory attributes or acceptability, the new measurement should also be compared directly to descriptive sensory analyses to develop calibration equations for quantitative attributes (how much of a trait is present) or to consumer evaluations to predict acceptability. Alternatively, instrumental measurements may be compared to commercially useful traits like bruising, days from bloom, or storage life to develop predictive equations. After the relationship between an instrumental measurement and a quality attribute or acceptability is well established, the instrumental measurement is usually used to replace human evaluations. It is advisable to verify the relationships occasionally, because changes in factors such as genetics, growing or storage conditions, consumer preference, or wear on the instrument may change the relationships.

6.2.1. Laser Air-Puff Test

A nondestructive, non-contact firmness detector was recently patented (Prussia *et al.*, 1994) that uses a laser to measure deflection caused by a short puff of high-pressure air, similar to some devices used by ophthalmologists to detect glaucoma. Abbott and Harker (2003) presents this as essentially a nondestructive compression test. Under fixed air pressure, firmer products deflect less than softer ones. Laser-puff readings correlate well with destructive Magness-Taylor firmness values for apple, cantaloupe, kiwifruit, nectarine, orange, pear, peach, plum, and strawberry (Fan *et al.*, 1994; Hung *et al.*, 1998; McGlone *et al.*, 1999; McGlone and Jordan, 2000).

6.2.2. Impact or Bounce Test

When one object collides with another object, its response is related to its mechanical properties, its mass, and the contact geometry (Abbott and Harker, 2003). Numerous studies have been conducted on the impact responses of horticultural products and a number of impact parameters have been proposed to measure firmness, including peak force, coefficient of restitution, contact time, and the impact frequency spectrum. The coefficient of restitution is the ratio of the velocities of the product just before and after impact and reflects the energy absorbed in the product during impact. There is no agreement on the best parameter to measure; selection seems to depend on commodity, impact method, and the firmness reference used by the investigators. Most impact tests involve dropping the product onto a sensor (Rohrbach, 1981; Delwiche *et al.*, 1987; Zapp *et al.*, 1990; McGlone and Schaare, 1993; Patel *et al.*, 1993) or striking the product with the sensor (Delwiche *et al.*, 1989; Brusewitz *et al.*, 1991; Chen *et al.*, 1996; Bajema and

Hyde, 1998). Delwiche *et al.* (1989, 1991) developed a single-lane firmness sorting system for pear and peach. Impact measurements often do not correlate highly with the Magness-Taylor puncture measurement (Hopkirk *et al.*, 1996). A potential problem with impact tests is that bruising may occur, unless a soft sensor is developed (Thai, 1994).

6.2.3. SONIC AND ULTRASONIC METHODS

The vibration characteristics of fruits are governed by their elasticity, mass, and size. Therefore, it is possible to evaluate firmness of fruits on the basis of their vibration characteristics. An extensive study of vibration characteristics of apples was conducted by Abbott *et al.* (1968). In general, the researchers detected a series of resonant frequencies. However, in the cases where the fruit was excited by a vibrator and the vibration was detected by an accelerometer, the lower resonant frequencies may not be those of the free vibration of the fruit, but may be resonant frequencies that were caused by the interaction between the fruit mass (or the accelerometer mass) and the force developed by local deformation of the fruit.

Ultrasonic techniques have been used quite successfully for evaluating subcutaneous fat, total fat, lean, and other internal properties of live animals. However, researchers have not been so successful in using ultrasonic measurements to evaluate internal quality of fruits and vegetables.

6.2.4. SONIC OR ACOUSTIC TESTS

Sonic (or acoustic) vibrations are those within the human audibility range of 20 to about 20,000 Hz (vibrations sec-1). Sonic measurements provide a means of measuring fruit and vegetable firmness (Abbott and Harker, 2003). The traditional watermelon ripeness test is based on the acoustic principle, where one thumps the melon and listens to the pitch of the response. A number of sonic instruments and laboratory prototype sorting machines have been developed and tested (Abbott *et al.*, 1968, 1992; Armstrong *et al.*,1990; Peleg *et al.*, 1990; Zhang *et al.*, 1994; Stone *et al.*, 1998; Schotte *et al.*, 1999; De Belie *et al.*, 2000b; Muramatsu *et al.*, 2000). When an object is caused to vibrate, amplitude varies with frequency of the vibration and will be at a maximum at some particular frequency determined by a combination of the shape, size, and density of the object; such a condition is referred to as resonance. Resonance measurement can be achieved by applying an impulse or thump that contains a range of frequencies. Modulus of elasticity values obtained from resonant frequency data have correlated well with those measured by conventional compression tests, but often were correlated poorly with MT puncture forces. Abbott *et al.* (1968) proposed a stiffness coefficient, f 2m, which was based on the modulus of elasticity using the resonant frequency (*f*) and mass (*m*) of the specimen; this was later modified by Cooke and Rand (1973) to f 2 m 2/3. Farabee and Stone (1991) developed a portable sonic instrument for field determination of watermelon ripeness and hollow heart detection. Kawano *et al.* (1994) reported a commercial sorting machine for detecting internal voids in Japanese watermelon. Shmulevich *et al.* (1995) developed a sonic instrument using a lightweight flexible piezoelectric film sensor to follow changes in fruit during storage. Muramatsu *et al.* (2000) examined the relationship of both phase shifts and resonant frequencies to firmness. Nybom (1962) and Peleg *et al.* (1990, 1999) examined the sonic energy transmitted by the specimen rather than the resonant frequencies. Despite considerable research, sonic vibration has not yet become a viable option for the horticultural industry. However, there are several advanced commercial prototypes currently being evaluated.

6.2.5. ULTRASONIC TESTS

Ultrasonics (frequencies > 20,000 Hz) is widely used in the medical field and for analyzing meat. Ultrasonics has been used with limited success for measuring physical and chemical properties of fruits and vegetables because of the high attenuation (energy absorption) of plant tissues. The commonly measured ultrasonic parameters are velocity, attenuation, and frequency spectrum composition. Bruises in apples (Upchurch *et al.*, 1987) and hollow heart of potatoes (Cheng and Haugh, 1994) could be detected in the laboratory using ultrasonics. Mizrach and Flitsanov (1999) and Mizrach *et al.* (1994, 1999) have followed the softening process in avocados, melons, and mangoes, respectively.

6.2.6. LIGHT SCATTER IMAGING

As light passes through tissue, cellular contents such as starch granules, cell walls, and intercellular spaces cause scatter. The extent of scatter of collumated light such as a laser beam may change during ripening due to changes in cell-to-cell contact and compositional changes. Measurement of the scatter using computer vision may thus provide an indirect indication of textural changes. Significant correlations between mechanical properties and image size have been shown in apples (Duprat *et al.*, 1995; McGlone *et al.*, 1997; Cho and Han, 1999; De Belie *et al.*, 2000a) and tomatoes (Tu *et al.*, 2000).

Interest is increasing in the development of machine vision systems to replace human visual inspection. One of the major requirements in developing machine vision systems for sorting fruits and vegetables is the ability to analyze an image accurately and quickly (Abbott and Harker, 2003).

Some methods are at a more advanced stage of development than others. Because each method is based on measurement of a given physical property, the effectiveness of the method depends on the correlation between the measured physical property and the quality factor of interest. Although researchers have developed relationships between physical properties and quality factors for a number of agricultural products. However, through use of computers and data processing techniques, researchers have been able to improve the correlations between some measured properties and quality factors of interest (Chen, 1996). Efforts have been made to develop rapid and simple methods for fruit firmness testing, and lately researchers focused on non-destructive methods (Chen and De Baerdemaeker, 1994; Peleg, 1994; Ruiz-Altisent *et al.*,1994; Shmulevich *et al.*, 1994). Non-destructive versions of the penetrometer test have been described, but as yet none have found widespread approval (Duprat *et al.*, 1994). The availability of high-speed data acquisition and processing technology has renewed researchers' interests in the development of impact and sonic response techniques.

6.3. PHYSIOLOGICAL BASIS OF TEXTURE

Abbott and Harker (2003) indicates that, most important to understand the texture of a product, is to identify the main elements of tissue strength and to determine which elements are responsible for the textural attributes of interest. For example, it may be necessary to avoid tough strands of vascular material when measuring texture of soft tissues because the small amount of fiber produces an artificially high reading that does not agree with the sensory assessment of softness. On the other hand, it is important to measure the strength of fibers when determining toughness, such as in asparagus spears or broccoli stalks. Thus, method development and the solution to many texture problems requires a good understanding of the anatomy of tissues within the fruit or vegetable, the structure of their cells, and biological changes that occur following harvest as well as some understanding of sensory texture perception (Abbott and Harker, 2003).

6.3.1. PARENCHYMA CELLS

Fruits are derived from flower parts; while vegetables are derived from roots, stems, leaves, or flowers and several that we call vegetables are actually fruit.

The common factor is that all are relatively soft, even carrots and apples, when eaten (either raw or after cooking), largely due to the presence of parenchyma cells. These parenchyma cells are not lignified, and their primary walls are separated by a morphologically distinct region known as the middle lamella, which separates adjacent cells and is rich in pectic substances. The unique mixture of matrix (pectic and hemicellulosic) and fibrous (cellulosic) polysaccharides in the cell wall mostly determines the mechanical properties of these cells. The polysaccharides confer on the wall two important but seemingly incompatible properties. The first is the wall’s plasticity which enables it to expand as the cell enlarges during plant development. The second is its rigidity, which confers strength and determines cell shape. However, on its own, the cell wall is unable to provide much mechanical support. Reassuming, Abbott and Harker (2003) expressed that rather it is the interaction between rigidity of the wall and internal hydrostatic pressure (turgor) of cell contents that provides support.

The arrangement and packing of parenchyma cells within the tissue is another factor that influences mechanical strength of produce (Abbott and Harker, 2003). In carrots, the cells are small (approximately 50 μm in diameter), isodiametric in shape, and closely packed with a high degree of contact between neighboring cells and a small volume of intercellular gas filled spaces. The cells can be arranged either as columns or as a staggered array where each cell overlays the junction of the two lower cells (Sørensen et al., 1999). These differences in cell packing may, in part, explain genotypic differences in susceptibility to harvest splitting in carrot. In apple cortical tissue, the cells are large (up to 300 μm in diameter), elongated along the direction of the fruit radius, and organized into distinct columns (Khan and Vincent, 1993). As a result of this orientation of apple cells, the tissue stiffness (elastic modulus) is higher and the strain at failure is lower when tissue plugs are compressed in a radial rather than a vertical or tangential orientation (Khan and Vincent, 1993; Abbott and Lu, 1996). Up to 25% of the volume of apple tissue may be gas-filled intercellular spaces, which indicates relatively inefficient cell packing and a low degree of cell-to-cell contact, both of which correlate well (negatively) with tissue stiffness (Vincent, 1989).

6.3.2. Cell Wall

From a chemical perspective, the primary cell wall of parenchyma cells is composed of a mixture of cellulose, hemicellulose, and pectin. The specific intermolecular interactions among these polysaccharides are poorly understood but usually assumed to follow the models described by Carpita and Gibeaut (1993). The cell wall itself is an important constituent of produce, providing dietary fiber, thought to protect against colorectal cancer (Harris et al., 1993). Changes that occur in the cell wall during ripening of fruit, storage of produce, and cooking are critical to the texture of the final product. During maturation of some vegetative parts, especially stems and petioles, cell walls become lignified (Okimoto, 1948; Price and Floros, 1993). Lignification results in toughening of the product, such as woodiness in asparagus, broccoli, pineapple, and rutabaga. During fruit ripening, cell wall changes include solublization and degradation of pectin and a net loss of the non-cellulosic neutral sugars galactose and arabinose, and there may be a decrease in the molecular weight distribution of hemicelluloses (Harker et al., 1997). Numerous enzymes have been suggested as being critical to these changes in the cell wall including polygalacturonases and several glycosidases, including β-galactosidase, xyloglucanase, endotransglycosylase, and cellulases (Dey and del

Campillo, 1984; Huber, 1992; Seymour and Gross, 1996; Harker et al., 1997). In recent years, the possible role of expansins, proteins that are proposed to disrupt hydrogen bonds within the cell wall, has been considered (Civello et al., 1999). The use of molecular approaches, including antisense technologies, has been a powerful tool in the search for an understanding of fruit softening (Giovannoni et al., 1989). However, no single enzyme has been identified as the major determinant of fruit softening, suggesting wall breakdown results from coordinated action of several enzymes, or that the key enzyme has not been identified. Cooking often results in degradation of pectic polymers via β-elimination, which is usually related to the degree of methyl esterification of pectin (Waldron et al., 1997). Along with turgor loss, this process is responsible for thermal softening. However, some vegetables either don't soften or soften very slowly during cooking, eg., Chinese water chestnut, sugar beet, and beetroot. In Chinese water chestnut, the thermal stability of texture is associated with the presence of ferulic acid in the cell wall (Waldron et al., 1997). Postharvest treatments involving dipping or infiltrating with calcium maintain firmness during storage of a wide range of fruit (Conway et al., 1994). Examination of fracture surfaces following tensile testing of apple cortex indicated that tissue failure from calcium-treated fruit was due to cell rupture, whereas failure in control apples was due to cell de-bonding (Glenn and Poovaiah, 1990). While evidence suggests that calcium influences texture through its interaction with the cell wall (pectin), it may also affect texture through interactions with membranes. The cell wall may also influence perception of juiciness through its ability to hold and release fluid. In some fruits, the cell wall swells considerably during ripening (Redgwell et al., 1997). It has been suggested that hydrated cell walls and perhaps the presence of free juice over the surface of undamaged cells could be responsible for the sensation of juiciness in fruit with soft melting textures (Harker et al., 1997). In stonefruit, loss of juiciness is thought to occur when pectates bind water into a gel-like structure within the wall (Ben-Arie and Lavee, 1971). Separation of cells at the middle lamella rather than rupture of cells during chewing is at least partially responsible for the dry, mealy mouth-feel of overripe apples and wooliness of peaches (Harker and Hallett, 1992).

6.3.3. CELL TURGOR

Plant cells tend to maintain a small positive pressure, known as turgor pressure. This pressure develops when the concentration of solutes inside the cell (more specifically inside the plasma membrane) is higher than outside the cell (Abbott and Harker, 2003). The extracellular solution fills the pores of the cell wall, sometimes infiltrates into gas filled spaces, and usually is continuous with vascular (water conducting) pathways of the plant. Differences in solute concentration at the inner and outer surface of the plasma membrane cause water to flow into the cell by the process of osmosis. This net movement of water is halted by the physical constraint of the rigid cell wall and, as a result of this, turgor develops inside the cell. At equilibrium, $\Psi = \Psi p + \Psi \pi$, where Ψ is the turgor (generally a positive value), Ψp is the water potential (water activity, generally a negative value) of the tissue, and $\Psi \pi$ is osmotic pressure (generally a positive value) of the cell (Tomos, 1988). Turgor has the effect of stressing the cell wall. The consequences of this stressing depend on whether compressive or tensile loads are applied. When tissues are subjected to compressive loads, higher turgor tends to make the cell more brittle, ie., makes it fail at a lower force (Lin and Pitt, 1986). When tissues are subjected to tensile measurements, turgor tends to harden the cell wall and a greater force is needed before cells fail (De Belie et al., 2000a). However, turgor is unlikely to influence tissue strength if the mechanism of failure is cell-to-cell de-bonding, rather than fracturing across individual cells, unless an increasing turgor and thus swelling reduces cell-to-cell contact area (Glenn and Poovaiah, 1990; Harker and Hallett, 1992). The importance of turgor has been demonstrated in a number of ways (Abbott and Harker, 2003). The rapid phase of cooking-induced softening of carrot occurs as a result of membrane disruption and the elimination of the turgor component of texture (Greve et al., 1994). Similarly, when produce experiences a freeze-thaw cycle the membranes are damaged and the tissues become more flaccid in the case of leafy vegetables and softer in the case of fruits, and often leak much juice upon thawing. Firmness and turgor correlate well in apple (Tong et al., 1999), and turgor declines during tomato ripening (Shackel et al., 1991). Also, turgor is thought to play a central role in softening and development of mealiness during storage of apples (Hatfield and Knee, 1988).

6.3.4. Cell-to-Cell De-bonding versus Cell Rupture

The strength of the cell wall relative to the adhesion between neighboring cells will determine whether cell rupture or cell-to-cell de-bonding is the mechanism of tissue failure. Cell rupture is generally associated with crisp and often juicy produce, as well as with unripe fruit and raw vegetables (Abbott and Harker, 2003). Cell-to-cell de-bonding is frequently associated with dry, unpleasant texture such as in mealy apples, chilling injured stonefruit and tomato, and juice loss in citrus (Harker et al., 1997). However, a dry texture is not always unacceptable to consumers, ex., banana. In some fruits, cell-to-cell de-bonding does not result in a dry texture; rather, a layer of juice covers the intact cells exposed following cell separation (Harker et al., 1997). Furthermore, cell-to-cell de-bonding is a common outcome of cooking of vegetables such as potato (Waldron et al., 1997) and carrot (Ng and Waldron, 1997). In fresh produce, cell adhesion is presumed to be a function of three factors: strength of the middle lamella; the area of cell-to-cell contact; and the extent of plasmodesmatal connections (Harker et al., 1997). Tissue collapse can also occur without cell wall breakdown or cell separation. In some tissues, fluids are forced out of cells by compressive forces known as 'cell relaxation' (Peleg et al., 1976) or 'exosmosis' (Jackman and Stanley, 1995).

6.3.5. Other Elements of Tissue Strength

The strength and integrity of many edible plant organs are influenced by a number of additional factors (Harker et al., 1997). Many fruits and vegetables contain a number of tissue zones - periderm, pericycle, and phloem parenchyma in carrot; skin, outer pericarp, inner pericarp, and core in kiwifruit; and outer pericarp, locular gel, seeds, and columella in tomato. These tissues differ in strength and biological properties and often need to be considered individually when measuring texture. For example, failure of the core of kiwifruit to soften to the same extent as the pericarp causes a texture that is unacceptable to consumers. In some multiple fruit that do not adhere to the receptacle, such as raspberry, the main element of strength is the adhesion between neighboring drupelets due to hair-like protuberances. However, it is the skin of many types of produce that plays a key role in holding the flesh together, particularly in soft fruit (Abbott and Harker, 2003). The cuticle of epidermal cells and thickened cell walls of hypodermal cells contribute to strength of simple skins. In harder inedible skins, specialized cells may be present: collenchyma, sclerenchyma, tannin-impregnated cells, and cork. The presence of tough strands of vascular tissue may strengthen the flesh, but often results in an unpleasant fibrous texture. For example, toughness of asparagus spears is principally due to fiber content and fiber lignification (Lipton, 1990). Rarely, the stringiness is desirable, as in spaghetti squash. In most commercial fruits, with the exception of pineapple (Okimoto, 1948), fibrousness of the flesh is not a major problem. However, some fruits including peaches and muskmelons can have a problem with stringiness (Diehl and Hamann, 1979). Generally, the perception of stringiness is enhanced in very ripe fruit due to the contrast between the soft melting texture of the parenchyma cells and the fibrousness of the vascular tissues. Similarly the gritty texture of pear and guava (Harker et al., 1997) becomes particularly noticeable when the surrounding cells are soft. However, while stringiness is caused by vascular tissues, grittiness is caused by sclerenchymatous stone cells (Harker et al., 1997).

6.4. Sensory Evaluation of Texture

People sense texture in numerous ways: the look of the product, the feel in the hand, the way it feels as they cut it, the sounds as they bite and chew, and most important of all, the feel in their mouth as they eat it. Szczesniak (1963) proposed a texture profile, a systematic approach to sensory texture analysis based on mechanical, geometrical, and other characteristics. Mechanical characteristics included basic parameters (hardness, cohesiveness, viscosity, elasticity, and adhesiveness) and secondary parameters (brittleness or fracturability, chewiness, and gumminess). Geometrical properties related to size, shape, and orientation of particles. The other characteristics comprised moisture and fat content. Sherman (1969) and others have proposed revisions of the texture profile classification scheme, but the original is generally used with only minor changes by sensory texture specialists. Most sensory analysis text books contain a small chapter on evaluation of texture, eg., Meilgaard et al. (1999). Harker et al. (1997) reviewed fruit texture and included extensive discussion of oral sensation of textural attributes. Shewfelt (1999) suggested that the combination of characteristics of the product be termed quality and that the consumer's perception and response to those characteristics be referred to as acceptability. Texture may be a limiting factor in acceptability if textural attributes are outside the individual's range of acceptability for that commodity; people have different expectations and impose different limits for various commodities. The relationship of instrumental measurements to specific sensory attributes and their relationship to consumer acceptability must be considered (Shewfelt, 1999). Instruments may be designed to imitate human testing methods or fundamental mechanical measurements may be statistically related to human perceptions and judgments to predict quality categories. Only people can *judge* quality, but instruments that *measure* quality-related attributes are vital for research and inspection (Abbott et al., 1997).

6.5. MECHANICAL PROPERTIES RELATED TO FRUIT FIRMNESS

In many agricultural products firmness is related to maturity. In general firmness of fruits decreases gradually as they become more mature and decreases rapidly as they ripen (Dobrzański and Rybczyński, 2000). Overripe and damaged fruits become relatively soft. Thus firmness can be used as a criterion for sorting agricultural products into different maturity groups or for separating overripe and damaged fruits from good ones. Several methods for measuring fruit firmness have been developed. Fekete and Felföldi, (1994) reckoned firmness as a principal characteristic of fruits, importance for the quality, the optimum harvest date, the evaluation of the maturity, for storage, and for shelf life. They divided the methods of fruit firmness measure on direct (contact; compression, shear, impact, rebound) and indirect (non-contact; vibrational, sonic) methods. Firmness is a property that is often used for evaluating the quality of fruits. Firmness is not a physical quantity, however, is strongly related to numerous physical properties.

6.5.1. Instrumental Measurement of Texture and Firmness

The ability to measure texture is critical for evaluation and control of quality. The complex nature of texture is associated with the diversity of tissues involved, the attributes required to describe textural properties, and changes in these attributes as the product ripens and senesces. Instrumental measurements are preferred over sensory evaluations for research and commercial applications because instruments reduce variation among measurements due to human factors; are more precise; and can provide a common language among researchers, companies, regulatory agencies, and customers (Abbott and Harker, 2003). It is often suggested that the relevance of instrumental measurements depends on how well they predict sensory attributes (Voisey, 1971), but there are also valid uses for mechanical property measurements that relate only to functional behavior of the fruit or vegetable, such as bruise resistance or the ability to be sliced for fresh-cut preparations. There have been numerous reviews of methods for instumental measurement of fruit and vegetable texture (Bourne, 1980; Chen and Sun, 1991; Abbott *et al.*, 1997; Harker *et al.*, 1997). Interaction among characteristics and the continuing physiological changes over time complicate the measurement of fruit or vegetable texture. For example, as the parenchymal tissue of honeydew melon softens, the perception of fibers (vascular bundles) increases (Diehl and Hamann, 1979). On the other hand, the fibrousness in asparagus is related to active lignification of fiber and vascular bundles (Chang, 1987). Similar effects can affect instrument measurements. For example, fibers are held relatively rigidly in a hard melon, and so contribute to the overall force required to cut through the flesh, but the fibers are displaced by the instrument's probe in a soft one and alter distribution of forces within tissue. The displaced fibers can also effectively change the shape of the probe as it progresses through the flesh accumulating a "cap" of fibers. Most instrumental measurements of texture have been developed empirically. While they may provide satisfactory assessments of the quality of produce, they often do not fulfill engineering requirements for fundamental measurements (Bourne, 1982). Fundamental material properties measurements were developed to study the strength of materials for construction or manufacture. After the failure point of such a material is exceeded, there is little interest in the subsequent behavior of the material (Abbott and Harker, 2003). On the other hand, scientists that deal with food are interested in initial failure, but they are also interested in the continuous breakdown of the food in the mouth in preparation for swallowing. As Bourne (1982) pointed out, "food texture measurement might be considered more as a study of the weakness of materials rather than strength of materials." In fact, both strength and breakdown characteristics are important components of texture.

6.5.2. Elastic and Viscoelastic Behavior

Fruits and vegetables exhibit viscoelastic behavior under mechanical loading, which means that force, distance, and time - in the form of rate, extent, and duration of load - determine the value of measurements. For example, impact of the fruit against a hard surface is very rapid loading, whereas the weight of other fruit on an individual fruit at the bottom of a bin and the force of a carton wall against tightly packed fruit are long-term loads (Abbott and Harker, 2003). The fruit will respond quite differently to the two forms of loading. Because of the viscoelastic character of fruit and vegetable tissues, every effort should be made to use a consistent action and speed when making manual texture measurements, such as the Magness-Taylor puncture test (Blanpied *et al*., 1978; Harker *et al*., 1996). The rate of loading should be controlled and specified in mechanized measurements. The optimal rate of loading differs for different commodities. Indeed, people use different loading rates (chewing speeds) when eating foods of different textures (Harker *et al*., 1997); but the optimum loading rate for instrumental measurements may not resemble the rate of human mastication (Thybo *et al*., 2000). There are many types of mechanical loading: puncture, compression, shearing, twisting, extrusion, crushing, tension, bending, vibration, and impact. And there are four basic values that can be obtained from mechanical properties tests: force (load), deformation (distance, displacement, penetration), slope (ratio of force to deformation), and area under the force/deformation curve (energy). The engineering terms based on these measurements are stress, strain, modulus, and energy, respectively. Stress is force per unit area, either of contact or cross-section, depending on the test. Strain is deformation as a percentage of initial height or length of the portion of sample subject to loading. Modulus of elasticity (tangent, secant, chord, or initial tangent) is a measure of stiffness based on the stress/strain ratio. Force and deformation values are more commonly used in food applications than stress and strain values and are sufficient, provided that the contact area and the distance the probe travels are constant and sample dimensions are similar from sample to sample. (Sample here means the portion of tissue tested, not necessarily the size of the fruit or vegetable.) In many horticultural texture tests, deformation is kept constant and the force value is reported. For example, in penetrometer tests of fruit firmness such as the Magness-Taylor test discussed later, the force required to insert a probe into the flesh to an inscribed mark is read from a gauge. No compensation is made for different probe diameters (contact areas), so the value read is force, not pressure or stress. In a few horticultural tests, a known force is applied to the product and the deformation after a specified time is reported; an example is the tomato creep test (Hamson, 1952; Ahrens and Huber, 1990). Puncture, compression, bending, and shear tests are made at relatively low speeds, usually 60 to 300 mm min^{-1} (0.1 to 20 in min^{-1}). In contrast, typical impact velocities in fruit and vegetable handling systems are likely to be around 400 mm s^{-1} (945 in min^{-1}), equivalent to a drop of only 8.1 mm, and sometimes much greater.

6.5.3. MAGNESS-TAYLOR FRUIT FIRMNESS TESTER AND RELATED PENETROMETERS

Idealized and typical force/deformation (F/D) curves for a cylindrical piece of apple tissue compressed at constant speed gives F/D curves for puncture tests look similar to compression curves. The portion of the initial slope up to point represents nondestructive elastic deformation; point is the inflection point where the curve begins to have a concave-downward shape and is called the elastic limit. The region before this point is where slope or elastic modulus should be measured. Beyond the elastic limit, permanent tissue damage begins. There may be a bioyield point where cells start to rupture or to move with respect to their neighbors, causing a noticeable decrease in slope (Abbott and Harker, 2003). Rupture point marks, where major tissue failure causes the force to decrease substantially. In some F/D curves, bioyield may not be distinguishable from rupture. Beyond rupture, the force may again increase, level off, or decrease as deformation increases (Bourne, 1965). At the maximum deformation point specified by the user, the probe is withdrawn and the force diminishes until contact is lost. In the apple tissue maximum force occurred at the maximum deformation, but other apples in the same lot had maxims at rupture or at some point between rupture and maximum deformation. Of course, F/D curves that differ from the ones are also reported for apple and for other commodities. F/D curves for very soft, noncrisp, or spongy tissues do not have sharp peaks but show gradual increase in force to a rupture point, followed by gradual decrease. Some may not even show rupture; for example, a cylinder of eggplant tissue compressed like the apple tissue may show smoothly increasing force to the point of maximum deformation. Products containing a mixture of parenchyma and fibers or stone cells may have quite jagged F/D curves, with several local maxims and ruptures as the probe encounters resistant clusters of stone or fiber cells.

6.5.4. HIGH RATE DEFORMATION - RESPONCE OF PHYSICAL QUANTITY ON IMPACT

The force response of an elastic sphere impacting a rigid surface is governed by the impacting velocity, mass, radius of curvature, elastic modulus, and Poisson's ratio of the sphere. A problem inherent to the technique of dropping the fruit on a force sensor is that the impact force is also a function of the mass and radius of curvature of the fruit (Chen, 1996). Therefore, a large variation in these two parameters will affect the accuracy in firmness measurement.

A different approach is to impact the fruit with a small spherical impactor of known mass and shape and measuring the acceleration of the impactor. The advantage of this method is that the impact-force response is independent of the fruit mass and is less sensitive to the variation of the fruit dimension. This technique was first described by Chen *et al*. (1985). A low-mass high-speed impact sensor was designed and tested (Chen and Ruiz-Altisent, 1996) with good results, however, only on kiwifruits and peaches.

6.5.5. FORCE/DEFORMATION CURVES AND RELATIONSHIP

The force-deformation test was used frequently for agricultural products and most widely utilized methods for mechanical properties estimation. Generally, these methods were based on the high precision measurement, usually performed with expensive equipment i.e. the Instron machine. The mechanical tests (Instron) performed on apple and apple specimens of flesh and skin showed different behavior of apple firmness (Rybczyński and Dobrzański, 1994a). The results obtained by Dobrzański *et al*. (1995) suggest that the penetration test was the sufficient to compare firmness of different apple varieties.

Mizrach *et al*. (1992) used a 3-mm diameter pin as a mechanical thumb to sense firmness of oranges and tomatoes. Takao (1994) developed a force-deformation type firmness tester named HIT (hardness, immaturity, and texture) that can measure firmness of fruit nondestructively. Armstrong *et al*. (1995) developed an automatic instrument to nondestructively determine the firmness of small fruits, such as blue berries or cherries. Fekete and Felföldi (1994) have been reported four rapid penetration methods, where the values of force or deformation were measured. Bellon *et al.* (1993), reported the rapid method, where the deformation was measured at constant force. Fekete (1993) designed device equipped with force sensor, an amplifier and A/D converter, connected to a hand-held microcomputer for data recording. Dobrzański and Horabik (1994) described the method of direct measurement of strain for pea seed and they observed high correlation to the indirectly method of high accuracy laboratory technique. It made the bases to develop a new device; non-destructive strain meter for fruit. Some of results were presented in previous paper (Dobrzański and Rybczyński, 1995).

Firmness is related to maturity and it is well known, that firmness of fruits decreases gradually as they become more mature and decreases rapidly as they ripen. Overripe and damaged fruits become relatively soft. Fekete and Felföldi (1994) reckoned firmness as a principal characteristic of fruits, importance for the quality, harvest, maturity, storage, and shelf life. Thus firmness can be used as a criterion for sorting of agricultural products into different maturity groups or for separating overripe and damaged fruits from good ones. Takao (1994) developed a force-deformation type firmness tester named HIT (hardness, immaturity, and texture) that can measure firmness of fruit nondestructively. Armstrong *et al.* (1995) developed an automatic instrument to nondestructively determine the firmness of small fruits, such as blue berries or cherries. Fekete and Felföldi

(1994) have been reported four rapid penetration methods, where the values of force or deformation were measured. Fekete (1993) designed device equipped with force sensor and Bellon *et al.* (1993), reported the rapid method, where the deformation was measured at constant force. Firmness is related to the quality factors, however, through use of simply penetrometers, only the maximum squeezing force has been correlated frequently with numerous quality factors. Including external and internal properties of fruit, the firmness depends to the shape and size of fruit; size and contact area of plunger; rate of deformation; the way of fruit fixing, and measurement technique influenced a final accuracy. In this mean firmness is not an independent physical quantity connected with mechanical properties, although is frequently related to maturity of fruit.

According to the ASAE Standards, 1989 deformation of compressive properties requires the production of a complete force-deformation curve. From the force-deformation curve, stiffness; modulus of elasticity; modulus of deformability; toughness; force and deformation to point of inflection, to bioyield, and rupture, and maximum normal contact stress or stress index at low levels of deformation can be obtained. Any number of these mechanical properties can, by agreement, be chosen for the purpose of evaluation and control of quality. The force-deformation curve was used frequently for agricultural products and most widely utilized methods for mechanical properties estimation. Generally, these methods were based on the high precision measurement, usually performed with expensive equipment i.e. the Instron machine.

Idealized curve demonstrating elastic limit, bioyield, and rupture or massive tissue failure. Actual force/deformation curve of a cylindrical piece of apple tissue under compression at 1 mm s-1. Force/deformation for Magness-Taylor puncture would look similar (with somewhat different maximum forces), but would terminate at 5/16 in or 8 mm, depending on whether original or metric specification was selected to control the universal testing instrument. Firmness of horticultural products can be measured at different force or deformation levels in all three regions, depending on the purpose of the measurement and the definitions of the quality attributes. F/D characteristics beyond the elastic limit may be more important than those before it because they simulate the destruction that occurs in bruising or eating (Szczesniak 1963; Bourne 1968). The two most common texture tests of fruits and vegetables, the Magness-Taylor puncture and the Kramer Shear report only the maximum force attained, regardless of the deformation at which it occurs. On the other hand, elastic modulus or Young's modulus is often used by engineers as an index of product firmness. The modulus of elasticity is the ratio of stress to strain as calculated from the slope of the force/deformation curve before the elastic limit. Any nondestructive method should limit the force or deformation level to the elastic region so that negligible tissue damage will be sustained during measurement. It is important to recognize and understand the fundamental properties measured by both destructive tests and nondestructive methods, the differences between them, and the factors that can affect the tests. Numerous mechanical instruments have been developed over the past century for measuring textural attributes of horticultural products. Despite the large variations in design, these mechanical instruments either measure or control functions of force, deformation, and time. The types of loading by these instruments include: puncture, compression, shearing, twisting, extrusion, crushing, tension, and bending.

6.5.5.1. PUNCTURE TESTS

Puncture testers based on the original Magness-Taylor pressure tester, also called the USDA or Ballauff tester (Magness and Taylor, 1925; Haller, 1941) and more correctly called the Magness-Taylor fruit firmness tester, are used to measure firmness of numerous fruits and vegetables to estimate harvest maturity or for postharvest evaluation of firmness (Abbott and Harker, 2003). There are several adaptations of the Magness-Taylor (MT) tester that differ in instrument size and shape, manual or mechanical use, and dial (analog) or digital readout. The term "Magness-Taylor firmness" is used generically for the measurements made with the several variants of the MT. All use rounded-tip probes of specific geometry and measure the maximum force required to insert the probe 7.94 mm (5/16 in) into the flesh (Haller, 1941). Note that the rounded portion of a Magness-Taylor probe is only a portion of a full hemisphere (Fig. 2; dimensions provided by John Cook, former Pres., Ballauf Mfr., Laurel, MD). An 11.11 mm (28/64 in) diameter probe. Similar probes of other dimensions are sometimes used for measuring texture of fruits and vegetables, as well as probes of different geometry. Note that the larger Magness-Taylor probe is used for apples and the smaller probe is used for most other commodities (nominally 11 and 8 mm, respectively). with a radius of curvature of 8.73 mm (11/32 in) is used for apples. A 7.94 mm (5/16 in) diameter probe with a radius of curvature of 5.16 mm (13/64 in) is used for cucumber, kiwifruit, mango, papaya, peaches, pears, and plums. A thin slice of skin (about 2-mm thick and slightly larger diameter than the probe) should be removed from the area to be tested except for cucumbers, which are tested with the skin intact. A group of U.S. researchers published recommendations for making manual penetrometer tests (Blanpied et al., 1978), stating that steady force should be applied such that the probe is inserted to the inscribed depth mark in 2 s. The probes can also be mounted in materials testers (universal force/deformation testing machines) made by numerous manufacturers (some are listed in Table 2) (Bourne, 1974; Breene *et al*., 1974; Abbott *et al*., 1976; Harker *et al*, 1996; Lehman-Salada, 1996). A group sponsored by the Commission of the European Communities recommended that a materials tester should be used to drive the probe to a depth of 8 mm at speeds between 50 and 250 mm min^{-1} (Smith, 1985). Because of the curvature of the MT probes and the fact that firmness as measured in puncture is a combination of shear and compression in variable proportions, it is not possible to convert measurements made with one size MT probe to the other MT size, or to accurately convert to or from values for probes of other geometries (Bourne, 1982). A random sample of 20 to 30 fruit of similar size and temperature should be tested with punches on two opposite sides, depending on uniformity of the lot. Peaches are often more variable around the circumference than other fruit so the larger number is recommended (Blanpied *et al.*, 1978). Similar measurements are made on cherry, grape, and strawberry using a 3-mm probe and on olive using a 1.5-mm probe on the U.C. tester (E.J. Mitcham, 2000, personal communication). Numerous puncture tests with flat-faced cylindrical or hemispherical probes and a few with conical probes have been conducted. None have achieved the acceptance of the Magness-Taylor fruit firmness test.

6.5.5.2. SHEAR TESTS

Shearing in engineering terms does not mean cutting with a knife or scissors, but instead sliding adjacent parallel planes of cells past one another (Abbott and Harker, 2003). Engineering shear tests are seldom used on fruits and vegetables, but shear modulus can be obtained from compression (Mohsenin, 1986), torsion (Diehl *et al.*, 1979), impact (Bajema and Hyde, 1998), extrusion, and dynamic (Ramana and Taylor, 1992) tests. Although it does not measure true shear, the Kramer Shear device (FTC Texture Test System, Food Technology Corporation, Reston, VA) is used extensively in the food processing industry and is used by some fresh-cut processors for quality control. The key component of the original Kramer Shear device is a multiblade cell with ten blades 2.9 mm (about 7/64 in) thick that mesh with slots in the bottom of a 67 x 67 x 63 mm cell (approximately 2 5/8 x 2 5/8 x 2 1/2 in; internal dimensions) that can be used on any materials tester with sufficient load capacity. The cell is generally filled with randomly oriented pieces of the product, either to full capacity or to 100 g. The force measured by the test involves compression, shear, extrusion, and friction between the tissue and blades. While the maximum force to pass the blades through the sample may relate to the complex of material properties sensed in the mouth during chewing, the test does not satisfy requirements for engineering tests because of the undefined and uncontrolled stresses and strains applied to the food. The amount of sample and the pattern of loading the cell, size and orientation of pieces, etc., affect the maximum force value as well as the shape of the force/deformation curve (Szczesniak *et al.*, 1970; Voisey and Kloek, 1981). The orientation of pieces of fruit or vegetable, especially with regard to vascular bundles and fibers, and the spaces between pieces would be expected to affect significantly the force/deformation profile as the blades penetrate through the contents of the shear cell, therefore some standardization of loading practice is advisable. Adaptations with smaller cells and fewer blades are available, eg., Stable Micro Systems. As with the MT probe, comparisons should not be made between results from cells of different geometries.

6.5.5.3. COMPRESSION

Although compression tests are not commonly used by the fruit and vegetable industry, they are widely used in research on horticultural products (Abbott and Harker, 2003). They can be made on tissue specimens or intact products using a variety of contact geometries (Mohsenin, 1986; ASAE Std. 368.4, 2000). Although fruits and vegetables are viscoelastic, they are often treated as elastic, so the force required to attain a specified deformation or to rupture (bruise or burst) the product is generally measured. Modulus of elasticity, stiffness, force and deformation to bioyield and to rupture, and contact stress can be calculated from elastic measurements, dimensions of the specimen, and Poisson's ratio (the ratio of transverse strain to axial strain at less than the elastic limit). For convex specimens such as whole or halved fruits, see ASAE Std. 368.4 (2000). Often, for food science applications, only maximum force or distance is reported. Compression tests using pieces of tissue, usually cylindrical, excised from the fruit or vegetable are quite common in research (Bourne, 1968; Khan and Vincent, 1993; Abbott and Lu, 1996; Wann, 1996). Intact product compression tests involve contact with small flat or curved indentors or with parallel plates significantly larger than the area of contact (ASAE Std. 368.4, 2000). Modulus of elasticity values from whole fruit compression represents fruit morphology, size, shape, cellular structure, strength, and turgor. Although elastic properties can be determined nondestructively (discussed later), horticultural and food science measurements are frequently made beyond the elastic limit. Sundstrom and Carter (1983) used rupture force of intact *watermelons pressed between parallel flat plates to evaluate causes of cracking. Jackman et* al. (1990) found that whole tomato compression was relatively insensitive to small differences in firmness due to chilling injury. Kader *et al*. (1978) compressed tomatoes between a pair of spherical indentors as a measure of firmness. If the viscous element is a significant contributor to the texture, as it is for intact tomatoes and citrus, measurement of continuing deformation under a constant force (creep) (Hamson, 1952; El Assi *et al*., 1997) or decrease in force under a fixed deformation (relaxation) (Sakurai and Nevins, 1992; Errington *et al*., 1997; Kajuna *et al*., 1998;Wu and Abbott, 2002) provides textural information in addition to elastic properties. To minimize the effect of loading position on firmness measurement in tomato, Kattan (1957) designed a creep tester that applied force around the fruits circumference with a belt. The failure of creep or force-relaxation testers to be adopted commercially is due to time required for adequate relaxation, which can be up to 60 s.

Force/deformation curves for several fruits and vegetables, illustrating diversity of texture. All curves are for 15 mm diameter × 10 mm high cylinders cut parallel to the product axis, compressed between flat plates at 2 mm second^{-1} to 75% compression, and then released at the same rate. Note that the maximum force for yucca root greatly exceeded the capacity of the load cell used and that yucca showed a clear bioyield at about 230 N (Abbott and Harker, 2003).

6.5.5.4. TENSION TEST

Tensile tests measure the force required to stretch or to pull a sample apart. Failure can be through cell rupture, cell separation, or a combination of both. Tensile measurement has not been as popular as puncture or compression testing because it is not intuitively as related to crushing or chewing as are puncture or compression and because it requires gripping or otherwise holding the ends of the sample so they can be pulled apart without crushing the tissues where they are held. Schoorl and Holt (1983) used clamps to hold apple tissue, however, most satisfactory results obtained Dobrzański *et al*., (1995); Rybczyński and Dobrzański (1994b). Stow (1989) and Harker and Hallett (1992) used shaped samples held by special claw-like hooks. Harker and Hallett (1994) used quick-set adhesive to glue the ends to instrument fixtures. Researchers often examine the broken ends of tensile test samples to determine the mode of fracture. Microscopic analyses of the broken ends (Lapsley *et al*., 1992; Harker and Sutherland, 1993; Harker and Hallett, 1994; Harker *et al*., 1997) reveal that tissue from unripe fruit generally fractures due to individual cells breaking; whereas, cells from ripe fruits which tend to be crisp (apple and watermelon) usually break or rupture and cells from ripened soft fruits (banana, nectarine and kiwifruit) tend to separate at the middle lamellae.

6.5.5.5. TORSION TEST

True torsion tests are rarely used on horticultural specimens because of the difficulties in shaping and holding the tissue (Diehl, Hamann, 1979; Diehl *et al*., 1979).

6.5.5.6. TWIST TEST

Studman and Yuwana (1992) proposed a simple twist tester, consisting of a sharp spindle with a rectangular blade that is forced into the flesh and then the torque (twisting force) required to cause crushing or yielding of the tissue is measured. Although called a twist test, this is not to be confused with a torsion test; the properties tested are likely a combination of shear and compression. Harker *et al*. (1996) found the twist test to be more precise than several testers using the MT puncture probe; however, Hopkirk *et al*. (1996) suggest that puncture and twist tests may measure different mechanical properties, resulting in quite different firmness judgments. The twist test has the advantage of being able to measure strength of tissue zones at specific depths from the surface without requiring the excision of tissue samples.

6.5.5.7. BENDING TEST

Dobrzański and Rybczyński (1994) proposed a very precisions test for study the elasticity of apple, that only a superficial layer of apple flesh was used. The beam of apple flesh, the beam of the flesh with the skin over was loaded in this test. The cross-section of the beam was 3x3 mm, while distance between supports was 10 millimetres. Forces at the elastic range were used to calculate the modulus of elasticity. The highest differences of elasticity of apple at different stage of maturity were noticed using bending test of flesh beam with skin. It shows that fruit firmness was most influenced by elasticity of apple flesh and strength of apple skin. Rybczyński and Dobrzański (1999;2000) proves that strength of superficial layer of apple flesh in bending test more accurately indicates the mechanical resistance of apple skin and fruit firmness.

6.6. JUICINESS

The importance of juiciness has been demonstrated by numerous consumer awareness studies; however, there has been little progress in developing instrumental measurements of juiciness (Abbott and Harker, 2003). Intuitively, one would expect total moisture content to determine juiciness, but the correlations between them are often low for fruits and vegetables (Szczesniak and Ilker, 1988). Apparently, inability of cells to release juice has a greater impact. For example, water content of juicy and chilling-injured peaches is similar, yet injured fruit have a dry mouth-feel; also mealy apples feel dry to the palate because cells separate at the middle lamella, rather than being ruptured and releasing juice during chewing. Generally, juiciness is characterized as weight or percentage of juice released from a fixed weight of tissue. Juice can be extracted from tissue using a press (like a cider press), homogenizing and centrifuging to separate juice from solids, using juice extractors, or measuring juice released during compression testing of excised tissue (Harker *et al.* 1997).

6.7. DENSITY

The density of many fruits and vegetables increases with maturity. On the other hand, certain types of damage and defects tend to reduce the density of the product. Zaltzman *et al.* (1987) presented a comprehensive literature review of previous studies related to quality evaluation of agricultural products based on density differences. However, internal structure of tissue more distinctly affected the mechanical properties than density differentiation of fruit tissue (Abbott and Harker, 2003).

CHAPTER 7

QUALITY PROPERTIES OF APPLE

World crop of apples reaches about 42 millions tons yearly. The apples are on the forth place as far as the overall crop is concerned; after grapes, citrus fruits and bananas. Major producers of apples are European countries such as France, Italy, Poland and Hungary (Dobrzański, jr., *et al.*, 2001). In Europe last couple of years brought domination of the supply of apples over the demand. Poland is in world vanguard of apple's producers, being situated at the entry to the Eastern markets might play important role among European exporters. Poland develops apple production, however, exports cover most industrial apples and it's concentrate. The best quality apples of 15 % and 35 % of the II -nd sort quality are suitable for consumption. As much as half production of apples in Poland, did not meet quality requirement of market and is destined for industrial processing. To become an exporter of apples for consumption that the most expensive ones; the quality should be improved.

Varieties of apples can be roughly divided into dessert, table and industrial apples. When apples are grown for consumption the following features are favoured: crispness, content of juice, good taste and aroma, nice colouring of the skin.

Most important commercial criteria are based on the evaluation of firmness, colouring and size of apples (Dobrzański, jr. *et al.*, 2001). To meet these criteria, producers should sort apples into quality groups during organisation of the harvest, calibrating fruits and dividing them into size classes. In Poland apples are sorted into three groups which meet certain norms. Large fruits like Lobo, Boskoop, Red Delicious, Melrose, Jonagold and Gloster should have 7 cm minimal diameter in the best quality "Extra" group. Dividing into size classes by 0.5 cm, make marketing easier and allows to obtain a higher price. The other groups of apples should be divided into size classes by 1.0 cm. Admissible low diameter of fruit in the 1st assortment is 6 cm and 5.5 cm in the 2nd assortment. Apples smaller then 4.5 cm in diameter are classified as an industrial.

In most Polish farm's apples are sorted by hand. Farm producers should have sorting lines connected to various packing equipment, like: box filling units, bag filling units, tray-packing units etc. allows preparation of fruits according to the order guaranteeing selling of the crop with the highest prices (Dobrzański, jr., *et al.*, 2001). These lines are very expensive and only some producers can afford to buy them not being sure that their investment will pay off considering current relations between fruit prices and costs of production.

The influence of a sorting line on the final quality of fruits were studied. The authors applied the Cascade M-625 sorting line suitable for grading of all spherical crops like: apples, oranges, grape fruits, lemons, pears, tomatoes, kiwi fruits and plums. For sizing and sorting of apples they modified this sorter in order to minimising damage and bruising of fruit. The fruits were rolling on the moving belt in the front of different gates to obtain outstanding sizing diameter. Sizing by diameter was done between 50-90 mm, in which size groups adjustable in steps of 5 mm for each. All fruits from the outlets of the sorting line were weight and measured with high accuracy.

Mechanical damage and bruising of apples were carefully recognize after sorting to check the quality of grading and establish the acceptability of product for a particular market or storage condition. Colour, firmness and size of apple are most important criteria among other quality parameters estimated by consumer.

The fruit quality adapted from market is mostly connected with cosmetic appearance, however, for human nutrition apples should be valid continually after storage, especially after long storage. Reducing sugar and L-ascorbic acid were estimated to determine the final quality of storage apple.

According to the previous papers (Dobrzański, jr., *et al*, 2001) the dinitrosalicylic acid reagent was composed with Rochelle salt, phenol, sodium bisulfite, and sodium hydroxide for determination of reducing sugar. The effect of different concentrations of sulphite in the modified reagent indicated that a maximum colour intensity was obtained at 0.05 % sulphite, being adequate for this purpose.

7.1. SIZE, SHAPE AND WEIGHT

The physical characteristics connected with; size, shape and weight of fruit were determined for numerous varietys. For all studied varietys similar relations and linear regression between the maximum and minimum size of fruit were observed, however, in this capture the results for Priam apples only as an example is presented. The linear regression and correlation coefficients for Priam variety and relation between the maximum and minimum size of fruit is shown in Figure 21. This indicates that apples of Priam variety presents more regular shape; nearly to the circle in cross-section. However, correlation coefficients between the maximum size of fruit and its axis high indicate irregular proportions of fruit shape (Fig. 21). The correlation coefficient (R=0.70) between maximum diameter (D_{max}) and axis high (h) was low, what indicates irregular shape of fruit in vertical cross-section (Fig. 21).

Low correlation was observed between axis height (h) and diameter of fruit for other studied apples. The circular shape in top view of apples was presented by high correlation coefficient close to 1, covering values of the range from 0.92 to 0.97 for both diameters of fruit. The high correlation coefficient (R=0.98) for Red Elstar apples shows that the weight is strongly related to maximum diameter of fruit D_{max} (Fig. 26) and both of these factors should be used equivalently for quality estimation.

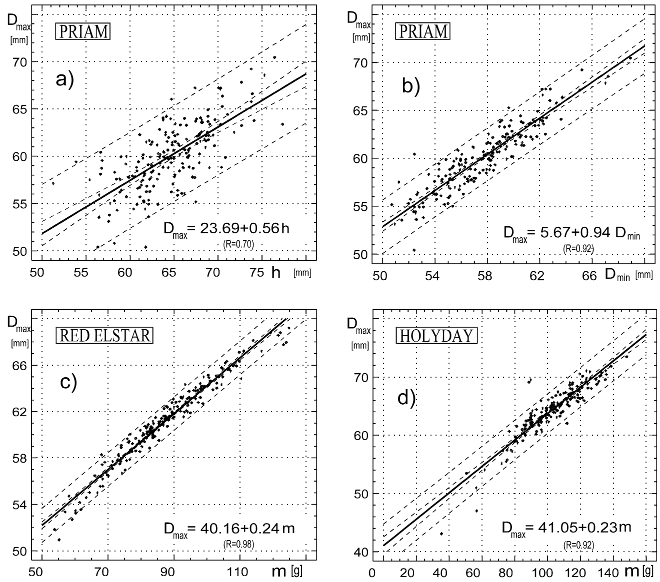

Fig. 26. Physical characteristics of apple size and weight

The differentiation of fruit size indicated that apples should be sorted to quality improve. For example, the Gloster apples are large (63.3-88.6 mm), that weight corresponding to the fruit size covering the values from 101 g to 256 g. Most of them should be clasyfied to the best quality group "Extra". In comparison, Holyday apples (Fig. 27) of diameter, which are in the range of 43.3 mm to 73.8 mm, consist the weight from 36 g to 147 g. Only some of larger ones are adequate for "Extra" quality group. The benefits of mechanical sorting of Holyday apples are not certain, because most of fruits are small and must be classified as an industrial with low price.

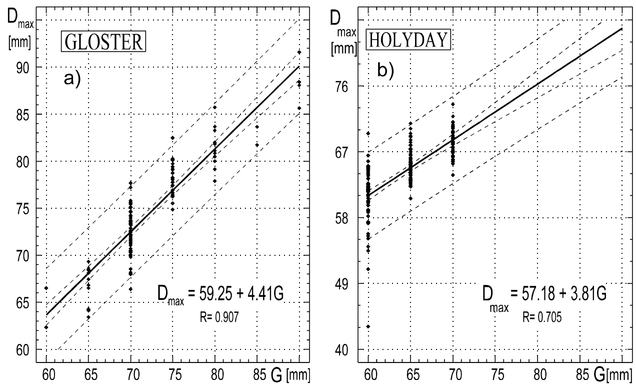

Fig. 27. The effect of fruit grading with Cascade sorter

High correlation coefficients between the maximum size of fruit and weight proves that dimension of fruit is mostly connected with it's weight. It hopes that weight of single fruit should be proper index of grading quality.

For example, the final quality of grading are shown in Figure 22 for Gloster and in Figure 27 for Holyday variety. The higher correlation (R = 0.907) between weight and size of gate for Gloster variety proves that the Cascade M-625 is suitable for grading of spherical apples. Irregular shape of Holyday apples had significance influence on low quality grading (R = 0.705). On the other hand, most of apples are small and diameter of fruit is less than 7 cm, the limit for "Extra" class. This indicates the influence of a sorting line on the grading quality of fruits.

The way of grading, that the apples are rolling on the moving belt in the front of different gates suggest that only apples of regular shape are sizing with sufficient accuracy. Sizing with simply sorter makes improving quality of apples at low cost, however, sorting of small fruits as Holyday variety should be done by hand.

On the other hand, in any measurements and testing of mechanical behaviour, the size differentiation indicated that apple quality based on mechanical factors should contain the values connected with the fruit size.

7.2. MECHANICAL PARAMETERS OF APPLE

Apple quality at purchase and consumption is dependent on the degree of ripeness and the absence of mechanical damage and decay. The mechanical resistance of fruit generally decreased with storage time and maturity. Mechanization of horticulture production has subjected fruits to situations that often cause mechanical damage, mainly bruising. The apple's resistance to bruising and the potential for good storability are related to its firmness.

The physical attributes' indicative of fruit firmness is elastic behavior of the apple, which is mainly consists of the flesh and covers by the skin. So, attempts have been made by several researchers to provide mechanical characteristics of the apple’s skin and flesh (Dobrzański and Rybczyński, 1994; Rybczyński and Dobrzański, 1994a; Dobrzański *et al*., 1996).

The following varieties of apple: Cortland, Gala, Gloster, Holyday, Jonagold, Idared, McIntosh, Melrose, Priam, Red Elstar, Spartan, Šampion were hand-picked and the extra class fruits (the same size for each variety), at harvest ripeness, were sorted and held in the refrigerated storage at 2÷4^{0}C temperature. The resistance tests were performed with the Instron machine at 10 mm/min rate of crosshead move using different equipment of sample preparation for following tests:

- compression (cylindrical flesh sample),
- tension (skin belt),
- penetration (fruit),
- and bending (flesh beam without skin and with skin over).

The fruits were tested twice; once at harvest maturity (hm) and second time after storage at consumption maturity (cm).

The flesh samples, cut out perpendicularly to the stem calyx axis of the fruit, had a cylindrical shape with both diameter and length of 13 mm. Four samples were cut out from each apple. Thirty samples were used as one combination. The samples were compressed between parallel plates to the rapid decrease of force. The work deformation, force and deformation at damage of the apple flesh were noticed. The values related to the modulus of elasticity have been determined from the elastic range of force-deformation curve.

Thirty skin belts (five from one apple) with cross section area 2 mm x 0.3 mm were cut out for tension test. The skin belts were placed in special holder fixed to cross-head of the Instron apparatus. Ten millimetres of belt between holder was used for calculation as the initial size of sample. The maximum force, deformation and work deformation were also noticed. The modulus of elasticity was determined from the simple equation according to the Hook's low.

The penetration test was also performed at the same speed rate of cross-head move. All values as force, deformation and work deformation connected with fruit firmness were recorded at point when penetrometer squeeze in flesh after skin damage. The values related to the modulus of elasticity have been determined from the elastic range of force-deformation curve used equation according to the Hook's low:

- for the compression, penetration and tensile tests:

$$E = \frac{(F_2 - F_1)}{A(\varepsilon_2 - \varepsilon_1)} \tag{7}$$

where: E – modulus of elasticity [MPa]; F_1, F_2 – forces causing elastic deformation [N]; ε_1, ε_2 – relative strains for the elastic deformations [mm/mm]; A – cross-sectional area [mm^2].

- for the bending test

$$E = \frac{L^3(F_2 - F_1)}{4bh^3(d_2 - d_1)} \tag{8}$$

where: E – modulus of elasticity [MPa]; L – distance between supports [mm]; F_1, F_2 – forces causing elastic deformation [N]; b – width of the beam [mm]; h – height of the beam [mm]; d_1, d_2 – elastic deformations [mm].

Thirty, not more than five samples from each fruit were cut out for bending test and only 8 mm superficial layer of apple was used. The beam of apple flesh, the beam of the flesh with the skin over was loaded in bending test. The cross-section of the beam was 3x3 mm. The distance between cylindrical supports was 10 millimetres. Forces caused deformations at the elastic range were used to calculate the modulus of elasticity.

7.2.1. TENSION TEST

Mean values of tensile strength (F) at break of the apple skin for twelve apple varieties are shown in Figure 28. In some cases the tensile force (F) of skin after storage had significance lowest values at the 5-percent level (Cortland, Holyday, Priam, Red Elstar,

Spartan and Melrose varieties) and reached the range from 0.66 N to 1.65 N. Similar tendency was observed for Gloster, Jonagold, McIntosh and Idared varieties, however the differences were not significance.

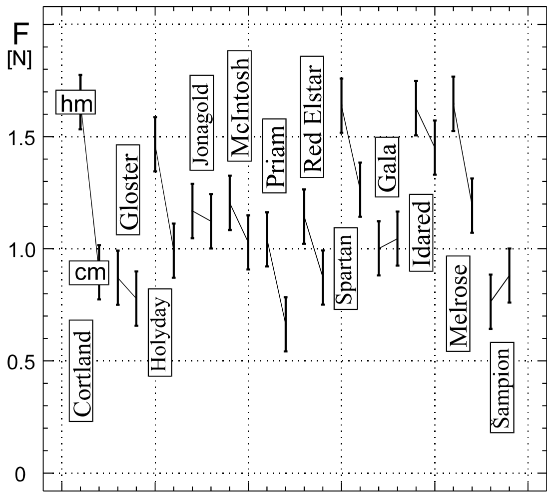

Fig. 28. Tensile strength of apple skin

Figure 29 shown the modulus of elasticity of apple skin for Cortland, Gala, Gloster, Holyday, Jonagold, Idared, McIntosh, Melrose, Priam, Red Elstar, Spartan, Šampion varieties at harvest maturity and after storage. Modulus of elasticity of apple skin reached values of the range (8.10-16.94 MPa). The values obtained for Cortland, Holyday, Spartan, Melrose and Šampion variety showed more distinctly the effect of storage on the skin strength. The highest values (16.94 MPa – Melrose variety, 14.84 MPa – Šampion variety and 14.80 MPa – Idared variety) were obtained for skin at harvest maturity of apples. After storage the highest values were noticed for Idared (13.71 MPa) and Melrose (13.55 MPa) varieties. The modulus of elasticity determined for apple skin shown the weakest mechanical properties of skin for Priam variety.

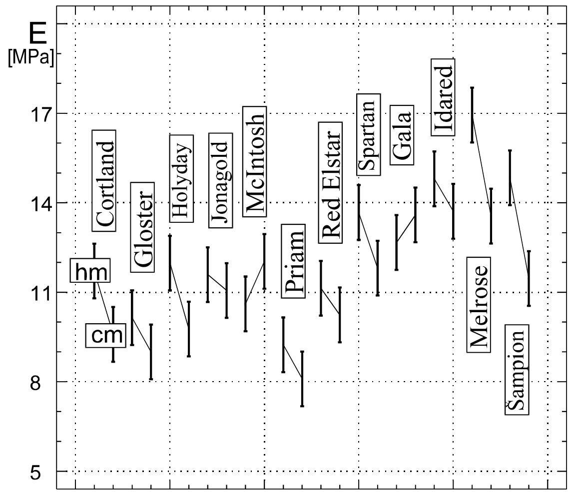

Fig. 29. Modulus of elasticity of apple skin

7.2.2. COMPRESSION TEST

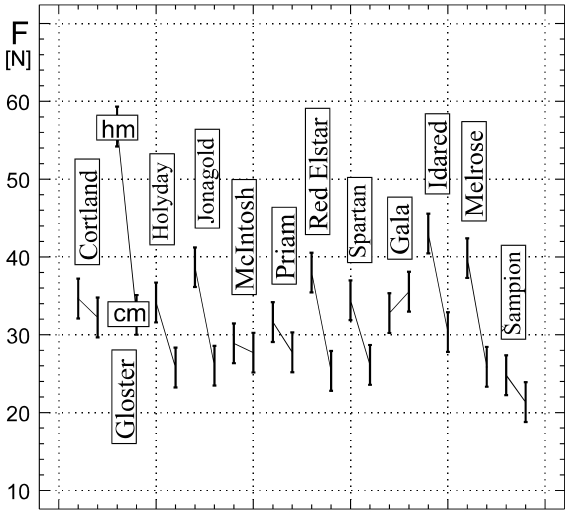

Fig. 30. Compression force at damage of apple flesh

Compression force (F) at flesh damage for twelve apples' varieties are shown in Figure 30. Mostly, the storage had significance influence on decrease of force noticed at flesh damage (Gloster, Holyday, Jonagold, Red Elstar, Spartan, Idared and Melrose varieties) at the 5-percent level. Similar tendency was observed for Cortland, McIntosh, Priam and Šampion varieties, however there were not significance differences.

The range (21.34÷56.75 N) covered all the values reached in compression test. The flesh of Gloster variety was significantly stronger after harvest (56.75 N). In comparison after storage the mean value decreased to 32.55 N. The compression force obtained for Cortland, McIntosh, Priam and Idared varieties was on similar level. The lowest values of force at flesh damage were obtained in both terms; after harvest and after storage, for Šampion variety and reached 24.81 N and 21.34 N respectively.

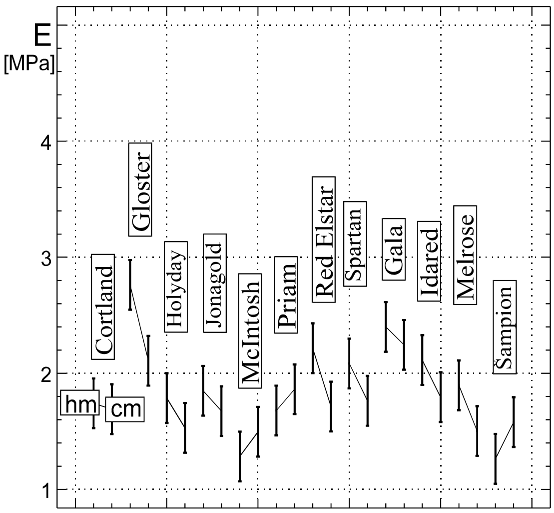

Fig. 31. Modulus of elasticity of apple flesh

Average values of modulus of elasticity (E) of the flesh determined during compression test are present on Figure 31. Slightly decrease of elasticity during storage was noticed. However, only for Gloster and Red Elstar varieties significant ($p = 5\%$) differences were observed. The highest value of the modulus of elasticity (2.76 MPa) was obtained for Gloster variety at harvest maturity. The mean values obtained in compression test for other studied varieties reached the range from 1.26 MPa to 2.40 MPa. However, decreasing tendency of flesh firmness after storage was observed for modulus of elasticity of cylindrical flesh compressed between parallel plates.

7.2.3. PENETRATION TEST

Average values of force (F) at damage of skin received in penetration test of apple for twelve varieties presents Figure 32. The storage had significance influence on the values of force obtained at skin damage for most of studied varieties at the 5-percent level. After harvest the highest values were obtained for Gloster (35 N), Melrose (30.98 N), Holyday (30.71 N) and Jonagold (30.09 N) varieties, and the lowest for Priam (19.74 N) and Šampion (15.34 N) varieties. The force obtained in penetration test shown the phenomenon of fruit firmness decreasing after storage for all studied varieties except Priam, Spartan and Šampion varieties. In this case the force at harvest and after storage reached values on similar level.

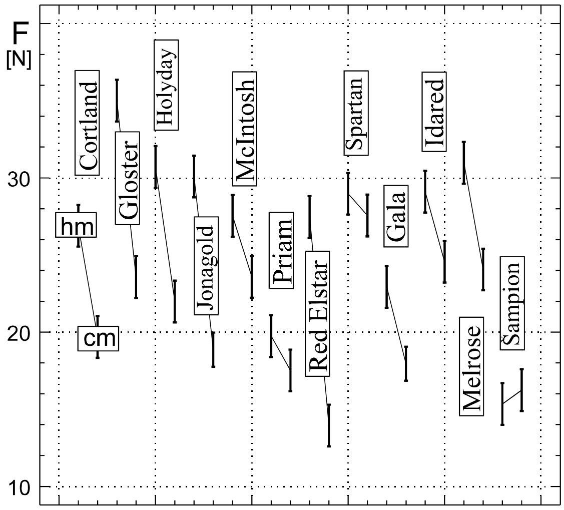

Fig. 32. The penetration force at skin damage

The values related to elasticity determined with penetration test (Fig. 33) decreased after storage. Mostly, the storage had highest statistically significant effect ($p = 5\%$) on decrease of calculated values related to the modulus of elasticity. The highest elasticity of apple at harvest maturity was observed for Holyday (5.96 MPa) and Melrose (5.65 MPa) varieties. The lowest values at consumption maturity after storage obtained in penetration test for apple of Red Elstar variety (0.34 MPa) was close to being ten times lower than for Gala (3.29 MPa), Melrose (3.22 MPa), Holyday (3.13 MPa) or Idared (2.75 MPa) varieties.

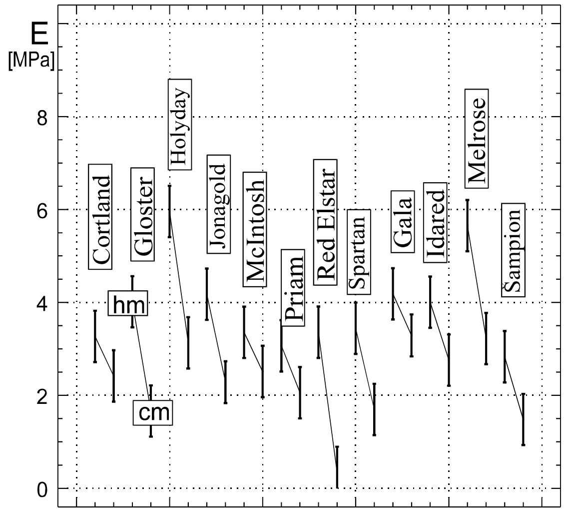

Fig. 33. Elasticity at small deformation

7.2.4. Bending Test

The force at damage obtained for the flesh beam at bending test for studied varieties are shown in Figure 34. For all studied varieties the force determined at break decrease after storage. However, significance difference only for Gloster, Holyday, Jonagold and Melrose varieties was observed. The highest values of force after harvest were noticed for Gloster (1.17 N) and Melrose (0.71 N) varieties. The lowest values were obtained for Šampion variety: 0.33 N after harvest and 0.24 N after storage, respectively. Other studied varieties reached the range of damage force from 0.25 N to 0.58 N.

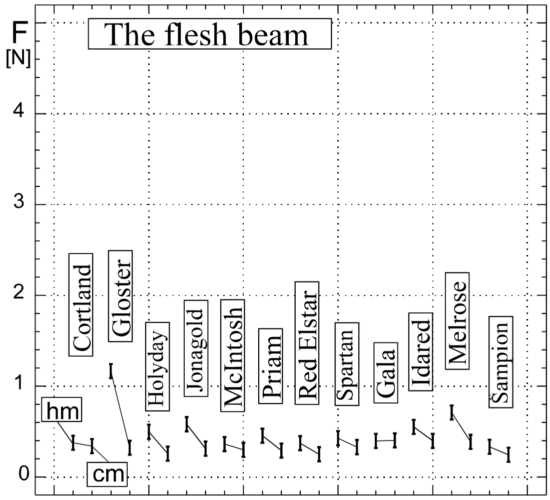

Fig. 34. Damage force at bending of apple flesh beam

The similar tendency was observed during bending test for damage force (Fig. 35) of the beam with the skin over the flesh. The highest values of force after harvest were noticed for Gloster (2.50 N), Jonagold (1.58 N) and Melrose (1.42 N) varieties. Other studied varieties reached the similar range of the damage force from 0.44 N to 1.22 N. The influence of skin resistance was observed on strength of apple tissue superficial layer.

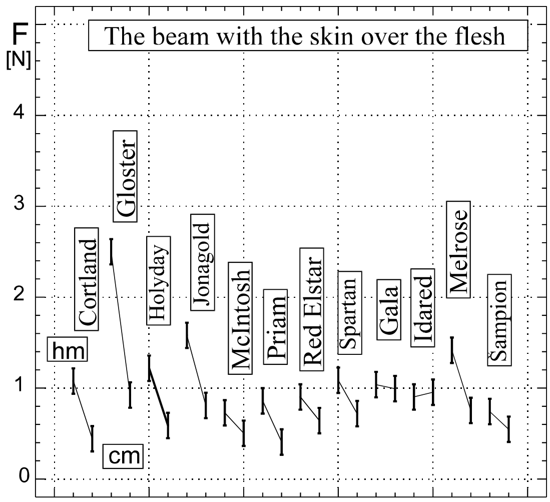

Fig. 35. Damage force at bending of apple flesh beam

The modulus of elasticity obtained for the flesh beam at bending test for studied varieties are shown in Figure 36. Modulus of elasticity reached values of the range (1.04-2.45 MPa). The storage had significance influence on decrease of the value related to the modulus of elasticity for the most varieties used in this study. Only Cortland variety reached mean values on similar level (1.41 MPa at harvest maturity and 1.49 MPa after storage) and there were not noticed significance differences.

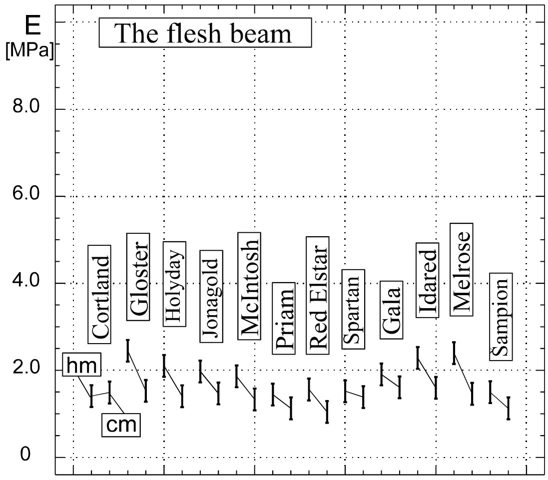

Fig. 36. Modulus of elasticity of apple flesh beam determined in bending test

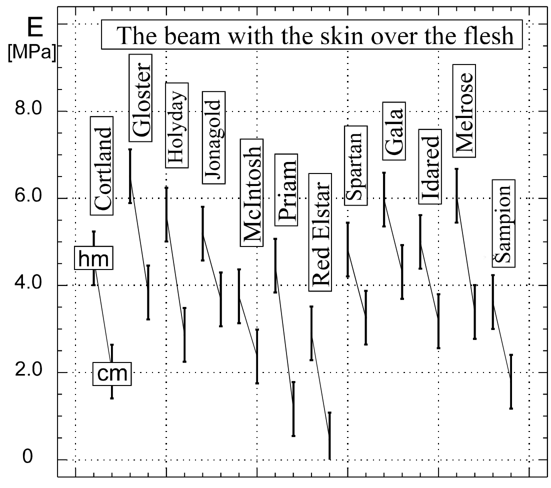

Fig. 37. Modulus of elasticity of apple flesh beam with skin determined in bending test

The values of the elasticity modulus (Fig. 37) obtained during the bending test (flesh beam with skin) showed more distinctly the effect of storage on fruit firmness and it allows to distinguish most of varieties. The values noticed after harvest ranged from 2.90 MPa for Red Elstar variety to 6.50 MPa for Gloster variety and were close to being two times higher than after storage. The highest differences of elasticity of apple at different stage of maturity were noticed using bending test of flesh beam with skin. It shows that fruit firmness was strongly associated to the modulus of elasticity of apple flesh as well as to the modulus of elasticity of apple skin. The strength of superficial layer of apple flesh determined using bending test more correctly reflects the influence of mechanical resistance of apple skin on fruit firmness.

Mechanical tests performed on apple flesh and skin shown behavior of apple firmness. In most cases the storage had significance influence on the mechanical properties estimated at different tests used in this study. After storage fruit firmness decreased unequally and vary on variety.

The bending technique (flesh beam and flesh beam with skin) allowed to evaluate a flesh firmness of apple from the under skin layer. The estimations of the mechanical resistance of apple using bending test evaluate a susceptibility to bruising and skin damage. According to this method the values related to the modulus of elasticity more distinctly show the changes of apple firmness after storage.

Although, these mechanical tests are still destructive ones, but are very useful as resource of basic information and comparing to the tests that will be developed and designed as non destructive.

7.3. APPLE FIRMNESS

Overripe and damaged fruits become relatively soft. Thus firmness can be used as a criterion for sorting of agricultural products into different maturity groups or for separating overripe and damaged fruits from good ones. Including external and internal properties of fruit, the firmness depends to the shape and size of fruit; size and contact area of plunger; rate of deformation; the way of fruit fixing, and measurement technique influenced a final accuracy. Looking for a simple test of firmness estimation, various mechanical properties were studied on apple fruit and specimens of apple flesh and skin.

Refrigerated storage at of 0-2^{o}C, regular storage (commonly used in small farm in Poland) at of 6-8^{o}C and storage with high temperature (14-16^{o}C) were used to obtain different degree of fruit softness. However, only Gloster, Jonagold, Idared and Šampion apples were held in different conditions up to 30 weeks to have a wide range of mechanical behaviour of fruit. The firmness was determined with the Instron machine and Elasticity Meter. In both case the modulus of elasticity was determined at small deformation. All these tests were performed on apple with skin and apple after skin removed, according to the Magnes-Taylor method (1925) to established a measurement range of deformation independence to the skin absence. The previous study concerning on the compression test and the measurement of fruit strain under the break point, made the bases to develop a device for fruit firmness estimation and some results obtained with this meter for different pin were presented by authors (Dobrzański and Rybczyński, 1998).

The Elasticity Meter used for fruit firmness estimation was described in previous papers (Dobrzański and Rybczyński, 1997). This meter allows on the measurement of fruit elasticity at the limit force corresponding to the fingers touch.

The modulus of elasticity reached values of the range (1.04-2.45 MPa) for the flesh beam at bending test. The storage had significance influence on decrease of the value related to the modulus of elasticity for the most varieties used in study.

The values of elasticity modulus obtained during the bending test of the flesh beam with skin over showed more distinctly the effect of storage on fruit firmness and it allows to distinguish most of varieties. The values noticed after harvest ranged from 2.9 MPa for Red Elstar variety to 6.5 MPa for Gloster variety and were about two times higher than after storage. The highest differences of elasticity of apple at different stage of maturity were noticed using bending test of flesh beam with skin. It shows that fruit firmness was strongly connected to the modulus of elasticity of apple flesh as well as to the modulus of elasticity of apple skin.

The strength of superficial layer of the apple flesh determined using bending test reflects more correctly the influence of mechanical resistance of apple skin on the fruit firmness. However, this test needs high experience of the method of flesh preparation being most complicated in performance. Thus distinguish

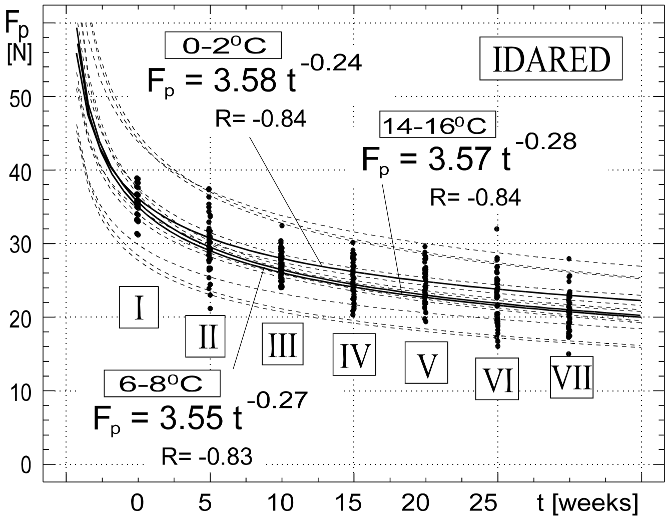

Fig. 38. The squeezing force for Idared variety at penetration with 6 mm plunger

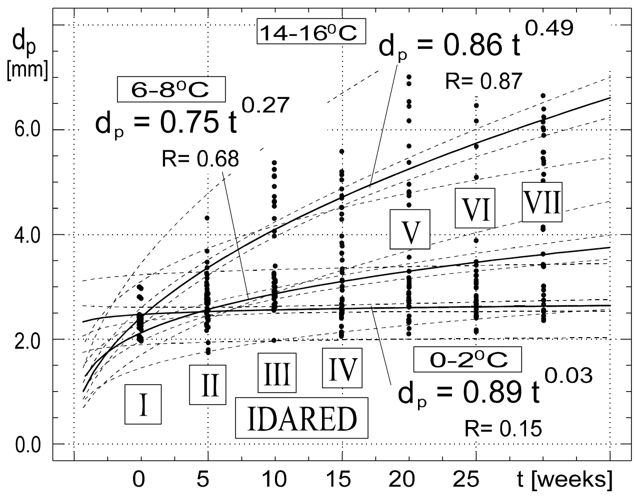

Fig. 39. The flesh deformation of Idared apple at peak of force

differentiation of fruit firmness observed in previous paper [Dobrzański et al., 1994], as well as results obtained in this study for the penetration test allowed used this method to compare the apples during storage.

The force for Idared apples storage in different temperature received in penetration test with 6 mm plunger is presented in Figure 38. For other varieties similar tendency was observed. It was also noticed that Idared apples were more firm, however, significant differences were observed for apple with skin only. The results obtained using penetration test allow to compare the varieties according to the fruit hardness, however, firmness of flesh was similar and frequently there was no significance difference for fruits, storage at various conditions. It shows that using simply penetration test slightly changes of fruit firmness were not observed for apple's storage at various conditions.

More distinctly effect of storage was observed, while deformation at peak of squeezing force was noticed, however, only the apples storage in unsuitable condition are more significant soft and large deformation for studied varieties was noticed. The influence of temperature on the flesh deformation of Idared apple is presented on Figure 39. High deformation of apple flesh was observed for storage fruits, particularly for apples held more than 10 weeks of storage at 14-16°C.

The significance higher flesh deformation obtained at peak of force for storage apples showed, weakly reaction of fruit on the squeezing force. On the other hand, not significance differences of force at peak, proved, that penetration test performed according to the Magness-Tylor method not correctly present behaviour of apple flesh. Result obtained for four apple varieties by Dobrzański *et al.* (1995) using penetration, compression and tension tests suggest that the values related to the elasticity limits determined in penetration test at small deformation allow to compare time and temperature of storage.

7.3.1. Water Potential of Tissue and Elasticity of Apple Flesh

The results obtained by Gołacki (1994) showed that the water potential of apple tissue is mostly connected with fruit's firmness and indicates the physical state of fruit during storage (Gołacki, 1994; Murase *et al.*, 1980; Nilsson et al., 1958; Segerlind, Del Fabbro, 1978). The water potential of apple flesh was measured using the HR-33T dew point microvoltmeter equipped with C-52 sample chamber, according to the method elaborated by Wescor, Inc.

$$\psi = \frac{RT}{V_w} \ln \frac{p}{p_o} \qquad (9)$$

where: V_w - molar volume of water [1,8 10^{-5} $m^3 mol^{-1}$]
R - gaseous constant, [8,31 J mol^{-1} $^0K^{-1}$]
p - vapour pressure above the solution
p_o - vapour pressure above pure solvent
T - absolute temperature [^{0}K]

After 3, 4 and 5 month of storage the apples were analyzed. The water potential of apple tissue were determined after 5 hours, four and eight days of storage at 20^{0}C to cover a time necessary for handling operations.

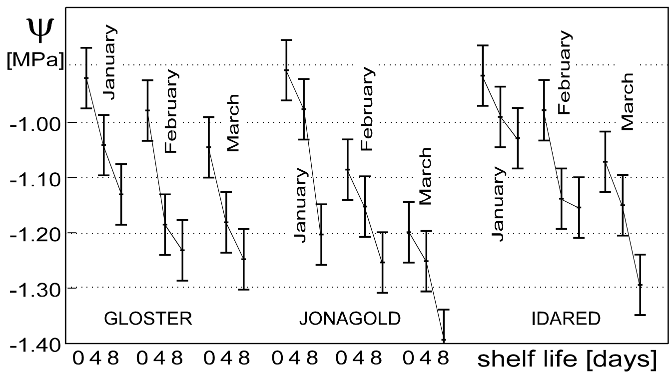

Fig. 40. Water potential for Golster, Jonagold and Idared apples during storage and shelf life

According to the method elaborated by Gołacki (1994) the water potential was determined for Golster, Jonagold and Idared apples during storage and shelf life. The negative tendency of water potential decrease was observed (Figure 40). It testifies viscoelasticity of apple flesh (specially for slightly dehydrated apples with water potential under 1.2 MPa). After harvest the water potential were ranged among 0.7 MPa for Jonagold variety and 0.9 MPa for Gloster and after storage increased to 1.1 MPa for Gloster and to 1.2 MPa for Jonagold. The most distinctly increase of water potential where observed for Jonagold variety. For Gloster and Idared varieties only slightly changes of water potential were observed.

It was also noticed, that different squeezing force commonly understood as fruit firmness; frequently is affected at the same deformation. From the other hand the same force is noticed at different deformation. Because only, the modulus of elasticity covers following parameters such as: force, stress, deformation and strain; a new device was elaborated for elasticity estimation.

The elasticity meter was applied for apple (with skin) and apple flesh (skin of) and not significance differences for both of method were observed. The results almost the same for 3 and 6 mm pin for apple with skin and of skin prove that modulus of elasticity was determined at small deformation under the break point; and the Elasticity Meter have been used successfully, as a quasi non-destructive device.

Some of results obtained using Elasticity Meter presented in this paper gives hope that the modulus of elasticity more distinctly shows slightly changes of apple firmness during storage and shelf life. The Elasticity Meter should be useful for a system of fruit quality on the base of firmness of fresh and storage apple evaluation. However, further work is needed to study correlation between many quality factors and fruit firmness.

Mechanical tests performed on apple flesh and skin shown different behaviour of apple firmness. In most cases the storage had significance influence on the mechanical properties estimated at different tests used in this study. The elastic behaviour of fruit shown that fruit firmness decreased unequally for studied varieties after storage.

The bending technique (flesh beam and flesh beam with skin) allowed to evaluate a flesh firmness of apple from the under skin layer. The estimations of the mechanical resistance of apple using bending test evaluate a susceptibility to bruising and skin damage. According to this method the values related to the modulus of elasticity more distinctly show the changes of apple firmness after storage.

The results obtained in this experiment show that the water potential of apple tissue is mostly connected with fruit's firmness and determines the physical state of apples during storage. The obtained results show that the water potential allows to determine the quality of apple during storage and shelf life, however is difficult method to adapt and develop in practice.

Although, these mechanical tests are still destructive ones, but are very useful as resource of basic information and comparing to the tests that will be developed and designed as non destructive.

7.4. BACKGROUND FOR THE STUDY OF FIRMNESS MEASURING

Many researchers have developed relationships between firmness and quality factors for a number of agricultural products. Lately researchers focused on non-destructive methods (Chen and De Baerdemaeker, 1994; Peleg, 1994; Chen and Ruiz-Altisent, 1996; Ruiz-Altisent *et al*.,1994; Shmulevich *et al*., 1994). Non-destructive versions of the penetrometer test have been described, but as yet none have found widespread approval (Duprat *et al*., 1995).

Because each method is based on measurement of a given physical property, the effectiveness of method depends on the correlation between the measured physical property and the quality factor of interest. Although researchers have developed relationships between physical properties and quality factors for a number of horticultural products, firmness is a property that is often used for evaluating the quality of fruits.

Firmness is related to maturity and it is well known, that fruit firmness decreases gradually during maturation and decreases rapidly during ripening (Dobrzański and Rybczyński, 1997; Mizrach *et al*., 1992; Rybczyński and Dobrzański, 1994a,b; Studman and Boyd, 1994). Overripe and damaged fruits become relatively soft. Fekete and Felföldi (1994) reckoned firmness as a principal characteristic of fruits, importance for the quality, harvest, maturity, storage, and shelf life. Using penetrometer and impact tests Yuwana and Duprat (1996,1997) measured bruise volume of apple to predict mechanical resistance of fruit to damage. Duprat *et al*., (1995) used a multi-purpose penetrometer based on high accuracy measurement of deformation and force to estimate fruit firmness. Mizrach *et al*. (1992) used a 3-mm diameter pin as a mechanical thumb to sense firmness of oranges and tomatoes. Takao (1994) developed a force-deformation type firmness tester named HIT (hardness, immaturity, and texture) that can measure nondestructively fruit firmness. Armstrong *et al*., (1995) developed an automatic instrument to nondestructively determine the firmness of small fruits, such as blue berries or cherries. Fekete and Felföldi (1994) have been reported four rapid penetration methods, where the values of force or deformation were measured. Fekete (1993) designed device equipped with force sensor and Bellon *et al*., (1993), reported the rapid method, where the deformation was measured at constant force. Thus firmness can be used as a criterion for sorting of agricultural products into different maturity groups or for separating overripe and damaged fruits from good ones. Firmness is related to the quality factors, however, through use of simply penetrometers, only the maximum squeezing force has been correlated frequently with numerous quality factors. Including external and internal properties of fruit, the firmness depends to the shape and size of fruit; size and contact area of plunger; rate of deformation; the way of fruit fixing, and measurement technique influenced a final accuracy. The previous study concerning on the compression test and the measurement of fruit strain under the break point, made the bases to develop a device for fruit firmness estimation and some results obtained with this meter for different pin were presented by authors (Dobrzański and Rybczyński, 1998).

Frequently, the device used in practice is a penetrometer. The results obtained in this test mostly reflects the maximum squeezing force (fruit firmness), not a mechanical state of tissue (related with turgor). It was the reason that the correlation with results obtained in most of nondestructive method, as well with results obtained with precision laboratory equipment is poor. It is well known, that physical quantity such as: geometry, mass (weight), density, force (stress, pressure), deformation (strain), work (energy), velocity (rate of deformation) and acceleration are strongly related with the fruit firmness. However, only the modulus of elasticity contain all parameters indispensable to the estimation of mechanical behavior of tissue.

7.4.1. Deformation of Apple Under Plunger and Support

7.4.1.1. Fruit Deformation Under Support

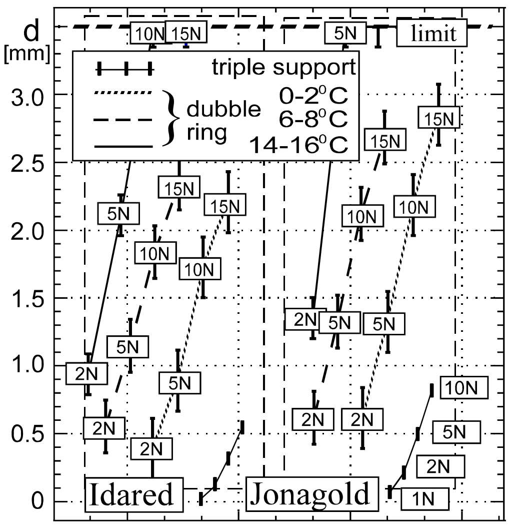

Fig. 41. The deformation of apple under dubble ring and triple support

Fruit deformation at studied force limits for Idared and Jonagold variety are presented in Figure 41. The results obtained for double ring support showed that at 2 N force limit, deformation reached values in the range 0.3 to 1.3 mm. For 5 N force limit deformation reached values of 1.3 mm to 2.4 mm. The storage at high temperature had statistically significant effect ($p = 5\%$) on deformation received for all variety at all limit force.

In comparison, for triple support deformation for Idared and Jonagold varieties are shown at following force limits; 1, 2, 5, and 10 N. For this range of force limit, the deformation did not exceed 0.5 mm for Idared and 0.8 mm for Jonagold apples. Limited area of triple support and slightly spherical shape of each arm assured, large and constant of contact area. The deformation at 2 N of force limit obtained the lowest value and not exceed 0.2 mm for both varieties.

7.4.1.2. FRUIT DEFORMATION UNDER PLUNGER

The results obtained using penetration test allow to compare the variety according to the fruit hardness, however, firmness of flesh was similar and frequently there was no significance difference for fruits, storage at various conditions. It shows that using simply penetration test slightly changes of fruit firmness were not observed for apple's storage at various conditions.

More distinctly differences were observed for apples held in different conditions, while the deformation at peak of squeezing force was noticed, however, only the apples storage in unsuitable condition are more significant soft and large deformation for studied variety was noticed. The influence of temperature on the flesh deformation of Idared apple and deformation under different plungers; 3, 6 and 11 mm at following limit force; 0.5, 1, 2 and 5 N were presented in previous paper (Dobrzański and Rybczyński, 1997). The cross-section area of 3 mm plunger (7.06 mm^2) was more than 40 times less than triple support, nevertheless results obtained for this plunger were the reason to reject this diameter in further study.

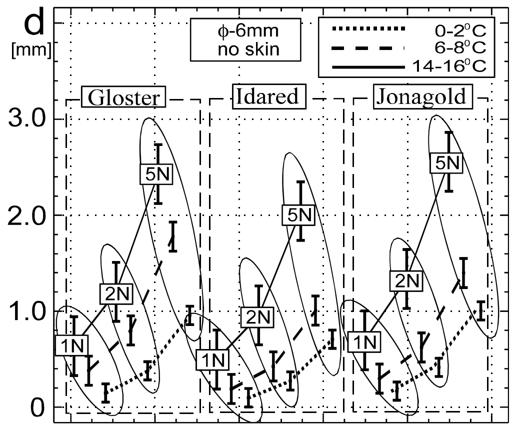

Fig. 42. Fruit deformation under 6 mm plunger for apple after skin removed

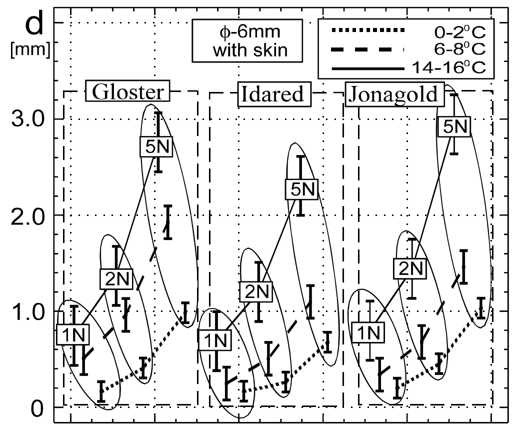

Fig. 43. Fruit deformation under 6 mm plunger for apple with skin

The deformation for 11 mm plunger of apples with skin and without skin was on similar level for all studied varieties. There were not significant differences between storage conditions at temperature of 6-8^{o}C and 14-16^{o}C. On the other hand, the cross-section area of 11 mm plunger (94.9 mm^2) only three times less than contact area with triple support was insufficient for the measurement of deformation from the plunger side. The highest influence of storage conditions on deformation of apples were observed for 6 mm plunger (Fig. 42) and (Fig. 43) and most distinctly difference for all limits of force was noticed.

7.4.1.3. WHY TRIPLE SUPPORT AND 6MM PLUNGER ARE USED FOR FIRMNESS METER

Deformation of apple flesh at 1 N was similar and frequently there was no significance difference for fruits. The cross-section area of 6 mm plunger (28.3 mm^2) over ten times lower than large contact area (300 mm^2) of triple support seems to be properly to compare the varieties according to different firmness of fruit storage at various conditions and assures the deformation, only under the plunger. The results obtained for all plungers and supports suggested that triple support and 6 mm plunger should be used in this device (Fig. 44).

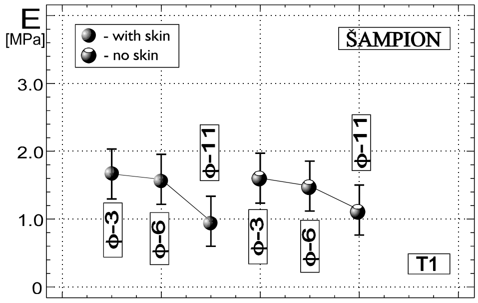

Fig. 44. Modulus of elasticity of apple flesh for 3, 6 and 11 mm plungers

The significance higher flesh deformation obtained at peak of force for storage apples showed, weakly reaction of fruit on the squeezing force. On the other hand, not significance differences of force at peak (Dobrzański and Rybczyński, 1999), proved, that penetration test performed according to the Magness-Tylor method not correctly present behaviour of apple flesh.

7.4.1.4. THE ELASTICITY METER

The elasticity meter was applied for apple (with skin) and apple flesh (skin of) and not significance differences for both of method were oserved. The results almost the same for 3 and 6 mm pin for apple with skin and of skin prove that modulus of elasticity was determined at small deformation under the break point; and the Elasticity Meter have been used successfully, as a quasi non-destructive device.

Looking for a simple test of firmness estimation, various mechanical properties were studied on apple fruit and specimens of skin and apple flesh. Firm apples of Jonagold, Idared, Gloster and Šampion variety were held in refrigerated storage and regular storage commonly used in small farms in Poland. Refrigerated storage of 0-2^{o}C, regular storage of 6-8^{o}C and storage with high temperature (14-16^{o}C) were used to have a wide range of mechanical behaviour. However, only Jonagold and Idared apples were held in different conditions up to 30 weeks to have a wide range of fruit softness. The firmness was determined with the Instron machine and elasticity meter. In both cases the modulus of elasticity was determined at small deformation. Force, deformation and work of deformation connected with fruit firmness were recorded at squeezing of plunger in the flesh after skin rupture, however, the values corresponding to the modulus of elasticity were determined from elastic range of deformation, before skin rupture.

All these tests were performed on apple with skin and apple after skin removed, according to the Magnes-Taylor method (1925) to established a measurement range of deformation independence to the skin absence.

The mechanical properties were determined with three different plungers (3, 6 and 11 mm) at 0.5, 1, 2 and 5 N of force limit to fix the range of fruit elasticity. Convex and irregular shape of fruit and differ deformation under the plunger and support from the opposite side to plunger influences the accuracy of strain measurement. It was the reason to study fruit deformation for varietal supports. Different shapes of support (spherical thrust bed, double ring and triple support) were used.

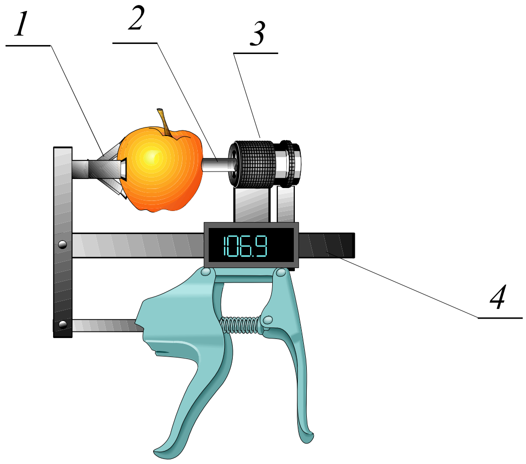

Fig. 45. The elasticity meter.
1 - triple arm support; 2 - replaceable plunger; 3 - double spring set for presetting of compression force; 4 - digital slide calliper

The elasticity meter (Figure 45) equipped with a digital slide caliper, is designed as a compression jaw, that is possible to hold fruit on the tree. The compression force is received by presetting of two springs at force limits listed above. First spring is compressed while the fruit is fixed by holder to a triple support. After that, the force during compression, reached the first limit. It releases a trigger of the second spring (compressed initially to the next limit). The modulus of elasticity is determined from the force-deformation curve for the 1st and 2nd force limit (both under elasticity strain limit according to the following formula:

$$E = \frac{D(F_2 - F_1)}{A(d_2 - d_1)} \tag{10}$$

where: E – modulus of elasticity [MPa], F_2 – force limit of the second spring [N], F_1 – force limit of first spring relased the second spring [N], d_2 – deformation under second spring [mm], d_1 – deformation under the holder (first spring) [N], D – diameter of fruit [mm], A – contact area of the plunger [mm^2].

Large contact area (300 mm^2) over ten times higher than plunger cross-section (28.3 mm^2) assures deformation of fruit, only from the opposite side to support. Triple support gives a similar contact area independently to the shape and size of fruit. Elasticity meter allows on the measurement of following values such as: diameter of fruit, strain of apple and modulus of elasticity. This meter allows on the measurement of fruit elasticity at the limit force corresponding to the fingers touch.

According to results of the previous study, the modulus of elasticity was determined using elasticity meter. It showed highest firmness of apple storage at 0-2°C for Idared variety.

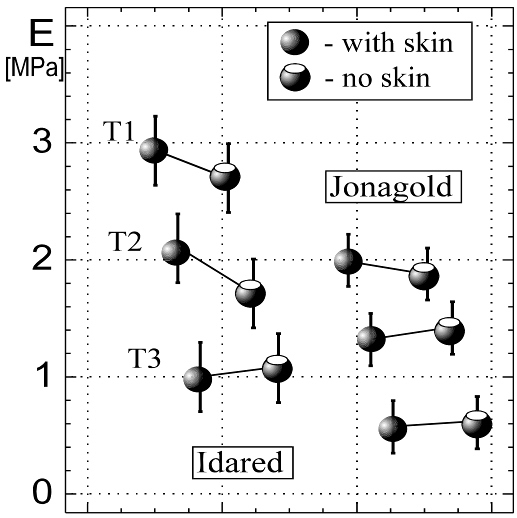

Fig. 46. Modulus of elasticity of Jonagold and Idared apples storage at different temperature

The modulus of elasticity reached values: 2.94 MPa for apple with skin and 2.70 MPa for apple flesh (Fig. 46). The elasticity connected with fruit firmness decreased for all studied varietys at temperature 6-8°C (T2) and 14-16°C (T3). For Jonagold variety, mean values of modulus of elasticity decreased from 2.0 MPa (0-2°C) to 0.57 MPa (14-16°C). The modulus of elasticity allowed to compare the influence of storage conditions on the fruit firmness.

The lowest elasticity was observed for Šampion variety. The modulus of elasticity reached values; 1.81, 1.58, and 1.04 MPa for apple with skin and 1.74, 1.49, and 1.23 MPa for apple flesh, respectively for plungers: 3, 6 and 11 mm. Slightly lower value of elasticity for 11 mm plunger was connected with a convex shape of fruit and small contact area with the plunger. It caused low stress of initial deformation and consequently large displacement of plunger to achieve a full contact of surface with apple. However, there were no significant differences between diameter of plungers used in this study.

Some of results obtained using elasticity meter presented in this paper gives hope that the modulus of elasticity more distinctly shows slightly changes of apple firmness during storage and shelf life. The similar value of modulus of elasticity was obtained in both of cases: for apple with skin and for apple after skin removed (plunger pressed only the flesh). It's prove that elasticity meter allows on the measure independent to the strength of skin, and firmness determined in this way, more correctly than with Magness-Tylor method, reflects the mechanical properties of flesh. The similar values, determined for fruit with skin and for apple after skin removed prove that the Elasticity Meter allow on the measure of flesh firmness. The modulus of elasticity determined with elasticity meter indicates a slightly changes of firmness allowing to compare the influence of storage conditions on the fruit firmness and significant differences were observed.

The Elasticity Meter has been used successfully to measure of apple firmness a specially for apple with skin, as a quasi non-destructive method and allows to measure a values at limit force corresponding to the fingers touch.

7.5. FRICTION BETWEEN APPLE AND FLAT SURFACES

Improved handling and storage methods are needed to provide high quality apples (McClure, 1995). The coefficient of friction is an important physical property in engineering design of equipment for harvesting and handling to minimize abrasion of fruits (Puchalski and Brusewitz, 1996). Fruit surface quality is affected by surrounding environmental factors such as, temperature, humidity, and airflow (Grierson and Wardowski, 1978). Apples became more susceptible to bruises when stored at low temperature and high humidity (Zhang *et al*., 1992; Dobrzański and Rybczyński, 2000). Halderson and Henning (1993) found differences in tuber skin strength kept in two different soil moisture conditions. Schaper and Yaeger (1992) found significant differences in static and dynamic coefficient of friction between washed and unwashed potatoes, which was related to the type of surface.

A modified direct shear apparatus used for determining the coefficient of friction of granular materials on smooth and corrugated surfaces should be useful because it most closely simulates the actual conditions at the frictional interface in grain bin when grain slides down the wall (Molenda *et al*., 1996;2000; Horabik and Molenda, 2000). The coefficients of static and dynamic friction of sunflower seed and kernels increased linearly with moisture in the range of 4-20% MC (Gupta and Das, 1998), for lentil seeds at 7-33% MC (Carman, 1996), and for soybeans at 8-17% MC, red kidney beans at 10-15% MC and peanuts at 3-15% MC (Chung and Verma, 1989). The static coefficient of friction increased linearly over the range of 4-27% MC for pumpkin seeds (Joshi *et al*, 1993), over the range of 6-15% MC for pigeon peas (Shepherd, 1986), over the range of 7-22% MC for cumin seed (Singh and Goswami, 1996). Moisture content affected the static coefficient more than the type of surface while the type of surface affected the dynamic coefficient more than sample moisture content (Chung and Verma, 1989). Two varieties of raisons had different changes in friction forces at moistures below 18% while at moistures above 30% friction was relatively constant (Kostaropoulos, 1997). For low grain moisture (12% wheat, 6% canola, 11% lentils) the dynamic coefficient of friction increased over the range of 25 to 85% RH while at higher grain moisture (19% wheat, 16% canola, 21% lentil) the friction coefficient increased for humidity from 25 to 70% and then decreased at 85% (Zhang and Kushwaha, 1993).

Two apple varieties: Gala and McLemore Galas were used to represent different surface characteristics. Apples were taken out from storage 12 h before measurement were to be made and they were separated into five, 35%, 55%, 70%, 95% and dipped in water groups of 10 apples each. One group was dipped in water for 10 h, removed, wiped dry, and covered with plastic until testing. A second group was left in the room which was at 24ºC, 70% RH. The other three groups were placed in environmental chambers at either 35, 55, or 95% RH until testing.

Immediately following friction tests firmness readings (with an Effegi penetrometer) were taken on each apple using 11.1 mm probe pressed against a peeled side. Moisture content of each apple was determined by drying finely cut pieces of apple to constant weight at 70ºC. Friction coefficients for four sliding surfaces (masonite, paper, plastic, and rubber) were determined using a device proposed by Puchalski and Brusewitz (1996). A simplified diagram of this device was shown in previous paper (Puchalski et al., 2002). The device was made up of four major components: the frame, stationary sample holder, moveable horizontal plate connected to the crosshead of an Instron machine and data acquisition system.

The sample holder had two independently adjustable jaws that held the sample in place as the horizontal plate (and abrasive test surface) moves. The *sandbag* (part of the sample holder) applied the required normal force generated through the "pivot arm" by the counter weight. The movable horizontal plate, 0.1 m wide and 0.6 m long, was mounted on precision rails and linear bearings to minimise friction. The horizontal plate was connected to the crosshead of an Instron machine by a 1.0 mm diameter steel cable. All tests were conducted with a constant normal force of 17 N and sliding speed of 4.17 mm s^{-1} over a travelling distance of 0.3 m.

7.5.1 STATIC AND DYNAMIC COEFFICIENT OF FRICTION

The effect of RH and water-dipping on static coefficient of friction of both varieties is given in Table 38. Variability in the data depends on both variety and surface material. The static coefficient of friction of the Gala variety decreased with increasing in RH from 35 to 70%, except for rubber at 35% RH. The average decreases in static coefficient of friction were 18.8, 15.0, 8.4 and 5.3% for masonite, paper, plastic and rubber surfaces, respectively. This is due to the decreased adhesion between the apple and the test surfaces as the RH increases. After passing the 70% RH, the static coefficient of friction for the Gala increased with increasing in RH by 29.4, 6.1, 1.4 and 1.5% on masonite, paper, plastic and rubber, respectively.

Table 38. Analysis of variance probabilities for significant F values of static and dynamic coefficient of friction

Independent variable	Static coefficient of friction		Dynamic coefficient of friction	
	Gala	McLemore	Gala	McLemore
Treatment	0.0028	0.00	0.000	0.000
Surface	0.0000	0.00	0.000	0.000
Variety ripe	-	0.00	-	0.000
Treatment · surface	0.0053	0.00	0.002	0.000
Treatment · ripe	-	0.00	-	0.150
Surface · ripe	-	0.00	-	0.000
Treatment · surface · ripe	-	0.00	-	0.012

Since the McLemore apples were more ripe than Gala an inverse relationship was noted between coefficient of friction and apple treatment i.e., RH and dipping in water, except on masonite and rubber surfaces. Changes in static coefficient of friction for McLemore apples on masonite were very small and not significant.

At 70% RH the static coefficient of friction of McLemore showed largest value on paper and plastic surfaces. From 35 to 70% RH, the SCF increased linearly 22% followed a decreasing tendency in SCF.

It should be noted at this point that McLemore and Gala apples have different surface characteristics which could influence the magnitude of the SCF at different RHs. Changes in adhesion (affecting the SCF between fruit and sliding surface) appears to depend on level of moisture in the sample surface, characteristics of the fruit surface that relate to the variety.

The effects of RH and water-dipping on the dynamic coefficient of friction (DCF) of both varieties were presented in previous paper (Puchalski *et al*., 2002). These data follow the same trend as shown. Up to the 70% RH (for masonite, plastic, and rubber) and 95% (on paper) the DCF decreased with increasing in relative humidity. Above these RH levels the DCF then increased at higher levels of RH.

Increase in adhesion, between fruit and sliding surface, affecting the value of coefficient of friction (Mohsenin, 1986), started after reaching the certain level of moisture content of sample surface exposed to the action of environment. It depended on characteristic of sliding surface. Plastic, with very smooth and wet surface, tended to show an increase in DCF in an increase in RH. Paper with its tendency to absorbed water needed high RH before the DCF tended to increase. The average change of the DCF was 24% on masonite, paper and plastic and 10% on the rubber surface.

Table 39. Polynomial models of friction coefficient vs surrounding RH (x^*) of Gala apples

Coefficient of friction	Sliding surface	Regression equation	r^2
	Masonite	$4.0917 x^3 - 7.753 x^2 + 4.50 x - 0.46$	0.967
Static	Paper	$- 0.5498 x^3 + 1.474 x^2 - 1.25 x + 0.64$	0.759
	Plastic	$- 0.5456 x^3 + 1.262 x^2 - 0.94 x + 0.44$	1.000
	Rubber	$3.3939 x^3 - 7.192 x^2 + 4.83 x - 0.23$	0.798
	Masonite	$3.3546 x^3 - 5.912 x^2 + 3.06 x - 0.09$	0.970
Dynamic	Paper	$2.2205 x^3 - 3.919 x^2 + 1.98 x + 0.04$	0.820
	Plastic	$- 2.4533 x^3 + 5.995 x^2 - 4.64 x + 1.42$	0.998
	Rubber	$3.9901 x^3 - 7.505 x^2 + 4.28 x - 0.22$	0.965

* values from 0.35 to 0.95 – apples kept in air RH from 35 to 95% and 1– ones dipping in water

All of the curves were modeled on a third degree polynomial equations that provided a better fit to the raw data than other models for Gala and McLemore apples. All equations are shown in Table 39. All polynomial models were significant at P=0.05. The plastic surface produced the best fit. It was also observed, that generally coefficients of regression equation of the DCF versus RH have larger absolute values for ripe fruits (firmness of 33 N) than for unripe ones (firmness of 71 N). Hence, these measurements could be used to show differences in ripeness (see Table 40).

Table 40. Coefficients* of equation of $ax^3 + bx^2 + cx + d$ of dynamic coefficient of friction vs. surrounding RH of unripe U and ripe R McLemore fruits

Sliding surface	Coefficients							
	a		b		c		d	
	U	R	U	R	U	R	U	R
Masonite	-0.1537	-1.7913	0.800	4.447	-0.91	-3.46	0.62	1.22
Paper	1.9224	7.0030	-3.842	-14.149	2.33	8.79	-0.19	-1.37
Plastic	-0.2087	2.4064	0.565	-4.529	-0.45	2.55	0.35	-0.14
Rubber	3.8759	11.0840	-7.695	-20.999	4.91	2.30	-0.14	-1.29

* for all $r^2 > 0.718$

The RH surrounding apples had significant effect on both static and dynamic coefficients of friction. The changes in static coefficient of friction with increasing air RH were different for Gala and McLemore apples. All three parameters considered in this study (variety, sample moisture and surface type) had a definite influence on SCF and DCF.

The dynamic coefficient of friction decreased with increasing RH up to the either 70 or 95% depending on sliding surface for both varieties. RH had a greater effect on the coefficient of friction for paper and plastic than for rubber surface. Wetting by dipping in water had a 33% greater effect than 95% RH on the dynamic coefficient of friction on paper and rubber surfaces.

Knowledge of the coefficient of friction of fruits and vegetables is useful in the design of handling equipment and improving the production systems that will reduce apple damage. The tests were carried out with ten replications per treatment combination under constant sliding speed and sample temperature. Samples were placed in air at 35, 55, 70, 95% RH and dipped in water. Relative humidity (RH) and dipping in water (WD) treatments had significant effect on both static and dynamic coefficients of friction. Changes in static coefficient of friction (SCF) with increasing RH were different for Gala and McLemore apples. Coefficient of friction tended to increase or decrease depending on sample moisture content, type of sliding surface and variety. Two different varieties tested using a linear sliding friction test device connected to an Instron universal testing machine, data acquisition system, and a personal computer some data useful in designing sorting equipment in all handling chain operations.

7.6. COLOR OF APPLE

With the increasing diversity of pome fruits varieties, fruit quality recognition is becoming more and more important. Along with quality estimation (quality is not a parameter, but determined by the values of the individual parameters, including color), color is one of the major factors in creating a fruit image (Studman, 1994; Alchanatis and Searcy, 1995; Felföldi *et al.*, 1996; Kader, 1983; Kameoka *et al.*, 1994; Lancaster, 1992; Molto *et al.*, 1996; Motonaga *et al.*, 1997; Nielsen, 1996).

Studman (1994) observed, that consumers of the 1990's are more conscious of quality than any previous generation. There is no doubt that the market has changed over the last decade, in most developing countries, including the East-European countries. Therefore the appearance of fruits and vegetables has a major influence on perceived quality. However, color as one of the most important quality parameter is influenced by cultural and consumer preferences.

The preferences of color depend on: uniformity of external color, repeatability of fruit color in crop, differences between high and ground color, intensity of blush and ground color (saturation of red), size of high color area, lightness-darkness, whiteness, physical defects, dents, browning, bruising, and stage of maturity (ripeness).

After harvest, cosmetic appearance of apples seems to be the most important quality factor. However, the storage has substantial influence on final quality of fruits, as it affects the appearance and induces color changes (Dobrzański *et al.*, 2001; Kader, 1999; Kameoka *et al.*, 1994; Saks *et al.*, 1999). Firstly, some of fruits are more influenced by storage conditions than others. Secondly, shelf-life is a period of storage, with unsuitable conditions, i.e. high temperature and low humidity, for keeping apple in good quality. At this time, darkening of the skin observed by consumers, decreases perceptions of color, which influences the estimation of fruit quality. Impacts on fruits causes damages, and bruising leads to enzymatic changes expressed as browning of the tissue (Kuczyński *et al.*, 1994). Frequently, internal browning is visible in externally.

One of the basic conditions for improvement of quality is proper sorting and handling of the fruit for market (Bellon *et al.*, 1992; Bennedsen, 2002; Guyer *et al.*, 1993; Miller and Delviche, 1988; Studman, 1998). Hence, sorting the apples for separating the fruit with the same level of high color or heaving the same base color, should be the most important factor for improving quality and influence price. Separating ripe from over ripe or damaged would allow the "good" food (having adequate shelf life) to be shipped to fresh market while the less desirable, the green and the over ripe and bruised fraction, could be send to a processing plant where quality could be enhanced by appropriate bioprocessing techniques (McClure, 1995).

Color control has a great effect on sales, however, in many cases it is performed by visual evaluation, relying on the accuracy of an individual's eyes to determine color. Unfortunately, every individual's color perception is slightly different. Also, it is extremely difficult to accurately describe a color in words, since each person will interpret the described color a little differently.

7.6.1. PHYSICAL BASES OF HUMAN PERCEPTION OF COLOR

An illuminated object reflects light, which is perceived and interpreted by persons. In physics, visible light is said to be composed of electromagnetic rays. The electromagnetic rays of visible light are different only in their frequency from the other rays such as: gamma rays, X-rays, ultraviolet, infrared, microwaves and rays carrying radio and television (Epson, 1995). The frequency range reflected is influenced by the physical and chemical properties of the object and by the frequency ranges which are absorbed. However, the color of an object is unknown, because electromagnetic rays are colorless. The human eye converts the electromagnetic rays into information which can be understood by the human brain. The brain then interprets this information as sensation of color. The eye is able to convert varying frequencies of electromagnetic rays into information which the brain perceives as different colors. The eye is also able to convert the intensity of rays into information which the brain interprets as a sensation of lightness. It is important to remember that all objects are colorless and the sensation of color originates only in the human brain.

Embedded in the eye's retina are the staff cells and three different types of cone cells, which are responsible for daylight and color vision. The retina contains approximately 120 million staff cells and 6.5 million cone cells. Three different types of cone cells convert various wavelengths of electromagnetic rays (Achenbach, 2001). The perception of red color is allocated to cone cells with maximum sensitivity of 620 nm. Green is allocated to cone cells with maximum sensitivity of 520 nm and blue to the cells with maximum sensitivity of 450 nm.

Based on the fact that the retina of the human eye contains three different type's of cone cells which are sensitive to the primary colors of red, green, and blue respectively, it is possible to formulate laws. These laws state that all colors can be derived from a mixture of three primary colors. The additive color mixing process states that by mixing red, green, and blue the color white is produced. This color mixing process is used wherever light passed directly into the eye without being reflected from an object, e.g. monitors and televisions. In the case of the subtractive color mixing from the primary colors cyan, magenta, and yellow using the process of subtracting or filtering. Subtractive color mixing are used when the reflection of light from object, e.g. colored paper or fruit skin, passes into the eye.

Because humans are able to distinguish between several hundred thousand shades of color (approx. 350000), it is necessary to introduce mathematical color models which enable each shade to be described exactly in terms of a numbered value. Due to the number of colors, it is impossible to give each particular shade an individual name.

To enable colors to be described as geometrical interpretation, there are various 3-D models for color description. Some of these, e.g. the RGB color model are derived directly from the additive or CMY from the subtractive color mixing system, which converts directly into numbers. The RGB color system is often used by software as an internal color model as it can easily be used for calculating and requires no conversion in order to display colors on computer screen. The CMY color model enables any color to be created from the primary colors cyan, magenta, and yellow, which are converted into a system of numbers. Each of the primary colors in both models is allocated to one of the eight corners of the cube. Therefore, each color in this cube is identified by its co-ordinates. Compared with the RGB and CMY color models, the HSV (hue, saturation, and value) color model, hexagon pyramid, has the advantage that the colors correspond closely to our perception of color. Consequently, this color space is often preferred for practical implementation of color measurement.

Most new colorimeters allow measurements of absolute color to be displayed in any of five color systems: Yxy, L*a*b*, L*C*Ho, Hunter Lab, or tristimulus values XYZ. Measurements of color difference can be displayed in any of four systems: Δ(L*a*b*)/ΔE*ab, Δ(L*C*Ho)/ΔE*ab, Δ(Yxy), and Hunter Δ(Lab)/ΔE (Good, 2002). Two of these systems is frequently applied in any quality estimation of fruit color.

The L*a*b* color system is one of the uniform color spaces recommended by CIE in 1976 as a way of more closely representing perceived color and color difference. In this system, L* is the lightness factor; a* and b* are the chromaticity coordinates (Good, 2002).

- L* (lightness) axis – 0 is black; 100 is white.
- a* (red-green) axis – positive values are red; negative values are green; 0 is neutral.
- b* (yellow-blue) axis – positive values are yellow; negative values are blue; 0 is neutral.

The lightness factor L* and chromaticity coordinates a* and b* are defined as follows:

$$L^* = 116\left(\frac{Y}{Y_0}\right)^{\frac{1}{3}} - 16 \qquad (11)$$

$$a^* = 500\left[\left(\frac{X}{X_0}\right)^{\frac{1}{3}} - \left(\frac{Y}{Y_0}\right)^{\frac{1}{3}}\right] \quad (12)$$

$$b^* = 200\left[\left(\frac{Y}{Y_0}\right)^{\frac{1}{3}} - \left(\frac{Z}{Z_0}\right)^{\frac{1}{3}}\right] \quad (13)$$

where: X_o,Y_o, and Z_o – are Tristimulus values of luminance
X_o=98.072, Y_o=100, Z_o=118.225 for standard illumination C and (2° observer)
X_o=95.045, Y_o=100, Z_o=108.892 for standard illumination D_{65} and (2° observer)
Above formulas apply only when X/X_o, Y/Y_o, and Z/Z_o are greater than 0.008856.

ΔE*ab is the Euclidean distance between two colors in the L*a*b* system and is defined as follows:

$$\Delta E^*_{ab}=[(\Delta L^*)^2+(\Delta a^*)^2+(\Delta b^*)^2]^{1/2} \quad (14)$$

Two apple's varieties (Champion and Jonagold) were used to determine the color of fruit skin after storage. The apples were divided in 5 classes of quality. The color of each apple was measured at six points around the stem-axis from blush to ground color of the fruit. The color of fruit was studied after three and five moths of storage. After five moths the apples were kept at shelf condition for 15 days. The color was determined three times: At the day when the fruits were removed from the storage, after 7 days, and 15 days of shelf-life. The fruits were bruised twice: on the blush area and on the opposite side representing ground color. After impact the apples were tested each day during the first week, and then after 9, 13, and 17 days at shelf-life.

The measurements were performed with the Braive Instruments 6016 supercolor™ colorimeter (Braive, 1994) according to the L*a*b* system. The measuring system employed by Braive colorimeter is designed to provide accurate readings and uniform response. The light received by the meter is divided three ways and passed through special filters whose light absorbing characteristics combine with the spectral response of the photo cells. Upon reaching the silicon photocells, light energy is converted into electrical signals and sent to the microprocessor, where it is adjusted for the illuminating condition desired and then converted into co-ordinates according to the chosen color space. Readings are displayed on the LCD panel and can be transferred to a separate computer or processor through the data output terminal. For color readings, these values are translated into Yxy coordinates or in color L*a*b* standard. The device allows for different settings for illumination and Observer.

The lightbooth screen displays the values of all standards, and following illuminations:

A – incandescent (tungsten) lamplight
C – daylight (filtered tungsten)
D65 – daylight, color temperature (6500 K)
F2/CWF – cool white fluorescent lamplight (4200 K)
F11 – narrow band fluorescent lamplight (4200 K)

and Observer:

CIE 2° – Standard Observer
CIE 10° – Supplementary Observer

All results were determined at daylight D65 of color temperature 6500 K.

7.6.2 Color Change of Apple as a Result of Storage, Shelf-Life and Bruising

The lightness and chromaticity coordinates of the skin color of Champion apples are presented in 3-d view on (Fig. 47). The lightness indexes L* shows intensity of fruit color and most of the Champion apples range from 40 to 72. Red color, as the index of chromaticity a*, ranges for this variety from –10 to 53. A negative a* values of the ground color was observed, and indicated partly, slightly green color of the skin.

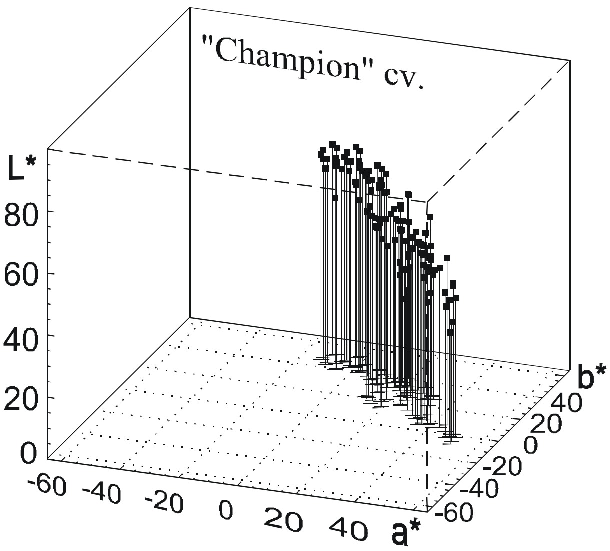

Fig. 47. Lightness and chromaticity of color skin of Champion apples in 3-d view

The values of the index b* for these apples were in the range from –5 to 43, indicating that the skin of Champion apples is more yellow as the red component of color is low. All indexes of color (L*a*b* parameters) presented in this way shows large differentiation in skin color for Champion apples, however, the L*a*b* indexes for several apples were not significantly different. Some differences between varieties were observed in a previous paper (Dobrzański and Rybczyński, 2001) on the cube of color coordinates, where factors of lightness L* and chromaticity coordinates of a* and b* are represented in 3-d Figures. Nonetheless, determination of fruit quality based on 3-d view should be improve to clearly define blush and ground color of apple skin.

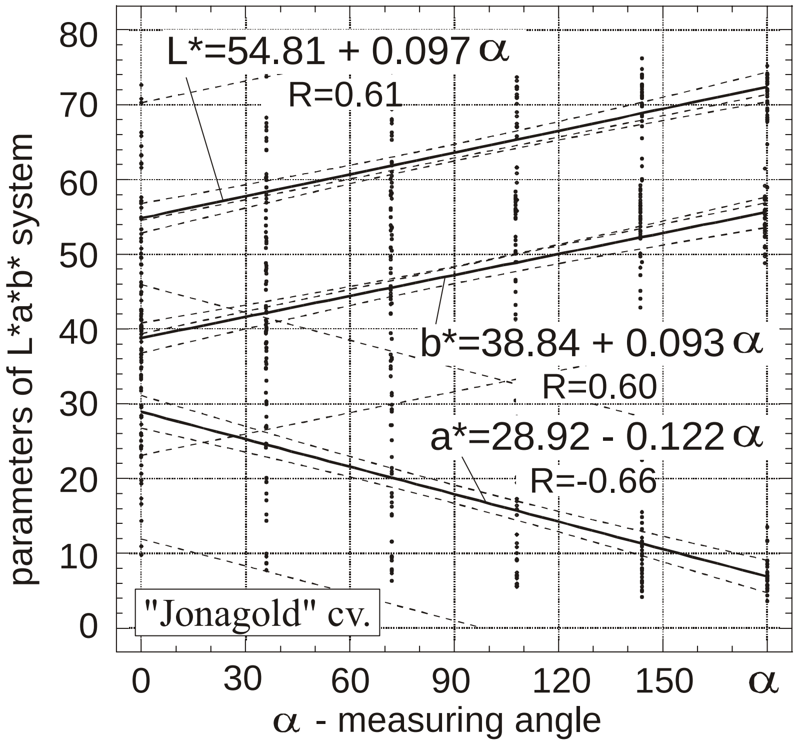

Fig. 48. The L*a*b* color coordinates of best quality (5) Jonagold apples storage for three months

Figure 48 presents the L*a*b* coordinates of the color of best quality Jonagold apples stored for three months. The color determined at six areas around the fruit shoves differentiation of each L*a*b* indexes from blush to ground. The most sensitive parameter is a*, which indicates high red color. In this case the correlation coefficient and slope parameter are higher than for both L* and b*.

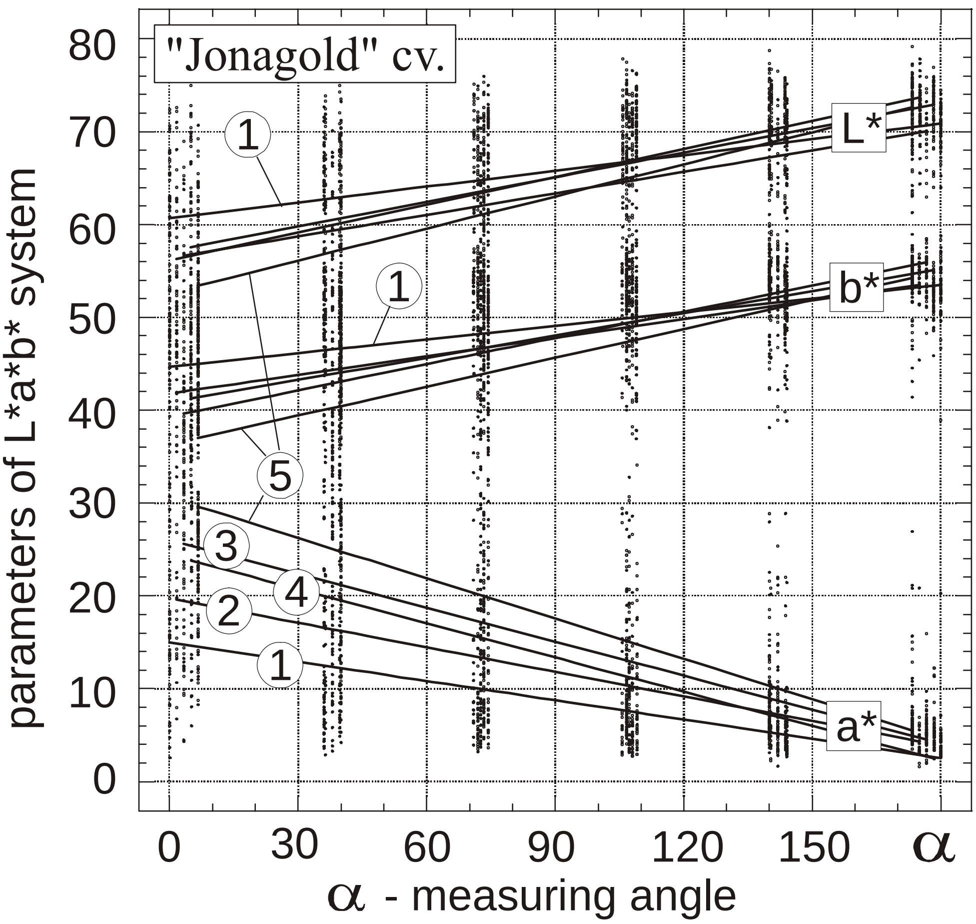

Fig. 49. The L*a*b* color coordinates of five quality classes (1-5) of Jonagold apples storage for five months

Further, the storage of Jonagold apples for two additional months does not change the color of fruits, however, slight differences for all quality classes are observed (Fig. 49). The intensity of blush, indicate high values for red, ranging from 14.37 for low quality apples (1) to 29.62 for the best quality apples (5). The parameters of a linear regression prove the differentiation in the high values of index a*, where the slope range from –0.08 to –0.134, while the correlation coefficient range from –0.46 to –0.68 respectively (Tab. 42).

Table 42. Lightness parameter L* and chromaticity factors a* and b* of differ quality apple after 5 months of ULO storage

Regression analysis - Linear model: Y = a + bX				
Q	Y	a	b	R
1	L*	60.67	0.056	0.52
2	L*	56.64	0.074	0.55
3	L*	56.28	0.096	0.65
4	L*	57.55	0.085	0.57
5	L*	53.40	0.107	0.64
1	a*	14.37	-0.080	-0.46
2	a*	19.65	-0.092	-0.57
3	a*	23.79	-0.118	-0.65
4	a*	25.63	-0.117	-0.64
5	a*	29.62	-0.134	-0.68
1	b*	44.66	0.049	0.56
2	b*	41.89	0.064	0.49
3	b*	39.62	0.091	0.62
4	b*	41.24	0.077	0.57
5	b*	36.99	0.096	0.61

Q – quality class, Y – dependent variable, a – intercept, b – slope, R – correlation coefficient

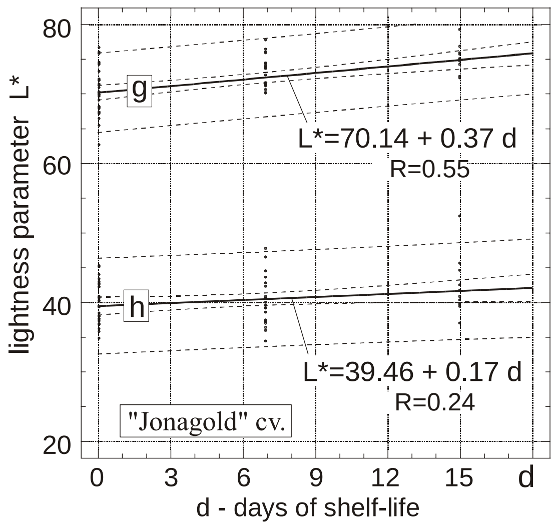

Fig. 50. The lightness coordinate L* of blush (h) and ground color (g) of Jonagold apples at shelf-life

The lightness parameter L* of the ground color and blush dependent on sun rays during growing. On the other hand, the low value of L* parameter indicates dark skin of observed fruit. After five moths of storage the color of apples was stable, however, some changes of color components at shelf-life were observed. The lightness parameter L* of blush was completely different to the ground color. The high color of blush (Fig. 50) was not changing, while the slight increase in ground color is indicated by higher value of the slope (0.37) and correlation coefficient (0.55). The increases of the L* coordinate in this case tells us, that the apples seem to become brighter during the shelf-life.

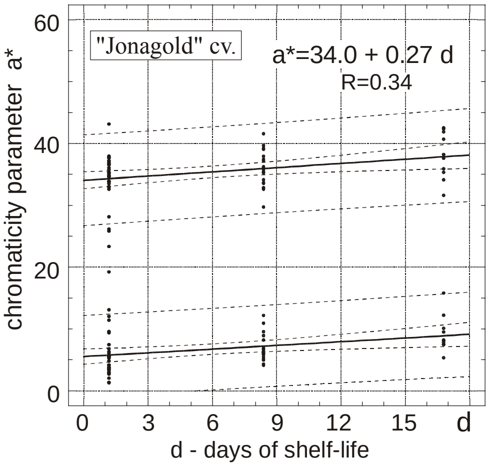

Fig. 51. The chromaticity coordinate a* of blush (h) and ground color (g) of Jonagold apples at shelf-life

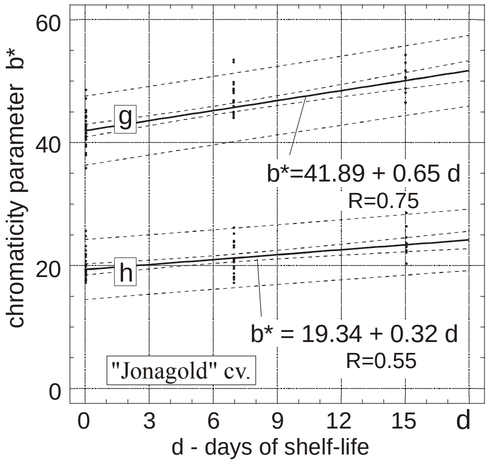

Fig. 52. The chromaticity coordinate b* of blush (h) and ground color (g) of Jonagold apples at shelf-life

The red component of color on both sides, blush and ground color, is steady at shelf-life. The low values of slope (0.24 and 0.27) show that only slight increases in parameter a* is observed (Fig. 51).

The chromaticity coordinate b* is the parameter, which most significantly indicate, the color change of apple at shelf-life (Fig. 52). Especially, the ground color of fruit becomes more yellow after 7 days. The b* coordinate increases slightly after eight additional days of shelf-life. Linear regression (b* = 41.89 + 0.65 d), a high value of the slope, and correlation coefficient (R = 0.75) describes the influence of shelf-life on the coordinate b*. The increase of yellow color of apple skin, during shelf-life, represented by the coordinate b* influences the perception of darkness and increase of L* previously presented on Figure 50.

The figures from 53 to 58 present the L*a*b* color coordinates of the best quality Champion apples during the shelf period and bruised apples kept up to seventeen days at the same conditions. The inflicted bruising, which caused darkening of the fruit skin. All changes of color at shelf-life are well describe by linear regression, while the multiplicative model indicates more closely the influences of time after bruising on all color coordinates. The high color of blush consists of more intensive components, which is frequently the reason why bruising is invisible on this area (Fig. 53,55,57). Only the component of red color presented by a* decrease after bruising, while it increases at shelf-life (Fig. 56).

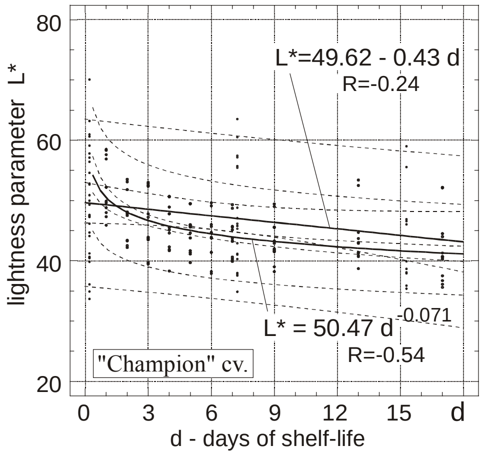

Fig. 53. The lightness coordinate L* of high color of blush (h) at shelf-life of Champion apples and the change of color after bruising

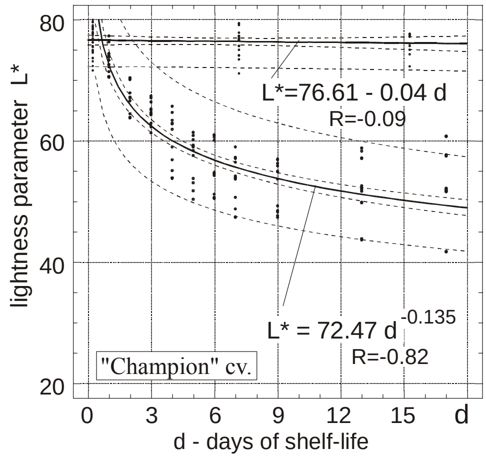

Fig. 54. The lightness coordinate L* of ground color at shelf-life of Champion apples and the change of color after bruising

More distinct differences are visible on the ground area (Fig. 54,56,58). The lightness coordinate L* of the ground color is stable during shelf-life. Darkening of apple increases each day, especially during the first five days after bruising when L* rapidly decrease from 72.4 to 55.2 (Fig. 54). Keeping bruised apples for a long time at this condition involve further darkening and large differentiation in lightness (41.3 to 60.8).

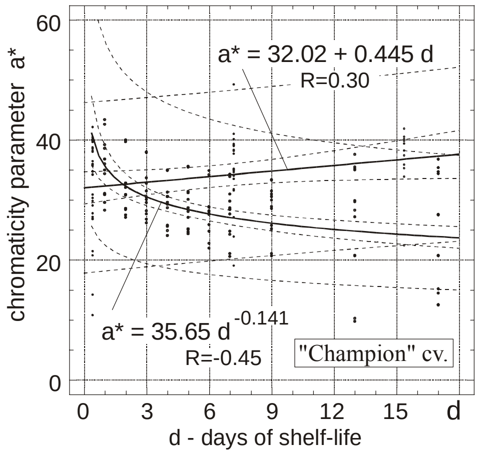

Fig. 55. The chromaticity coordinate a* of high color of blush at shelf-life of Champion apples and the change of color after bruising

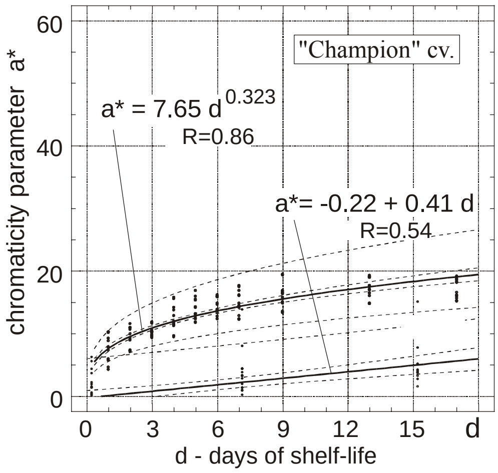

Fig. 56. The chromaticity coordinate a* of ground color at shelf-life of Champion apples and the change of color after bruising

After bruising, the red color represented by chromaticity parameter a* increases for ground area from 3.27 to 18.3, while increases from 0.39 to 4.78 at shelf-life. Champion apples, having no red in ground color, gave a* values very near to zero

(Fig. 56). However, the bruising caused browning of tissue, which appearing intensity of red color component on the skin and increase of the index a*. One day after bruising, the skin of this area becomes statistically different to the ground color of Champion apples, being stable during further period of shelf-life from 4 to 17 days (Fig. 56). It is easy to conclude, that only the bright side of fruit changes its color significantly (R = –0.82 and R = 0.86) for L* and a* respectively. The red component of bruising is similar to the high color, being invisible on blush area, while, the bruising appears on the ground area, just after 2 days of shelf-life, affecting not satisfactory quality estimation.

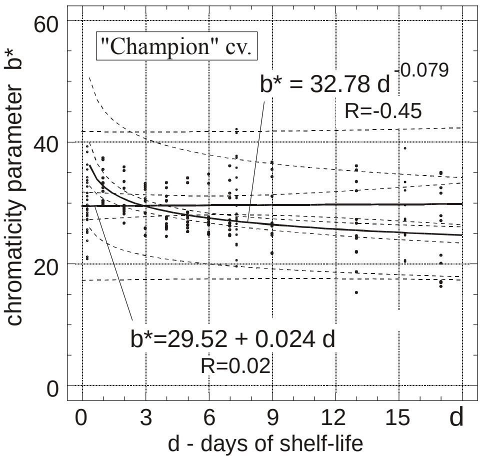

Fig. 57. The chromaticity coordinate b* of high color of blush at shelf-life of Champion apples and the change of color after bruising

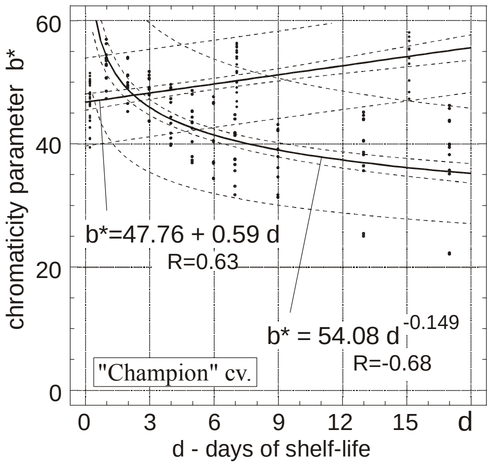

Fig. 58. The chromaticity coordinate b* of ground color at shelf-life of Champion apples and the change of color after bruising

The increase of yellow color co-ordinates b* of Champion apples (Fig. 58), is similar to results presented previously on Figure 53 for Jonagold apples over the range of shelf-life. Positive linear regression (b* = 47.76 + 0.59 d), slope, and correlation coefficient (R = 0.63) indicates similar influence of shelf-life on the coordinate b* for Champion apples. On the ground color of Champion apples the bruising was statistically different after four days. At this time, the yellow color of fruit, represented by chromaticity parameter b*, decreases from 44.8 to 39.9. The shelf-life caused further decrease of coordinate b*, however, the values covering larger differentiation in the range from 28.3 to 42.4.

The ground color as well as blush depends on the sun light during ripening. Lightness parameter L* describing skin darkness represents freshness of product. Low value of L* indicates dark skin of fruit. The change of this parameter as a result of storage or shelf-life depends on storage conditions or bruising. More distinct differences are visible on the ground color area. The lightness coordinate L* of ground color is stable at shelf-life of apples. Darkness of apple increases each day, especially during five days after bruising when L* rapidly decrease. Keeping bruised apples for a long time at this condition involve further darkening and large differentiation of lightness.

Impact causes bruising, which results in darkening of apples. All changes of color at shelf-life are well describe by linear regression, while the multiplicative model indicates more closely the influences of a time after bruising on all coordinate of color. The high color of blush consists of more intensive component, which is frequently a reason why bruising is invisible on this area.

The value of the chromaticity parameter a* indicates the high color of blush affecting the cosmetic's appearance. One day after bruising, the color of bruised apples becomes statistically different from the ground color, and remain uniform and stable over the range of shelf-life. It can be concluded, that only the bright side of the fruit changes its color significantly. The red component of the color is similar to the high area of blush, however, after 2 days of shelf-life the appearance of bruising on the area of ground color seems not to be satisfactory for the consumer.

The increase of yellow color of Champion apples is similar to Jonagold at the range of shelf-life. Positive linear regression indicates similar influence of shelf-life on the coordinate b*. On the ground area the bruising was statistically different after four days. At this time, the yellow color of fruit decreases. The shelf-life caused further decrease of yellow color of bruised apples, however, the values covers larger differentiation of coordinate b*.

Estimation of fruit quality based on L*a*b* system describing coordinates of color could be useful in connection with marketing, for monitoring consumer preferences and assessing the products after storage and at shelf-life. This system, if properly integrated into a marketing plan, could improve appearance of fruits, making consumers more aware of true quality factors.

7.7. NUTRITIONAL VALUE OF APPLE

The reducing sugar contents after 20 weeks of storage obtained the values on similar level for all apples (black spot close to the mean value of 1.07%, represented by horizontal line). Further storage caused processes, which provide to increase of reducing sugar. After 35 weeks this line represents mean value equal 2.66% (Fig. 59). However, the increase of reducing sugar content occurs differently for varietys. The sweetest apples after long storage are: Šampion (4.08%) and Gala (4.01%). The other apples contain the sugar in tissue from 2.14% to 2.89%. Those for Gloster and Melrose apples low sweetness was observed.

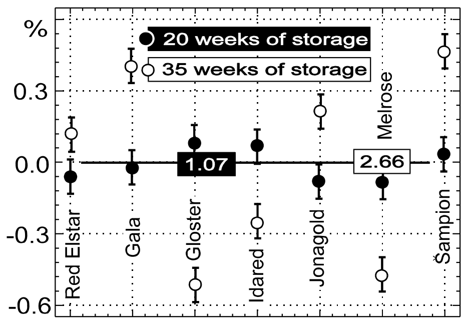

Fig. 59. The sugar contents in the apple flesh after fruit storage

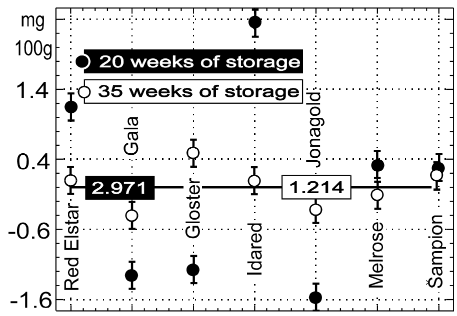

Fig. 60. The L-ascorbic acid content in apple tissue after fruit storage

The L-ascorbic acid strongly related to the vitamin C contents were estimated to determine the final quality of storage apple. The L-ascorbic acid content in 100 g of product, after 20 weeks of storage obtained different values for studied varietys (Figure 60). Idared apples covered 5.36 mg and Red Elstar 4.44 mg of L-ascorbic acid in 100 g of apple tissue. The vitamin C in Melrose apples was on the same level as for Šampion fruits and L-ascorbic acid content obtained values in the range 3.25-3.32 mg in 100 g of tissue. Low level of vitamin C was represented by tissue of Gala (1.54 mg), Gloster (1.68 mg) and Jonagold (1.35 mg) apples. After 35 weeks of storage L-ascorbic acid content definitely decreased more than four times for Idared and Red Elstar apples. The L-ascorbic acid contents equal 1.68 mg in 100 g of product was stable for Gloster apple tissue, during all period of storage.

7.8. WHAT PROPERTY IS MOST AFFECTING FACTOR ON QUALITY OF APPLE

Firstly, quality standards are affected by international and cultural preferences. Secondly, standards can be affected by cultural changes or by strong marketing in the media. Quality standards may involve appearance, feel, taste, consistency, handling characteristics, and ability to retain properties for long periods of time Kader (1983). At harvest, the following features for consumption are favoured: crispness, content of juice, good taste and aroma, nice colouring of the skin. Further, quality factors for fresh fruit and vegetables after harvest adapted from Kader (1983) are: cosmetic appearance, texture, flavour, nutritional, hygiene and quarantine factors.

When apples are grown, it is possible to eliminate the negative influence of some hygiene and quarantine factors such as parasite's larvae, pupae, natural toxicants, contaminants, spray residues, heavy metals, etc., affecting fruit quality. After harvest, most important become cosmetic appearance and numerous researchers were studied many factors such as: size, weight, volume, dimensions, shape, regularity, surface texture, smoothness, waxiness, gloss, colour, uniformity, intensity, spectral, and physical defects, splits, cuts, dents, and bruises (Bennedsen, Nielsen, 1997; Delwiche, Baumgardner, 1985; Guyer, Brook, Timm, 1993; Kawano, 1994; Park, Hong, 1997; Paulus, Schrevens, 1997; Shewfelt, Prussia, 1993; Van Woensel, Wouters, de Baerdemaeker, 1987). Preparing for the market by sorting on the basic of physical parameter of apples is adequate for quality improvement (Bellon, Rabatel, Guizard, 1992; Bennedsen, Nielsen, 1997; Brown *et al*., 1990; Chen,1996; Delwiche, 1987; Duprat *et al*., 1995; McClure, 1995; Watada, 1993). Various methods have been used to characterize apple shape that could help explain the preferred orientation for fruit in a given handling system. Whitelock *et al*. (1997) found that parameter ratios which describe elongation (h/D) were better predictors of apple rolling orientation than taper or symmetry. In this study, low correlation was observed between axis height (h) and diameter (D) of fruit for apples of most varieties. It was also observed that low correlation for this parameter influenced quality of grading representing apple's weight. Apples that were relatively irregular in the shape changed orientation during rolling, which caused nonadequate grading to it's weight and gate number. The apples of axis close to the gravity centre were rolled, that the axis move was parallel to belt, allowing the improve of grading quality.

The grading method and sizing are available for apple quality improvement according to external properties, such as size, shape, and weight, however, colour and texture were taken into the consideration of apple quality. Mechanical damage and bruising of apples were carefully recognize after sorting to establish the acceptability of product for a particular market. Firmness, crispness, hardness/softness, mealiness-grittiness, fibrousnesses, and toughness are influenced by mechanical properties. Mechanical tests performed on apple flesh and skin shown different behavior of apple firmness. In most cases the storage had significance influence on the mechanical properties estimated at different tests used in previous study. The elastic behaviour of fruit shown that fruit firmness decreased unequally for studied varieties after storage and the modulus of elasticity more distinctly show the slightly changes of apple firmness during the range of storage period. Most frequently studied parameter was firmness, therefore some results of mechanical properties connected with firmness were presented by Dobrzański, jr., *et al*., (2000).

Significantly changes of colour during fruit storage were observed only for bruise's apples (Shewfelt, Prussia, 1993). Bruising does not break the skin of an apple, but influences its appearance. During the range of storage period the colour of apple skin is unchanging, however, as an important factor must be included in any consumer quality estimation.

For the market the apples of each variety can be roughly divided into dessert, table and industrial. Although, quality of desert apples based on appearance factors, the nutritional factors must be included in quality estimation of table apples, as well as for industrial processes.

The wide range of studied parameters allow to estimate some quality factors of horticulture products such as: size; weight, dimensions, shape, colour, water potential and mechanical characteristics. Characteristic dimensions and physical properties of fruit were measured to estimate simple quality factors connected with firmness , size, shape and colour parameter. However, often nutritional values of fruits and vegetables decided final quality of food (Fig. 61).

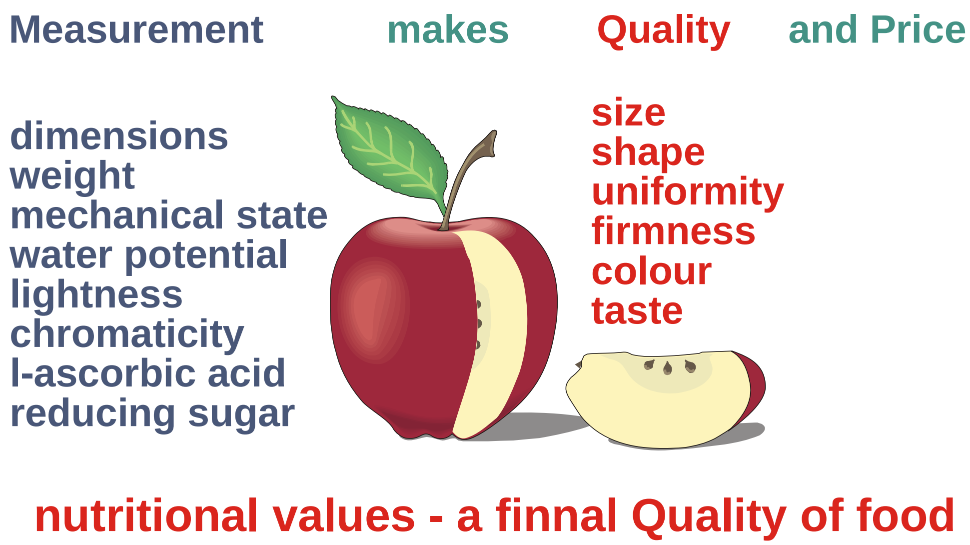

Fig. 61. The necessity of measurement of physical properties makes final quality of fruit (source: Dobrzański, jr. B., Rybczyński R., Dobrzańska A., 1998. Physical and nutritional properties of apple. Presented during XXV International Horticultural Congress, Brussels, PP 2/03/A-23, 358

Sizing with a simply sorter improves apple quality of at low cost. High correlation coefficients between the maximum size and weight of fruit prove that the weight should be a proper index of grading quality as well as dimension of fruit.

Determination of fruit quality based on L*a*b* system colour should be useful in handling of apples, make decision easy for marketing and being helpful in establish of consumer preferences. The L*a*b* system make these techniques affordable in the marketplace and especially to relate the measurement parameters to the very subjective, sensory evaluation of quality by consumers.

There are many different factors which can be included in any discussion of quality, however, it should be given appropriate care and attention for nutritional quality of fruit after storage.

CHAPTER 8

TRANSPORT REQUIREMENTS FOR APPLES*

8.1. PRODUCT INFORMATION

8.1.1. PRODUCT NAME

Table 43. Product name of apples in languages of major producers

Language	Name
English	Apples
French	Pommes
German	Äpfel
Polish	Jabłka
Spanish	Manzanas
Scientific	*Malus sylvestris* var. *domestica*
CN/HS number *	0808 ff.

(* EU Combined Nomenclature/Harmonized System)

8.1.2. TRADE PRODUCT DESCRIPTION

Apples (*rose* family, Rosaceae) are a pomaceous false fruit with whitish, firm pulp and a generally sour-sweet flavor. The small brown seeds (pips) are located in a parchment-like core with 5 compartments. The apple tree originated between the Black Sea and the Caspian Sea and spread to all temperate zones of the world.

Numerous apple varieties have been developed over the several thousand years that they have been cultivated. Taste and color differ depending on the variety and stage of ripeness.

A distinction may be drawn between dessert fruit (fruit for eating fresh), commercial fruit (industrial use, e.g. for apple puree, apple jelly and obtaining pectin) and cider apples (apple juice, wine).

Apples are divided into summer, autumn and late varieties (keeping apples) depending on when they ripen: the latter are the most common.

* This chapter based on Transport Information Service, (source: http://www.tis-gdv.de)

Apples are available all year round owing to their different ripening times and long-term storage as well as imports from the southern hemisphere.

Examples of well-known varieties are: "Boskoop", "Cox's Orange", "Golden Delicious", "Jonagold" and "Gravensteiner".

8.1.3. Quality / Duration of Storage

Apples are shipped at the preclimacteric stage (tree or picking ripe). The skin must exhibit lightening of the ground color and the pulp must be green. Apples are transportable if free from spoilage, damage, bruises and abnormal moisture. In addition, they must be free from diseases and pests. To determine the degree of ripeness of pomaceous fruit, the hardness of the pulp is measured using a pressure tester, which involves pressing a cylindrical steel plunger into the pulp.

The maximum pressure is read off in pounds. At the preclimacteric stage, the reading for most varieties of apple lies between 18 and 20 pounds. During ripening, hardness decreases by 5 - 6 pounds. Pulp temperature measurements are also performed, as with citrus fruits. Size grading is generally performed mechanically. If grading is performed by hand, gaging rings or gaging boards are used. Dessert apples are divided into three quality classes: extra, I and II. They may be stored for between 1 and 6 months, depending on variety and degree of ripeness.

Where controlled atmosphere transport is used, transport and storage duration may be extended to approx. 8 months.

Table 44. Recommended parameters of controlled atmosphere transport of apples

Temperature	Rel. humidity	O_2	CO_2	Suitability for controlled atmosphere
1.1 - 4.4°C	90 - 95%	2 - 3%	1 - 2%	very good

(Source: Firmenbroschüre Sea-Land Service, Inc.: Shipping Guide for Perishables, Edison, N.J. 1991)

8.1.4. Intended Use

Apples are the main type of fruit consumed fresh in European Communities. They are also used in preparing juices, ciders, salads, cakes, dishes of raw fruit and vegetables, jams etc..

8.1.5. Countries of Origin

Table 45 shows only a selection of the most important countries of origin.

Table 45. Major producers selected by region and country

Region	Country
Europe	Poland, Germany, Turkey, France, Italy, Russia, Hungary, Netherlands, Greece, Spain, Belgium
Africa	South Africa
Asia	China, Japan
North America	USA, Mexico
South America	Argentina, Chile, Brasil
Australia	Australia, New Zealand

(source: http://www.tis-gdv.de)

8.2. Packaging

Apples are transported in crates and cartons. Jointed boxes are made from resin-free wood (standard softwood boxes), to prevent odor tainting, and are strong. Package weight and dimensions are generally very variable.

8.2.1. Transport

8.2.1.1. Symbols

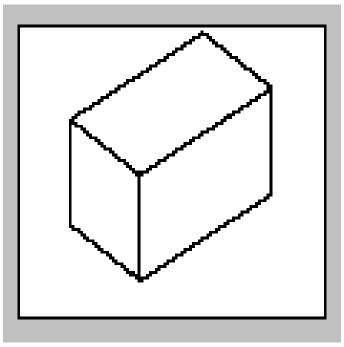

Fig. 62. Symbol of general cargo

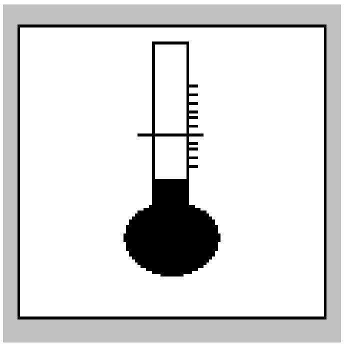

Fig. 63. Symbol of temperature-controlled

8.2.1.2. Means of Transport

Ship, aircraft, truck, railroad

8.2.1.3. CONTAINER TRANSPORT

Fig. 64. Refrigerated container with fresh air supply and controlled atmosphere

Fig. 65. Loading fruits into refrigerated container using diesel charged front forklift

8.2.1.4. CARGO HANDLING

Because of its impact- and pressure-sensitivity, the fruit has to be handled with appropriate care. The required refrigeration temperature must always be maintained, even during cargo handling. In damp weather (rain, snow), the cargo must be protected from moisture, as there is otherwise a risk of premature spoilage.

8.2.1.5. STOWAGE FACTOR

- 2.37 m^3/t (boxes, cartons)[1]
- 2.37 - 3.21 m^3/t (boxes, cartons)[2]
- 2.52 - 2.89 m^3/t (boxes, cartons)[3]

8.2.1.6. STOWAGE SPACE REQUIREMENTS

- cool
- dry
- good ventilation

8.2.1.7. SEGREGATION

- marker pen
- oil crayon
- fiber rope
- thin fiber nets

[1] Scharnow, R.: Codiertes Handbuch der Güter des Seetransports, VE Kombinat Seeverkehr und Hafenwirtschaft - Deutfracht/Seereederei - Ingenieurhochschule für Seefahrt Warnemünde/Wustrow, Rostock 1986, Bd. 1: Stückgut A-K, Bd.
[2] Thomas, R.E.: Thomas´ Stowage - The Properties and Stowage of Cargoes, Brown, Son & Ferguson Ltd., 3. Auflage, Glasgow 1996
[3] Ładunki okrętowe. Poradnik encyklopedyczny, Polskie Towarzystwo Towaroznawcze. Oddział Morski, Sopot 1994

8.2.1.8. CARGO SECURING

Because of its considerable impact- and pressure-sensitivity, packages of this cargo must be secured in such a way that they are prevented from damaging each other. Spaces between packages or pallets must be filled, to prevent slippage or tipping. By selecting the correct packaging size or cargo unit (area module or area module multiple), holds can be tightly loaded (without spaces).

Fig. 66. Packages with apples of this cargo was not correct secured against impact at travel in storage facility (source: http://www.tis-gdv.de)

Fig. 67. Prof. Shmulevich and Dr. Rybczyński checking quality of fruits and vegetables in packages in the storage facility of Saint-Charles International (Perpignan, France) at preparing cargo for selling it to the markets (photo: B. Dobrzański, jr.)[*]

8.3. RISK FACTORS AND LOSS PREVENTION

8.3.1. RF TEMPERATURE

Apples require particular temperature, humidity/moisture and ventilation conditions (SC VII) (storage climate conditions).

A written cooling order must be obtained from the consignor before loading is begun. This order must always be complied with during the entire transport chain.

[*] photo performed during the 2nd mission to the European Communities, in the frame of co-operation in the field of evaluation of fruits and vegetables quality (activity of Work Package 9)

Table 46 merely constitute an estimate of appropriate temperature ranges. Temperatures may deviate from these values, depending on the particular transport conditions.

Table 46. Travel temperature ranges for cold sensitive and cold-insensitive varieties

Designation	Temperature range	Source
Cold-insensitive varieties	0 - 2°C	Scharnow, R. (1986)[4]
	0.5 - 1°C	Thomas (1996)[5]
	-1 - +1°C	Alders (1995)[6]
Cold-sensitive varieties	4.5°C	Thomas (1996)[5]
	2 - 5°C	Alders (1995)[6]

(source: http://www.tis-gdv.de)

The refrigeration temperature is highly dependent on the different varieties and their susceptibility to internal breakdown.

Internal breakdown suggests excessively rapid cooling. Internal breakdown is the most frequent type of chilling damage in apples. It occurs at temperatures of around 0°C and is not generally visible from the outside. The pulp displays irregularly dispersed streaky brown marks and becomes mealy, with the consistency of the fruit becoming elastic. The riper side of the fruit generally suffers more than the greener side. Freezing injury in apples may be recognized by watery, deep brown-colored flesh after thawing. Supply air should never be < -1°C.

8.3.2. RF Humidity/Moisture

Apples require particular temperature, humidity/moisture and ventilation conditions (SC VII) (storage climate conditions)

Table 47. Temperature and humidity/moisture conditions of apple transport

Designation	Humidity/water content	Source
Relative humidity	85 - 90%	Scharnow, R. (1986)[4]
	90 - 95%	Alders (1995)[6]
Water content	82 - 83%	Scharnow, R. (1986)[4]
Maximum equilibrium moisture content	85%	Scharnow, R. (1986)[4]

At a rel. humidity > 90% there is a considerable risk of mold development. (source: http://www.tis-gdv.de)

[4] Scharnow, R.: Codiertes Handbuch der Güter des Seetransports, VE Kombinat Seeverkehr und Hafenwirtschaft - Deutfracht/Seereederei - Ingenieurhochschule für Seefahrt Warnemünde/Wustrow, Rostock 1986, Bd. 1: Stückgut A-K, Bd.

[5] Thomas, R.E.: Thomas´ Stowage - The Properties and Stowage of Cargoes, Brown, Son & Ferguson Ltd., 3. Auflage, Glasgow 1996

[6] Alders, A.W.C.: Reefer Transport & Technology, Rotterdam Marine Chartering Agents B.V. Krimpen a/d Yssel, 1995

8.3.3. RF VENTILATION

Apples require particular temperature, humidity/moisture and ventilation conditions (SC VII) (storage climate conditions).

Recommended ventilation conditions: circulating air, 40 - 60 circulations/hour with continuous supply of fresh air

The spoilage symptom storage scald indicates insufficient air exchange in the hold and is caused by an apple's own excretion products in the event of inadequate ventilation. This disease is manifested externally by discoloration of the skin.

8.3.4. RF BIOTIC ACTIVITY

Apples display 2nd order biotic activity. They are living organs in which respiration processes predominate, because their supply of new nutrients has been cut off by separation from the parent plant.

Care of the cargo during the voyage must be aimed at controlling respiration processes (release of CO_2, water vapor, ethylene and heat) in such a way that the cargo is at the desired stage of ripeness on reaching its destination. Inadequate ventilation may result in fermentation and rotting of the cargo as a result of increased CO_2 levels and inadequate supply of atmospheric oxygen (see Ventilation).

8.3.5. RF GASES

Table. 48. RF gases rates, CO_2 and ethylene evolution

Gases	Rates	Source
	2.0 - 7.0 mg/kg*h	Scharnow, R. (1986)[4]
Upper limit of permissible CO_2 content	1.0 vol.%	Scharnow, R. (1986)[4]
	2.0 vol.%	Thomas (1996)[5]
	0.4 vol.%	Ładunki okrętowe (1994)[3]
	< 0.8 vol.%	Alders (1995)[6]
Ethylene evolution	Descriptions	
Active behavior	Climacteric apples exhibit high levels of ethylene production (> 100 µl/kg*h) (Shipping Guide for Perishables, 1991)[7]. Early and late apple varieties should not be stowed together, since this may reduce the storage life of the late varieties. Bananas are also at considerable risk. Even where apples and bananas are stowed in different compartments of an ocean-going vessel, the turbulence caused by the return and fresh air fans may cause the bananas to ripen prematurely.	
Passive behavior	The sensitivity of apples to ethylene may be classified as high (Shipping Guide for Perishables, 1991)[7]. They must not therefore be stored together with ethylene-producing goods (allelopathy).	

(source: http://www.tis-gdv.de)

7 Firmenbroschüre Sea-Land Service, Inc.: Shipping Guide for Perishables, Edison, N.J. 1991

In fresh fruit, metabolic processes continue even after harvesting. The fruit absorbs oxygen (O_2) and excretes varying amounts of carbon dioxide (CO_2) and ethylene (C_2H_4) as well as aromatic compounds during the conversion of starch into sugar (ripening process).

If ventilation has been inadequate (frost) or has failed owing to a defect, life-threatening CO_2 concentrations or O_2 shortages may arise. Therefore, before anybody enters the hold, it must be ventilated and a gas measurement carried out. The TLV for CO_2 concentration is 0.49 vol.%.

8.3.6. RF Self-heating / Spontaneous Combustion

No risk.

8.3.7. RF Odor

Table 49. RF odor emergency at transport of apples

Active behavior	Apples have a strong, pleasant odor.
Passive behavior	Apples are very odor-sensitive and should not be stowed together with goods such as meat, butter and cheese.

(source: http://www.tis-gdv.de)

8.3.8. RF Contamination

Table 50. Active passive behavior of apples involving contamination

Behavior	Effect
Active	Apples do not cause contamination
Passive	Apples are sensitive to dust, dirt, fats and oils. Clean packaging is absolutely essential, since the cargo may spoil very rapidly as a result of mold or bacterial attack. The holds or containers must accordingly be clean and in a thoroughly hygienic condition before loading.

(source: http://www.tis-gdv.de)

8.3.9. RF MECHANICAL INFLUENCES

Apples are very sensitive to impact. The fruit must be handled very carefully, since, in the event of strong pressure or jolting/vibration, the fruit rapidly succumbs to bruising and may start to rot within just a few days. According to guide-book (Ładunki okrętowe, 1994)[3], no more than 10 - 12 cartons should be stowed on top of one another.

Where possible, the apples should be of uniform size to even out pressure and prevent damage. Size grading is generally performed mechanically. If grading is performed by hand, gaging rings or gaging boards are used. Dessert apples are divided into three quality classes: extra (minimum diameter 65 mm), I (minimum diameter 60 mm) and II (minimum diameter 55 mm).

8.3.10. RF TOXICITY / HAZARDS TO HEALTH

If ventilation has been inadequate (frost) or has failed owing to a defect, life-threatening CO_2 concentrations or O_2 shortages may arise. Therefore, before anybody enters the hold, it must be ventilated and a gas measurement carried out. The TLV for CO_2 concentration is 0.49 vol.%.

8.3.11. RF SHRINKAGE/SHORTAGE

The normal weight loss due to a reduction in the moisture content of the product is < 1% (Scharnow, 1986)[4], but according to Alders (1995)[6] may be 3 - 5% for some varieties.

Added to this are losses of volume caused by packaging breakage, which should not however be greater than 0.4% (Deutscher Transport-Versicherungs-Verband e.V) [8].

8.3.12. RF INSECT INFESTATION / DISEASES

The most important storage diseases are:

- Storage scald: the spoilage symptom storage scald indicates insufficient air exchange in the hold and is caused by an apple's own excretion products in the event of inadequate ventilation. This disease is manifested externally by discoloration of the skin.

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[8] Deutscher Transport-Versicherungs-Verband e.V.: Die Ware in der Transportversicherung, Hamburg 1990-1994

- Internal breakdown: internal breakdown suggests excessively rapid cooling. Internal breakdown is the most frequent type of chilling damage in apples and is not generally externally visible. The pulp displays irregularly dispersed streaky brown marks and becomes mealy, with the consistency of the fruit becoming elastic. The riper side of the fruit generally suffers more than the greener side.
- Brown heart: this condition, identifiable from a dark core, may arise as a result of an excessively high CO_2 content in the hold air.
- Bitter pit: brown, bitter-tasting spots appear just under the skin, as a result of metabolic disorders.
- Rot, e.g. brown rot caused by *Monilia fructigena*. It is manifested by brown spots and tufts of yellowish spores, which are typically arranged in circles. Like brown rot, gray and blue (mold) rot are also caused by molds.

Chewing and sucking injuries are caused by the following apple pests:

- fruitworm
- codling moth
- apple fruit moth
- apple sawfly
- apple psylla
- summer fruit tortrix moth
- apple-and-thorn skeletonizer
- scale insects etc.

The quarantine regulations of the country of destination must be complied with and a phytosanitary certificate may have to be enclosed with the shipping documents. Information may be obtained from the phytosanitary authorities of the countries concerned.

Chapter 9

EUROPEAN COMMUNITIES REGULATIONS AND STANDARDS FOR APPLES

9.1. COMMISSION REGULATION (EC) NO 85/2004 OF 15 JANUARY 2004[1]

The Commission of the European Communities, laying down the marketing standard for apples.

Having regard to the Treaty establishing the European Community, Having regard to Council Regulation (EC) No 2200/96 of 28 October 1996 on the common organisation of the market in fruit and vegetables[2], and in particular Article 2[2],

Whereas:

(1) Apples are among the products listed in Annex I to Regulation (EC) No 2200/96 for which standards must be adopted. Commission Regulation (EC) No 1619/2001 of 6 August 2001, laying down the marketing standard for apples and pears and amending Regulation (EEC) No 920/89[3], lays down a marketing standard common to apples and pears.

(2) In the interest of clarity, the Working Party on standardisation of perishable produce and quality development of the United Nations Economic Commission for Europe (UN/ECE) decided that the rules on apples should be separated from those on pears. In addition, it decided to update the UN/ECE standard FFV-50 concerning marketing and commercial quality control of apples with regards to the provisions

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(1) The Commission of the European Communities, laying down the marketing standard for apples: COMMISSION REGULATION (EC) No 85/2004 of 15 January 2004 (OJ L 13, 20.1.2004, p. 3) This document is meant purely as a documentation tool and the institutions do not assume any liability for its contents and was amended by two following regulations:

Commission Regulation (EC) No 907/2004 of 29 April 2004 L 163 50 30.4.2004

Commission Regulation (EC) No 1238/2005 of 28 July 2005 L 200 22 30.7.2005

(2) OJ L 297, 21.11.1996, p. 1. Regulation as last amended by Commission Regulation (EC) No 47/2003 (OJ L 7, 11.1.2003, p. 64).

(3) OJ L 215, 9.8.2001, p. 3. Regulation amended by Regulation (EC) No 46/ 2003 (OJ L 7, 11.1.2003, p. 61).

concerning quality and sizing. In the interest of preserving transparency on the world market, Regulation (EC) No 1619/2001 should be repealed and two new marketing standards for apples and pears respectively, should be adopted accordingly.

(3) The main maturity criteria laid down by Regulation (EC) No 1619/2001 is the definition of a minimum size for apples. In view of the recent technical developments concerning methods for measuring firmness and sugar contents as well as emerging new markets for small-sized mature apples, the minimum size for apples applicable in the Community should be reduced, new maturity criteria such as sugar content and firmness ensuring that such a reduction of the minimum size does not imply fruits insufficiently mature and/or developed are placed on the market.

(4) More work being needed for the precise definition of these new criteria, taking into account the varietal characteristics as to the size of apples, the implementation of the reduction of the minimum size should be delayed until 1 August 2005 and provisional measures concerning sizing should be laid down until then

(5) Application of these new standards should remove products of unsatisfactory quality from the market, bring production into line with consumer requirements and facilitate trade based on fair competition, thereby helping to improve profitability.

(6) The standards are applicable at all marketing stages. Longdistance transport, storage over a certain period and the various processes the products undergo may cause some degree of deterioration owing to the biological development of the products or their perishable nature. Account should be taken of such deterioration when applying the standard at the marketing stages following dispatch.

(7) As products in the ‘Extra’ class have to be particularly carefully sorted and packaged, only lack of freshness and turgidity is to be taken into account in their case.

(8) The measures provided for in this Regulation are in accordance with the opinion of the Management Committee for Fresh Fruit and Vegetables,

HAS ADOPTED THIS REGULATION:

Article 1

The marketing standard for apples, falling within CN code ex 0808 10, shall be as set out in the Annex.

The standard shall apply at all marketing stages under the conditions laid down in Regulation (EC) No 2200/96.

However, at stages following dispatch, products may show in relation to the requirements of the standard:

— a slight lack of freshness and turgidity,

— for products graded in classes other than the ‘Extra’ class, slight deterioration due to their development and their tendency to perish.

Article 2

Until 31 May 2008, the following provisions apply with regards to sizing:

(a) when size is determined by diameter, a minimum diameter is required in all classes as follows:

	Extra	I	II
Large fruited varieties (*)	70 mm	65 mm	65 mm
Other varieties	60 mm	55 mm	55 mm

(*) The non-exhaustive list of large fruited varieties is given in the appendix to the Annex.

(b) when size is determined by weight, a minimum weight is required in all classes as follows:

	Extra	I	II
Large fruited varieties (*)	140 g	110 g	110 g
Other varieties	90 g	80 g	80 g

(*) The non-exhaustive list of large fruited varieties is given in the appendix to the Annex.

Article 3

Regulation (EEC) No 1619/2001 is deleted.

Article 4

This Regulation shall enter into force on the 20th day following its publication in the *Official Journal of the European Union*.

The second and third subparagraph of point III of the Annex only apply as from 1 June 2008.

This Regulation shall be binding in its entirety and directly applicable in all Member States.

ANNEX

STANDARD FOR APPLES

I. DEFINITION OF PRODUCE

This standard applies to apples of varieties (cultivars) grown from *Malus domestica* Borkh., to be supplied fresh to the consumer, apples for industrial processing being excluded.

II. PROVISIONS CONCERNING QUALITY

The purpose of the standard is to define the quality requirements of apples, after preparation and packaging.

A. **Minimum requirements**

In all classes, subject to the special provisions for each class and the tolerances allowed, apples must be:

- — intact,
- — sound, produce affected by rotting or deterioration such as to make it unfit for consumption is excluded,
- — clean, practically free of any visible foreign matter,
- — practically free from pests,
- — practically free from damage caused by pests,
- — free of abnormal external moisture,
- — free of any foreign smell and/or taste.

In addition, they must have been carefully picked.

The development and condition of the apples must be such as to enable them:

- — to continue their maturing process and to reach the degree of maturity required in relation to the varietal characteristics[4][5],
- — to withstand transport and handling, and
- — to arrive in satisfactory condition at the place of destination.

B. **Classification**

Apples are classified in three classes defined below.
(i) *‘Extra’ class*

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[4] Due to varietal characteristics of the Fuji variety and its mutants concerning maturity at harvest, radial watercore is permitted provided it is contained within the vascular bundles of each fruit.
[5] To that end, they must show satisfactory soluble solids content and degree of firmness.

Apples in this class must be of superior quality. In shape, size and colouring, they must be characteristic of the variety[(6)] and with the stalk which must be intact.

The flesh must be perfectly sound.
They must be free from defects with the exception of very slight superficial defects provided these do not affect the general appearance of the produce, the quality, the keeping quality and presentation in the package.

(ii) *Class I*

Apples in this class must be of good quality. In shape, size and colouring, they must be characteristic of the variety[(4)].

The flesh must be perfectly sound.

The following slight defects, however, may be allowed provided these do not affect the general appearance of the produce, the quality, the keeping quality and presentation in the package:

— a slight defect in shape,
— a slight defect in development,
— a slight defect in colouring,
— slight skin defects which must not extend over more than:
    — 2 cm in length for defects of elongated shape,
    — 1 cm^2 of total surface area for other defects, with the exception of scab (*Venturia inaequalis*), which must not extend over more than 0,25 cm^2 of total surface area,
— slight bruising not exceeding 1 cm2 of total surface area and not discoloured.

The stalk may be missing, provided the break is clean and the adjacent skin is not damaged.

(iii) *Class II*

This class includes apples which do not qualify for inclusion in the higher classes but satisfy the minimum requirements specified above[(7)].
The flesh must be free from major defects.
The following defects are allowed provided the fruit retains its essential characteristics as regards the quality, the keeping quality and presentation:
— defects in shape,

[(6)] The criteria for colouring and russetting are given in the appendix to this standard, as well as a non-exhaustive list of the varieties concerned by each criteria.
[(7)] The criteria for colouring and russetting are given in the appendix to this standard, as well as a non-exhaustive list of the varieties concerned by each criteria.

— defects in development,
— defects in colouring,
— skin defects which must not extend over more than:
— 4 cm in length for defects of elongated shape,
— 2,5 cm^2 of total surface area for other defects, with the exception of scab (*Venturia inaequalis*), which must not extend over more than 1 cm^2 of total surface area,
— slight bruising not exceeding 1,5 cm^2 of total surface area which may be slightly discoloured.

III. PROVISIONS CONCERNING SIZING

Size is determined either by maximum diameter of the equatorial section or by weight.
When size is determined by diameter, the minimum diameter required for each class is as follows:

	Extra	Class I	Class II
Large fruited varieties (*)	65 mm	60 mm	60 mm
Other varieties	60 mm	55 mm	50 mm

(*) The non-exhaustive list of large fruited varieties is given in the appendix to this standard.

When size is determined by weight, the minimum weight required for each class is as follows:

	Extra	Class I	Class II
Large fruited varieties (*)	110 g	90 g	90 g
Other varieties	90 g	80 g	70 g

(*) The non-exhaustive list of large fruited varieties is given in the appendix to this standard.

To ensure there is uniformity of size within a package:

— for fruit sized according to diameter, the difference in diameter between fruit in the same package shall be limited to:
    — 5 mm for ‘Extra’ class fruit and for Class I and II fruit packed in rows and layers[8],
    — 10 mm for Class I fruit packed loose in the package or sales package[8];
— for fruit sized according to weight, the difference in weight between fruit in the same package shall be limited to:

[8] However, for apples of the varieties Bramley's Seedling (Bramley, Triomphe de Kiel) and Horneburger, the difference in diameter may amount to 20 mm.

— 20% of the average individual fruit weight in the package for 'Extra' class fruit and for Class I and II fruit packed in rows and layers,
— 25% of the average individual fruit weight in the package for Class I fruit packed loose in the package or sales package.

There is no sizing uniformity limit for Class II fruit packed loose in the package or sales package.

IV. PROVISIONS CONCERNING TOLERANCES

Tolerances in respect of quality and size shall be allowed in each package for produce not satisfying the requirements of the class indicated.

A. **Quality tolerances**

(i) *'Extra' class*

5% by number or weight of apples not satisfying the requirements of the class, but meeting those of Class I or, exceptionally, coming within the tolerances of that class.

(ii) *Class I*

10% by number or weight of apples not satisfying the requirements of the class, but meeting those of Class II, or exceptionally, coming within the tolerances of that class.

(iii) *Class II*

10% by number or weight of apples satisfying neither the requirements of the class nor the minimum requirements, with the exception of produce affected by rotting or any other deterioration rendering it unfit for consumption.

Within this tolerance, a maximum of 2% number or weight of fruit is allowed which shows the following defects:

— serious attacks of cork (bitter pit) or water-core,
— slight damage or unhealed cracks,
— very slight traces of rot,
— presence of internal feeding pests and/or damage to the flesh caused by pests.

B. **Size tolerances**

For all classes:

10% by number or weight of fruit not corresponding to the size immediately above or below that marked on the package, with, for fruit classified in the smallest grade allowed a maximum variation of:
— 5 mm below the minimum diameter when size is determined by diameter,
— 10 g below the minimum weight when size is determined by weight.

V. PROVISIONS CONCERNING PRESENTATION

A. **Uniformity**

The contents of each package must be uniform and contain only apples of the same origin, variety, quality and size (if sized) and the same degree of ripeness.

In the case of the ‘Extra’ class, uniformity also applies to colouring.

Sales packages of a net weight not exceeding 5 kg may contain mixtures of apples of different varieties, provided they are uniform in quality and, for each variety concerned, in origin, size (if sized) and degree of ripeness.

Notwithstanding the preceding provisions in this point, products covered by this Regulation may be mixed, in sales packages of a net weight of three kilograms or less, with different types of fresh fruit and vegetables on the conditions laid down by Commission Regulation (EC) No 48/2003[9].

The visible part of the contents of the package must be representative of the entire contents.

B. **Packaging**

The apples must be packed in such a way as to protect the produce properly. In particular, sales packages of a net weight exceeding 3 kg shall be sufficiently rigid to ensure proper protection of the produce.

The materials used inside the package must be new, clean and of a quality such as to avoid causing any external or internal damage to the produce. The use of materials, particularly of paper or stamps bearing trade specifications is allowed provided the printing or labelling has been done with non-toxic ink or glue.

Packages must be free of all foreign matter.

Stickers individually affixed on product shall be such as, when removed, neither to leave visible traces of glue, nor to lead to skin defects.

C. **Presentation**

For ‘Extra’ class, fruit must be packed in layers.

VI. PROVISIONS CONCERNING MARKING

Each package must bear the following particulars, in letters grouped on the same side, legibly and indelibly marked, and visible from the outside.

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(9) OJ L 7, 11.1.2003, p. 65.

A. **Identification**

The name and the address of the packer and/or the dispatcher This mention may be replaced:

— for all packages with the exception of pre-packages, by the officially issued or accepted code mark representing the packer and/or the dispatcher, indicated in close connection with the reference ‘Packer and/or Dispatcher’ (or equivalent abbreviations);

— for pre-packages only, by the name and the address of a seller established within the Community indicated in close connection with the mention ‘Packed for:’ or an equivalent mention. In this case, the labelling shall also include a code representing the packer and/or the dispatcher. The seller shall give all information deemed necessary by the inspection body as to the meaning of this code.

B. **Nature of produce**

— ‘Apples’ if the contents are not visible from the outside

— Name of the variety or varieties where appropriate.

— In the case of sales packages containing a mixture of apples of different varieties, names of each of the different varieties in the package.

C. **Origin of produce**

Country of origin and, optionally, district where grown, or national, regional or local place name

— In the case of sales packages containing a mixture of varieties of apples of different origins, the indication of each country of origin shall appear next to the name of the variety concerned.

D. **Commercial specifications**

— Class

— Size or, for fruit packed in layers, number of units.

If identification is by the size, this should be expressed:

(a) for produce subject to the uniformity rules, as minimum and maximum diameters or minimum and maximum weight;

(b) for produce not subject to the uniformity rules, the diameter or the weight of the smallest fruit in the package followed by ‘and over’ or ‘+’ or equivalent denomination or, where applicable, followed by the diameter or weight of the largest fruit.

E. **Official control mark (optional)**

Packages need not to bear the particulars mentioned in the first subparagraph, when they contain sales packages, clearly visible from the outside, and all bearing these particulars. These packages shall be free from any indications such as could mislead. When these packages are palletised, the particulars shall be given on a notice placed in an obvious position on at least two sides of the pallet.

APPENDIX

1. Colouring criteria, colouring groups and codes

Colouring group	A (Red varieties) Total surface area of red colouring characteristic of the variety	B (Mixed red colouring varieties) Total surface area of mixed red colouring characteristic of the variety	C (Striped slightly coloured varieties) Total surface area of slightly red coloured, blushed or striped characteristic of the variety	D (Other varieties)
Extra class	3/4	1/2	1/3	No requirement as to red colouring
Class I	1/2	1/3	1/10	
Class II	1/4	1/10	—	

2. Russeting criteria

— *Group R*: Varieties for which russeting is a characteristic of the skin and is not a defect if it corresponds to the typical appearance of the variety.
— For varieties not marked with an 'R' in the list below, russeting is allowed within the following limits:

	'Extra' class	Class I	Class II	Tolerance for Class II
(i) Brown patches	not outside the stem cavity	may go slightly beyond the stem or pistil cavities	may go beyond the stem or pistil cavities	fruit not seriously detracting from the appearance and condition of the package
	not rough	not rough	slightly rough	
(ii) Russeting		Maximum surface area of the fruit permitted		
thin net-like russeting (not contrasting strongly with the general colouring of the fruit)	slight and isolated traces of russeting not altering the general appearance of the fruit or of the package	1/5	1/2	fruit not seriously detracting from the appearance and condition of the package
heavy	none	1/20	1/3	fruit not seriously detracting from the appearance and condition of the package
cumulative defects (with the exception of the brown patches which are excluded from these cumulative defects). In no case may thin russeting and heavy russeting taken together exceed a maximum of:	—	1/5	1/2	fruit not seriously detracting from the appearance and condition of the package

3. Size criteria:

   Group L: large fruited apple varieties mentioned in the second subparagraph of title III of the present standard.

4. Non-exhaustive list of apple varieties classified according to their colouring, russeting and size criteria: Fruits of varieties that are not part of the list must be graded according to their varietal characteristics.

Some varieties in the following list may be marketed under trade names for which an application for protection has been made or protection has been granted in one or more country, provided that the name of the variety, or the synonym thereof, appears on the labelling. The first and second column of the table hereunder do not intend to include such trade names. References to known trademarks have been included in the third column for information only.

Variety	Synonyms	Trade name	C[1]	R[2]	S[3]	P[4]
African Red		African CarmineTM	B			
Akane	Tohoku 3	Primerouge®	B			
Alborz Seedling			C			
Aldas			B		L	
Alice			B			
Alkmene	Early Windsor		C			
Alwa			B		L	P
Angold			C			
Apollo	Beauty of Blackmoor		C		L	
Arkcharm	Arkansas No 18, A 18		C		L	
Arlet			B	R		
Aroma Red coloured mutants of Aroma, for example Aroma Amorosa			C B			
Auksis			B			
Belfort	Pella		B			
Belle de Boskoop			D	R	L	
Belle fleur double			D		L	
Berlepsch	Freiherr von Berlepsch		C			
Berlepsch rouge	Red Berlepsch, Roter Berlepsch		B			
Blushed Golden					L	
Bohemia			B		L	
Boskoop rouge	Red Boskoop, Roter Boskoop		B	R	L	
Braeburn Red coloured mutants of Braeburn, for example:			B A		L L	
Hidala		Hilwell®				
Joburn		Aurora^{TM}, Red				

		Braeburn™, Southern Rose™				
Lochbuie Red						
Braeburn						
Mahana Red		Redfield®				
Mariri Red		Eve™, Red Braeburn™, Southern Rose™				
Redfield		Red Braeburn™, Southern Rose™				
Royal Braeburn						
Bramley's Seedling	Bramley, Triomphe de Kiel		D		L	
Brettacher Sämling			D		L	
Calville (group of …)			D		L	
Cardinal			B			
Carola	Kalco		C		L	
Caudle		Cameo™	B			
Charden			D		L	
Charles Ross			D		L	
Civni		Rubens®	B			
Coromandel Red	Corodel		A			
Cortland			B		L	P
Cox's orange pippin and mutants	Cox Orange		C	R		
Red coloured mutants of Cox's Orange Pippin for example: Cherry Cox			B	R		
Crimson Bramley			D		L	
Cripps Pink		Pink Lady®	C			
Cripps Red		Sundowner™	C(1)			
Dalinbel			B			
Delblush		Tentation®	D		L	
Delcorf and mutants, for example:		Delbarestivale®	C		L	
Dalili		Ambassy®				
Monidel						
Delgollune		Delbard Jubilé®	B		L	
Delicious ordinaire	Ordinary Delicious		B			
Deljeni		Primgold®	D		L	
Delikates			B			P
Delor			C		L	
Discovery			C			P
Dunn's Seedling			D	R		
Dykmanns Zoet			C			
Egremont Russet			D	R		
Elan			D		L	
Elise	Red Delight	Roblos®	A		L	P

Ellison's orange	Ellison		C		L	
Elstar and mutants, for example:			C			
Daliter Elshof Elstar Armhold Elstar Reinhardt Red coloured mutants of Elstar, for example:		Elton™				
Bel-El		Red Elswout™	B			
Daliest		Elista™				
Goedhof		Elnica™				
Red Elstar						
Valstar						
Falstaff			C			
Fiesta	Red Pippin		C			
Florina		Querina®	B		L	
Fortune			D	R		
Fuji and mutants			B		L	
Gala			C			P
Red coloured mutants of Gala, for example:			A			
Annaglo						
Baigent Galaxy		Brookfield®				
Mitchgla		Mondial Gala®				
Obrogala		Delbard Gala®				
Regala						
Regal Prince		Gala Must®				
Tenroy		Royal Gala®				
Garcia			D		L	
Gloster			B		L	P
Goldbohemia			D		L	
Golden Delicious and mutants			D		L	P
Golden Russet			D	R		
Goldrush	Coop 38		D		L	
Goldstar			D		L	P
Gradigold		Golden Extreme® Golden Supreme®	D		L	
Granny Smith			D		L	
Gravenstein rouge	Red Gravenstein, Roter Gravensteiner		B		L	
Gravensteiner	Gravenstein		D		L	
Greensleeves			D		L	
Holsteiner Cox and mutants	Holstein		D	R		
Holstein rouge	Red Holstein,		C	R		

	Roter Holsteiner Cox					
Honeycrisp	Honeycrunch®		C		L	
Honeygold			D		L	P
Horneburger			D		L	
Howgate Wonder	Manga		D		L	
Idared			B		L	
Ingrid Marie			B	R		
Isbranica	Izbranica		C			
Jacob Fisher			D		L	
Jacques Lebel			D		L	
Jamba			C		L	
James Grieve and mutants			D		L	P
James Grieve rouge	Red James Grieve		B		L	
Jarka			C		L	
Jerseymac			B			
Jester			D		L	P
Jonagold[(2)] and mutants, for example Crowngold Daligo			C		L	
Daliguy Dalijean Jonagold 2000	Jonasty Jonamel Excel					
Jonabel Jonabres King Jonagold						
New Jonagold Novajo	Fukushima Veulemanns					
Schneica Wilmuta		Jonica®				
Jonagored and mutants, for example: Decosta			A		L	P
Jomured	Van de Poel					
Jonagold Boerekamp		Early Queen®				
Jomar Jonagored Supra		Marnica®				
Jonaveld Primo		First Red®				
Romagold Rubinstar	Surkijn					
Red Jonaprince		Wilton's®, Red Prince®				
Jonalord			C			
Jonathan			B			
Julia			B			
Jupiter			D		L	P
Karmijn de Sonnaville			C	R	L	

Katy	Katja		B			P
Kent			D	R		
Kidd's orange red			C	R		
Kim			B			
Koit			C		L	
Krameri Tuvioun			B			
Kukikovskoje			B			
Lady Williams			B		L	
Lane's Prince Albert			D		L	
Laxton's Superb	Laxtons Superb		C	R		
Ligol			B		L	P
Lobo			B			P
Lodel			A			P
Lord Lambourne			C			
Maigold			B			
Mc Intosh			B			
Meelis			B		L	
Melba			B			
Melodie			B		L	
Melrose			C		L	
Meridian			C			
Moonglo			C			
Morgenduft	Imperatore		B		L	
Mountain Cove		Ginger Gold™	D		L	
Mutsu		Crispin®	D		L	
Normanda			C		L	
Nueva Europa			C			
Nueva Orleans			B		L	
Odin			B			
Ontario			B		L	
Orlovskoje Polosatoje			C			
Ozark Gold			D		L	
Paula Red			B			P
Pero de Cirio			D		L	
Piglos			B		L	P
Pikant			B		L	
Pikkolo			C			
Pilot			C			P
Pimona			C			
Pinova		Corail®	C			P
Pirella		Pirol®	B		L	
Piros			C		L	P
Rafzubex		Rubinette® Rosso	A			
Rafzubin		Rubinette®	C			P
Rajka			B			
Rambour d'hiver			D		L	
Rambour Franc			B			
Reanda			B		L	

Rebella			C		L	
Red Delicious and mutants, for example:			A		L	
Camspur Erovan Evasni Flatrar		Redchief® Early Red One® Scarlet Spur® Starkspur Ultra Red®				
Fortuna Delicious Otago Red King Red Spur Red York Richared Royal Red						
Sandidge Shotwell Delicious Stark Delicious Starking Starkrimson Starkspur Topred		Super Chief®				
Trumdor Well Spur		Oregon Spur Delicious®				
Red Dougherty			A			
Red Rome			A			
Redkroft			A			P
Regal			A			
Regina			B		L	
Reglindis			C		L	
Reine des Reinettes	Goldparmäne, Gold Parmoné		C			
Reineta Encarnada			B			
Reinette Rouge du Canada			B		L	
Reinette d'Orléans			D		L	
Reinette Blanche du Canada	Reinette du Canada, Canada Blanc, Kanadarenette		D	R	L	
Reinette de France			D		L	
Reinette de Landsberg			D			
Reinette grise du Canada	Graue Kanadarenette		D	R	L	
Relinda			C			
Remo			B			
Renora			B		L	
Resi			B			
Resista			D		L	
Retina			B		L	
Rewena			B		L	
Roja de Benejama	Verruga, Roja del		A			

	Valle, Clavelina					
Rome Beauty	Belle de Rome, Rome		B			
Rosana	Berner Rosenapfel		B		L	
Royal	Beaut		A		L	
Rubin			C		L	P
Rubinola			B		L	
Sciearly		Pacific Beauty™	A			
Scifresh		Jazz™	B			
Sciglo		Southern Snap™	A			
Sciray	GS48		A			
Scired		Pacific Queen™	A	R		
Sciros	Pacific Rose™		A		L	
Selena			B		L	
Shampion	Szampion, Šampion		B		L	P
Sidrunkollane Talioun			D		L	
Sinap Orlovskij	Orlovski Sinap		D		L	
Snygold	Earlygold		D		L	
Sommerregent			C			
Spartan			A			P
Splendour			A			
St. Edmunds Pippin			D	R		
Stark's Earliest			C			
Štaris	Staris		A			
Sturmer Pippin			D	R		
Sügisdessert			C		L	
Sügisjoonik			C		L	
Summerred			B			P
Sunrise			A			
Sunset			D	R		
Suntan			D	R	L	
Sweet Caroline			C		L	
Talvenauding			B			
Tellisaare			B			
Tiina			B		L	
Topaz			B			P
Tydeman's Early Worcester	Tydeman's Early		B		L	
Veteran			B			
Vista Bella	Bellavista		B			
Wealthy			B			
Worcester Pearmain			B			
York			B			

[1]C - Colouring codes, [2]R – Russeting criteria, [3]S – Size, [4]P – Varieties included in Polish Hort.List

(1) With minimum 20 % red colouring for Class I and Class II.
(2) However, for the variety Jonagold, at least one tenth of the surface of the fruit in Class II must be streaked with red colouring.

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ABSTRACT

This is a book about handling of apple. Apple is a tree and its pomaceous fruit, of species *Malus domestica* Borkh. in the rose family Rosaceae, is one of the most widely cultivated tree fruits. There are more than 7,500 known cultivars of apples, however, most of them are differently resistent to transport that it frequentlly involves damages and bruising. 42 million tons of apples were grown worldwide in 2005. China produced almost half of this total. The United States is the second leading producer. Poland is a third producer with total production more than 2.4 million tons of apples, while following China keep the second position in juice production.

The authors describes botanical origin of apple and quality characteristics, health benefits, production, uses, and the World's leading producers and exporters of fresh and processed apples, however, harvesting and handling apples including: packaging and transportation, apple maturity indices, mechanical and physiological disorders, bruising and storage are described in detail. Readers can find characterization of transport techniques and vehicles used in orchard and storage. Efficiency of the transport techniques and economic evaluation of transport technologies, costs and fuel consumption are submitted. Factors affecting damages in transport of apples, vibrations, fruit accelerations in the bin as a consequence of vehicle vibrations and the effect of transport condition on the extent of bruising and damage classification of apple is also presented. Physical methods for fruit quality evaluation, sensory evaluation of texture and firmness, mechanical properties related to fruit firmness (background for this study), instrumental measurement of texture, as well as, the quality properties of apple including: size, shape weight, color and nutritional value are presented.

In this book, readers can find information on transport requirements for apples, packaging, risk factors and loss prevention. Additionally European Communities Regulations and Standards for Apples are submitted. Reader is inform of produce, quality, sizing, tolerance, presentation, marking, while in appendix can find colouring, russeting, size criteria and the apple varieties, listed in table, which are classified according to its quality criteria.

The study presented here is concerned with the problems involved in apple turnover on the long way from the orchard to the consumer's table. Much new knowledge is contained in this book. Anyone interested in any aspect of handling of apple research and development, marketing, transport utilization, etc., should find this monograph useful.

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