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IMPROVING THE POSTHARVEST PERFORMANCE OF OKRA (*Abelmoschus esculentus* L. MOENCH) USING HOT WATER TREATMENT, MODIFIED ATMOSPHERE AND STORAGE TEMPERATURE

By

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A Thesis Submitted in Partial Fulfilment for the Requirements of the Masters Degree in Horticulture of Egerton University

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DECLARATION AND RECOMMENDATION

DECLARATION

This is to certify that this research Thesis is my original work and has not been submitted to any University for any degree examination.

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RECOMMENDATION

The research thesis has been submitted with our approval as University supervisors

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ABSTRACT

Okra (*Abelmoschus esculentus* L. Moench) is an important export vegetable in Kenya because of its high nutritional attributes. However, okra is very perishable, usually blackening, shrivelling and decaying within two days under room temperature conditions leading to heavy postharvest losses. An appropriate technology is necessary to maintain produce quality over an extended period after harvesting so as to facilitate marketing and improve prices. This study was aimed at evaluating the potential benefits of hot water treatment, pre-packaging and storage temperature in extending the shelf life of okra. Treatments were tested by immersing pods in hot water dips at 40°C for 7 minutes, 50°C for one minute, room temperature for 10 minutes and control (no hot water treatment). Pods were then packaged in perforated and non-perforated packaging 0.03mm thick. Control was not packaged. Packaged produce was then stored in refrigerators set at 4°C, 8.5°C and 13 °C and in room conditions to simulate the most common farmer's method of storage. The experimental design was a split split plot in a complete randomised design (SSPCRD) with hot water treatment as main plot, storage temperatures as subplot and packaging as the sub-subplot factor. Treatments were replicated six times and the experiment was repeated twice. Variables assessed were weight loss, visual appearance, incidences of chilling injury, decay, electrolyte leakage and off odour. Data was subjected to analysis of variance at $p \leq 0.05$ and means separated by Duncan multiple range test. Gen start (vers. 9) was used in the analysis. The best treatment combination after 21 days storage was hot water treatment at 50°C for 1 minute, perforated packaging and room storage temperature. This treatment combination maintained pod quality by reducing decay, off odour, electrolyte leakage, preventing chilling injury and enhancing visual appearance. It had minimal weight loss of 7-30% as compared to non packaged pods, which had upto 80% weight loss, which did not reduce the pod quality. The above storage treatment combination is practical under rural farming conditions. It maybe ecomnomical to adopt and is therefore recommended to farmers for storage of okra.

DEDICATION

To dad, Dr. B. N. Kigomo, mum, Mary Ngure, my husband Onesmus Muroki and my baby Raphael Thuo.

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I want to thank God for his providence and guidance through out this work. When it looked like nothing could work He gave me hope and encouragement and that is why I am still in the struggle for knowledge. Giving me the gift of life and good health to accomplish this task is a favour and not a right.

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TABLE OF CONTENTS Page

Declaration page ii
Abstract iii
Dedication iv
Acknowledgement v
Table of contents vi
List of tables viii
List of figures x
List of acronyms xiii

CHAPTER ONE: INTRODUCTION 1
1.1 Problem statement 2
1.2 Justification 2
1.3 Objectives 2
1.3.1 Broad objectives 3
1.3.2 Specific objectives 3
1.4 Hypotheses 3

CHAPTER TWO: LITERATURE REVIEW 4
2.1 Okra botany 4
2.2 Non-chemical postharvest treatments 5
2.2.1 Effect of storage temperature on produce quality 5
2.2.2 Decay and hot water treatment 8
2.2.3 Detrimental effects of hot water treatment 10
2.2.4 Modified atmosphere treatments 10

CHAPTER THREE: MATERIALS AND METHODS 15
3.1 Experimental materials 15
3.2 Postharvest treatments 16
3.2.1 Hot water dipping 16
3.2.2 Packaging 17
3.2.3 Storage temperature 17
3.3 Experimental design and layout 18
3.4 Variable assessment 19
3.5 Data analysis 20

CHAPTER FOUR: RESULTS AND ANALYSIS 21

CHAPTER FIVE: DISCUSSION 73
5.0 Senescence and shelflife 73
5.1 Hot water dipping 74
5.2 Storage temperature 75
5.3 Packaging 76
5.4 Hot water treatment and storage temperature 77
5.5 Hot water treatment and packaging 79

5.6 Storage temperature and packaging..... 79

CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS..... 81
REFERENCES..... 82
APPENDIX..... 87

LIST OF TABLES

Table 1	Layout of split split plot in a completely randomised design.....	9
Table 2	Layout of split split plot in a completely randomised design.....	87
Table 3	Effect of hot water dipping on okra weight loss after 21 days storage.....	24
Table 4	Effect of storage temperature on okra weight loss after 21days storage.....	24
Table 5	Effect of packaging on okra weight loss after 21 days storage.....	24
Table 6a	Interaction of hot water dipping, storage temperature and packaging on okra weight loss after 21 days storage.....	30
Table 6b	Interaction of hot water dipping, storage temperature and packaging on okra weight loss after 21 days storage.....	31
Table 7	Effect of hot water dipping on chilling injury after 21 days of storage.....	32
Table 8	Effect of storage temperature on chilling injury after 21 days storage.....	32
Table 9	Effect of packaging on chilling injury after 21 days storage.....	32
Table 10a	Interaction of hot water dipping, storage temperature and packaging on chilling injury of okra after 21 days storage.....	38
Table 10b	Interaction of hot water dipping, storage temperature and packaging on chilling injury of okra after 21 days storage.....	39
Table 11	Effect of hot water dipping on decay after 21 days storage.....	40
Table 12	Effect of storage temperature on decay after 21days storage.....	40
Table 13	Effect of packaging on decay after 21 days storage.....	40
Table 14a	Interaction of hot water dipping, storage temperature and packaging on decay of okra after 21 days storage.....	46
Table 14b	Interaction of hot water dipping, storage temperature and packaging on decay of okra after 21 days storage.....	47
Table 15	Effect of hot water dipping on electrolyte leakage after 21 days storage.....	48
Table 16	Effect of storage temperature on electrolyte leakage after 21days storage...	48
Table 17	Effect of packaging on electrolyte leakage after 21 days storage.....	48
Table 18a	Interaction of hot water dipping, storage temperature and packaging on electrolyte leakage of okra after 21 days storage.....	54
Table 18b	Interaction of hot water dipping, storage temperature and	

packaging on electrolyte leakage of okra after 21 days storage..... 55
Table 19 Effect of hot water dipping on off odour after 21 days storage..... 56
Table 20 Effect of storage temperature on off odour after 21 days storage..... 56
Table 21 Effect of packaging on off odour after 21 days storage..... 56
Table 22a Interaction of hot water dipping, storage temperature and packaging on off odour of okra after 21 days storage..... 61
Table 22b Interaction of hot water dipping, storage temperature and packaging on off odour of okra after 21 days storage..... 62
Table 23 Effect of hot water dipping on visual appearance after 21 days storage..... 63
Table 24 Effect of temperature on visual appearance after 21 days storage..... 63
Table 25 Effect of packaging on visual appearance after 21 days storage..... 63
Table 26a Interaction of hot water dipping, storage temperature and packaging on visual appearance of okra after 21 days storage..... 69
Table 26b Interaction of hot water dipping, storage temperature and packaging on visual appearance of okra after 21 days storage..... 70

LIST OF FIGURES

Figure 1a Interaction of hot water dipping and storage temperature on okra weight loss after 21days storage (Trial 1)..... 25

Figure 1b Interaction of hot water dipping and storage temperature on okra weight loss after 21days storage (Trial 2)..... 26

Figure 2a Interaction of hot water dipping and packaging on okra weight loss after 21days storage (Trial 1)..... 27

Figure 2b Interaction of hot water dipping and packaging on okra weight loss after 21days storage (Trial 2)..... 27

Figure 3a Interaction of storage temperature and packaging on okra weight loss after 21days storage (Trial 1)..... 28

Figure 3b Interaction of storage temperature and packaging on okra weight loss after 21days storage (Trial 2)..... 29

Figure 4a Interaction of hot water dipping and storage temperature on chilling injury of okra after 21days storage (Trial 1)..... 33

Figure 4b Interaction of hot water dipping and storage temperature on chilling injury of okra after 21days storage (Trial 2)..... 34

Figure 5a Interaction of hot water dipping and packaging on chilling injury of okra after 21days storage (Trial 1)..... 35

Figure 5b Interaction of hot water dipping and packaging on chilling injury of okra after 21days storage (Trial 2)..... 35

Figure 6a Interaction of storage temperature and packaging on chilling injury of okra after 21days storage (Trial 1)..... 36

Figure 6b Interaction of storage temperature and packaging on chilling injury of okra after 21days storage (Trial 2)..... 36

Figure 7a Interaction of hot water dipping and storage temperature on okra decay after 21days storage (Trial 1)..... 41

Figure 7b Interaction of hot water dipping and storage temperature on okra decay after 21days storage (Trial 2)..... 42

Figure 8a Interaction of hot water dipping and packaging on okra decay after 21days storage (Trial 1)..... 43

Figure 8b Interaction of hot water dipping and packaging on okra decay after 21days storage (Trial 2)..... 43
Figure 9a Interaction of storage temperature and packaging on okra decay after 21days storage (Trial 1)..... 44
Figure 9b Interaction of storage temperature and packaging on okra decay after 21days storage (Trial 2)..... 45
Figure 10a Interaction of hot water dipping and storage temperature on electrolyte leakage of okra after 21days storage (Trial 1)..... 49
Figure 10b Interaction of hot water dipping and storage temperature on electrolyte leakage of okra after 21days storage (Trial 2)..... 50
Figure 11a Interaction of hot water dipping and packaging on electrolyte leakage of okra after 21days storage (Trial 1)..... 51
Figure 11b Interaction of hot water dipping and packaging on electrolyte leakage of okra after 21days storage (Trial 2)..... 51
Figure 12a Interaction of storage temperature and packaging on electrolyte leakage of okra after 21days storage (Trial 1)..... 52
Figure 12b Interaction of storage temperature and packaging on electrolyte leakage of okra after 21days storage (Trial 2)..... 53
Figure 13a Interaction of hot water dipping and storage temperature on off odour of okra after 21days storage (Trial 1)..... 57
Figure 13b Interaction of hot water dipping and storage temperature on off odour of okra after 21days storage (Trial 2)..... 58
Figure 14a Interaction of hot water dipping and packaging on off odour of okra after 21days storage (Trial 1)..... 59
Figure 14 b Interaction of hot water dipping and packaging on off odour of okra after 21days storage (Trial 2)..... 59
Figure 15a Interaction of storage temperature and packaging on off odour of okra after 21days storage (Trial 1)..... 60
Figure 15b Interaction of storage temperature and packaging on off odour of okra after 21days storage (Trial 2)..... 60
Figure 16a Interaction of hot water dipping and storage temperature on

visual appearance of okra after 21days storage (Trial 1)..... 64
Figure 16b Interaction of hot water dipping and storage temperature on visual appearance of okra after 21days storage (Trial 2)..... 65
Figure 17a Interaction of hot water dipping and packaging on visual appearance of okra after 21days storage (Trial 1)..... 66
Figure 17 b Interaction of hot water dipping and packaging on visual appearance of okra after 21days storage (Trial 2)..... 66
Figure 18a Interaction of storage temperature and packaging on visual appearance of okra after 21days storage (Trial 1)..... 67
Figure 18b Interaction of storage temperature and packaging on visual appearance of okra after 21days storage (Trial 2)..... 68

LIST OF ACRONYMS

NHWD	No water dipping
RTWD	Room temperature water dipping for 10 minutes
40HWD	40°C hot water dipping for 7 minutes
50HWD	50°C hot water dipping for 1 minute
FP	Free pod packaging
P	Perforated packaging
NP	Non perforated packaging
DMRT	Duncan's multiple range test

CHAPTER ONE

INTRODUCTION

Okra (*Abelmoschus esculentus* L.Moench) is widely grown as an Asian vegetable and is believed to have originated from Ethiopia. It is popular worldwide (FAO, 2001) and has increasingly become an important vegetable in Kenya, mainly as an export crop to the European Union (HCDA, 2002).

Fresh okra is a popular ingredient for soups and stews where a highly viscous consistency is desired (Baxter and Waters, 1990). The pods and leaves are rich in proteins, vitamins A and C and have traces of vitamins B and minerals (Calcium, Phosphorus and Iron). Mature seeds, which contain 20% edible oil, are eaten as snacks after roasting and can be used in the manufacture of margarine. Okra seed flour is used as an additive to maize flour in Egypt (Wahiu and Pandey, 1993). Plant mucilage is also used for industrial purposes. Okra is also processed (frozen or canned). The tender pods facilitate urination. Leaves relieve headaches and can be used for massaging aching muscles (KARI, 1999).

Okra pods are harvested as immature tender fruits, when they are rapidly growing. The pods have very high respiration rate and need to be used almost immediately. Under room conditions and without any care, the pods deteriorate within two days after harvest (Duzyaman, 1997). Temperature has significant effect on pod quality more than other environmental factors. If stored at higher temperatures, the pods lose quality very rapidly due to their high respiration rates by yellowing, decaying and toughening (Salunkhe and Desai, 1984).

World production of okra is estimated to be 5 to 6 million tons per year (KARI, 1999). In Kenya, exports between 1996 to 2000 were: 1996-1,898, 1997-2,048, 1998-2,640, 1999-2,145 and 2000-2,603 tonnes (HCDA, 2002). Okra grows easily and is adapted to high temperatures and low rainfall regions (Wahiu and Pandey, 1993). In Kenya, production is mainly at the Coast, Western and Kibwezi. With improved postharvest methods production could extend to other dry regions thus improving food security.

1.1 Problem statement

Okra pods are highly perishable and lose quality within a very short time at room conditions and therefore cannot be marketed for extended periods of time. Furthermore, okra develops chilling injury at low temperatures. Pods are susceptible to damage by decay microorganisms. There is little knowledge available on storage especially under rural farming conditions where modern storage facilities are not readily available.

1.2 Justification

Most farmers in Kenya incur heavy losses from okra farming especially during periods of market glut because of short shelf life and inappropriate storage management practices. This has lead to a decline in okra exportation over the years ***2000***-*2,603,474Kg*, ***2001***-*2,281,137Kg*, ***2002***-*2,382,309Kg*, ***2003***-*1,840,894*, ***2004***-*1,710,565,Kg*, ***2005***-*1,542,017Kg*. This decline is worrying as okra is nutritious and can provide food in marginal areas. Extending the shelf life of okra pods using hot water dips, modified atmosphere storage and low temperature storage can reduce postharvest losses and thereby prolong the marketing period. Improved storage will provide an alternative to chemical treatments, which are harmful and are being shunned by consumers. Use of methods like hot water dipping, modified atmosphere and low temperature storage are safe and were evaluated on okra. These treatment methods have shown success in extending storage of other fresh produce. Improved storage will improve food security, ensure more income to the farmers, better living standards and provide employment. It will also expand the production potential in Kenya since presently production is only in limited areas.

1.3 Objectives

1.3.1 Broad Objective

The broad objective of this study was to develop a postharvest technology that will improve the postharvest performance of okra.

1.3.2 Specific objectives

The specific objectives were to investigate the effects of:

1. Hot water dipping on the postharvest performance of okra.
2. Modified atmosphere storage on the postharvest performance of okra.
3. Storage temperature on the postharvest performance of okra.
4. Interactive effects of hot water dipping, modified atmosphere and storage temperatures on the postharvest performance of okra.

1.4 Hypotheses

1. Hot water dipping improves the postharvest performance of okra.
2. Modified atmosphere storage improves the postharvest performance of okra.
3. Storage temperature improves the postharvest performance of okra.
4. Interactive effects of hot water dipping, modified atmosphere and storage temperature improves the postharvest performance of okra.

CHAPTER TWO
LITERATURE REVIEW

2.1 Okra Botany

Okra is a warm-season annual dicotyledonous plant that may grow to a height of 1 m to 2 m. Okra belongs to the family *Malvaceae*, which also includes cotton and hibiscus. The stem is green in colour and has many short branches. The leaves are green, large, broad, palmate (heart-shaped), lobed and alternately arranged on the stem. Petiole is green or reddish in colour depending on the cultivar (Floridata, 2003).

Flowers are large and showy with five yellow petals, perfect and self-fertile. One flower appears in each alternating leaf axil after the 6-8 th node. Flowers open once for only a short period during the day. In the field, flowers are mostly cross-pollinated, but can be self-pollinated without reduction in yield (KARI, 1999).

The fruit is a long pod comprising several fused carpels. The developing pod and immature seeds are the edible portions. Earlier cultivars had prickly hairs on the pod, forcing workers to wear gloves. Breeders have eliminated this annoying characteristic from modern, commercial cultivars such as 'Clemson spineless'. A new cultivar, 'Clemson Spineless 80', is more uniform, early maturing, and higher yielding. The latter has replaced the original cultivar for much of the fresh market and processing uses (Peet, 2001).

Once flowering has begun, a pod will develop in the axil of every subsequent leaf. Fruit will set with either cross or self-pollination such that no special provision needs to be made for pollination. Pod colour can range from bright red to green, gold, or creams. Some cultivars, such as 'Lee' have a single main stem, making them easier to pick (Kemble, *et al.*, 1995). External pod colours range from white through pale to dark green. Cultivars with red pod colouration include 'Red Okra', 'Red Velvet' and 'Burgundy'. Pods of some cultivars such as 'Green Emerald' are of satisfactory quality even when as long as 15-20 cm in length and 2-3 cm in diameter. For optimum quality, pods are harvested when much smaller, about 8-15 cm by 1-2 cm (Veg. Home, 2002).

Most commercially grown cultivars are green, ridged and spineless. The common cultivar in Kenya is 'Pusa Sawani', which has long dark green fruits, smooth and with five ridges (HCDA, 1996). This cultivar is high yielding, tolerant to vein mosaic virus

disease and can be grown all year round (Fatokun and Chheda, 1983; HCDA, 1996). Other cultivars include 'Green Emerald' (with 20 cm pods that are slightly tapered, smooth and dark green) and 'Dwarf Long Pod Green' (pods measuring 18 to 20 cm long slightly ridged and green). In addition, 'White Velvet' with pods that are 15-18 cm long, slender, tapered, smooth and creamy white (Colditz, *et al.*, 1999) is also popular in Kenya. Okra has a taproot, which can grow to a depth of 60-120 cm with lateral root system (Peet, 2001).

2.2 Non-chemical postharvest treatments

Chlorine is normally added to washing water to disinfect the produce against decay-causing microorganisms. However, chlorine has an unpleasant smell and is easily vaporized. The use of chemicals in food is discouraged due to consumer concern on the dangers of chemicals to health and the development of pathogen resistance to chemicals (Salunkhe and Desai, 1984).

The use of non-chemical (hot water, vapour heat, forced hot air) methods in controlling postharvest pathogens is therefore widely recommended (Bauchmann and Earles, 2000). These include treatments to manipulate the environment, for example, cooling, packaging, control of air movement and circulation by ventilation, exclusion or removal of ethylene, controlled or modified atmospheres (CA or MA), and sanitation (Wills, *et al.*, 1998).

2.2.1 Effects of Storage Temperature on Fresh Produce Quality

Temperature is a major environmental factor that influences the deterioration rate of harvested commodities. For example, for each $10^{o}C$ rise in temperature above optimum, the rate of deterioration increases by two to threefold (Thompson, 1996). Exposure of okra to undesirable temperatures results in development of many physiological disorders. Heat injury is induced by exposure to direct sunlight or excessively high temperatures. The symptoms of heat damage include bleaching, surface burning or scalding, shrivelling, excessive softening and desiccation (Cantwell and Trevor, 2002).

Okra storage at room temperatures results in loss of pod quality within two days. Temperature also influences the effect of ethylene, reduces oxygen, and elevates carbon

dioxide levels; affect pathogen spore germination and growth rate. For instance, cooling commodities below 5°C immediately after harvest can greatly reduce the incidence of *Rhizopus* rot (Brackett, 1993). Okra is rapidly chill damaged when stored at temperatures less than 7°C for an extended period (Perkin-Veazie and Collins, 1992). The symptoms of chilling injury, which are mainly physiological disorders, become more noticeable upon transfer to higher (non-chilling) temperatures. Common symptoms include surface and internal discoloration (browning), pitting, water soaked areas, off-flavour development, and accelerated incidence of surface moulds and decay especially organisms not usually found growing on healthy tissue (Mitchel and Kader, 1992). Highly, moderately and non-chilling sensitive fresh vegetables are generally held at 10-13°C, 2 -7°C and 0 -2°C, respectively (Salunkhe and Desai, 1984).

As storage temperature decreases and approaches the freezing point, enzymatic reactions slow down including those responsible for respiration and senescence. Low temperatures also slow down the proliferation and activities of decay microorganisms (Shewfelt, 1993b). Calcium dips and modified atmospheres have been reported to reduce chilling injury symptoms (Klein and Lurie, 1992; Garcia, *et al*, 1996).

Chilling injury occurs in okra at temperatures of -1.8°C or below (Penelope, 1997). Chilling injury is a physical damage, which results when commodities are held below their freezing temperatures and okra is very susceptible to freezing temperatures. The disruption caused by chilling usually results in immediate collapse of the tissues and total loss (Gasti, *et al.*, 1997).

The rate of water loss from fruits and vegetables including okra depends upon the vapour pressure deficit between the commodity and the surrounding air conditions, which is influenced by temperature and relative humidity. At a given temperature and rate of air movement, the rate of water loss from the commodity depends on the relative humidity. At a given relative humidity, water loss increases with the increase in temperature (Shewfelt, 1993 a).

Water loss is the main cause of fresh produce deterioration because it results in direct quantitative losses (weight loss). Water loss also causes losses in appearance (wilting and shrivelling), textural quality (softening, flaccidity, limpness, loss of crispness and juiciness), and nutritional quality (Thompson, 1996).

The dermal system (outer protective coverings) controls water loss from the inside of the commodity. The dermal system includes the cuticle, epidermal cells, stomata, lenticels, and trichomes (hairs). The cuticle is composed of surface waxes, cutin embedded in wax, and a layer of mixtures of cutin, wax, and carbohydrate polymers. The thickness, structure, and chemical composition of the cuticle vary greatly among commodities and among developmental stages of a given commodity (Elsayed and Kardeel, 2000).

Transpiration rate is influenced by internal commodity factors (morphological and anatomical characteristics, surface area-to-volume ratios, surface injuries, and maturity stage) and external or environmental factors (temperature, relative humidity, air movement, and atmospheric pressure) (Crisosto, 1993). Transpiration (evaporation of water from the plant tissues) is a physical process that can be controlled by applying treatments to the commodity. Treatments to overcome these factors may include waxes and other surface coatings and wrapping with plastic films, or manipulating the environment such as maintenance of high relative humidity and control of air circulation (Sargent, *et al.*, 2000).

The objective of vegetable storage is to delay senescence so as to optimise marketing without loss of quality. Temperature management is the most effective tool for extending the shelf life of fresh horticultural produce. Temperature management begins with the rapid removal of field heat (precooling). In essence, successful storage depends on efficient control of temperature and humidity. Nature of produce determines the length of time as well as the temperature at which it can be stored (Kasmire, 1993).

To date refrigeration is the only known technology that is economically feasible for short-term storage of fresh vegetables. All other methods of regulating postharvest deterioration are at best only supplementary to low temperature. Other methods of quality maintenance will not work satisfactorily without refrigeration (Heyes and Bycroft, 2002). Storage temperature and humidity are most important as they influence the senescent phases of fresh vegetables by regulating the rate of all associated physiological and biochemical processes (Salunkhe and Desai, 1984).

Certain fungi and bacteria in their germination phase are susceptible to low temperatures and holding the produce for a few days at cold temperatures kills or

inactivates them hence the commodity can withstand longer storage without incurring damage and can reduce their infections. *Rhizopus stolonifer* and *Aspergillus niger* (black mould) can be killed when germinating by two or more days at 0°C (Sommer, 1992).

2.2.2 Postharvest decay and hot water treatment

One of the most common and obvious symptoms of deterioration results from the activity of fungi including grey moulds (*Botrytis cinerea),* mildew, yeast, *Rhizophus stolonifer, Rhizoctonia solani, Geotrichum* and bacteria such as *Pseudomonas syringae, Erwinia carotovora* among other pathogens (Snowdown, 1992). Attacks by most organisms follow stresses from sunscald, physical injury or physiological disorders that lowers resistance of the commodity (Wills, *et al.*, 1998). In a few cases, pathogens can infect apparently healthy tissues and become the primary cause of deterioration. In general, fruits and vegetables exhibit considerable resistance to potential pathogens during most of their postharvest life. However, the onset of senescence in all commodities renders them susceptible to infection by pathogens (Bauchmann and Earles, 2000).

Decay due to fungal pathogens (*Alternaria. spp*) is a common problem in okra pods (Baxter and Waters, 1990). Chilling injury also enhances rots in okra. Okra is often washed with water to improve appearance and freshness by removing chemical residues, dirt and soil (Mayberry, 1995).

The first line of defence against disease is good management during production followed by careful harvesting and preparation for market in the field. Sorting out damaged or decaying produce will also limit contamination of the remaining healthy produce (Sargent, *et al.*, 2000). Yet, even when the greatest care is taken, sometimes produce must be treated to control decay-causing organisms (Gasti *et a.l.*, 1997).

Washing vegetable and fruit produce with chlorinated water can prevent decay caused by bacteria, mould and yeasts on the surface of produce. Calcium hypochlorite (powder with 50-70 ppm available chlorine) and Sodium hypochlorite (25 ppm liquid) are inexpensive and widely available (Heyes and Bycroft, 2002). The produce is then rinsed with clean water. However, the effectiveness of the chlorinated water will be decreased if organic matter is allowed to build up in the wash water. In addition, the

effectiveness of chlorine increases as pH is reduced from pH 11 to pH 8, but at very low pH, chlorine becomes unstable (Ogawa and Manji, 1984). In addition, consumers are concerned about the dangers of chemicals in food (Wills *et al.*, 1998).

Postharvest heat treatments of fruits and vegetables for disease control have been used for many years (Paul and Chen, 1990). Heat has been applied to fruits and vegetables as hot water dips, vapour heat, or hot dry air (Fallik, *et al.*, 1996). Pre-storage heating of fruit is known to prevent the development of pathological (decay) and physiological disorders such as chilling injury (Lurie and Klein, 1992) of fruits and vegetables and thereby extends their shelf life (Klein and Lurie, 1990; Garcia, *et al.*, 1996; Mclauchlan, *et al.*, 1997; Schirra, *et al.*, 1997).

High temperatures have either lethal or sub-lethal effects on fungal spores and growth (Fallik, *et al.*, 2000). However, there is considerable variation in sensitivity to high temperatures among various fungi and their development phases (Civello, *et al.*, 1997).

Heat treatments at 38-42°C induce production of heat shock proteins that confer protection against high temperature injury (thermotolerance). However, the mechanism of protection is not well understood (Paull and Chen, 1990; Klein and Lurie, 1992; Shewfelt, 1993a; Civello, *et al.*, 1997). In addition, the effect of heat shock proteins in the postharvest performance of okra is not clear. Amongst the methods of heat treatments, vapour heat and forced hot air treatments require high initial capital investment and therefore not affordable for many farmers unlike hot water which is cheap to use (Klein and Lurie, 1992). Other added benefits of hot water include removal of soil, dust, dirt and fungal spores from the produce surface and partially or entirely sealed natural openings in the epidermis (Paull and Chen, 1990). Hot water treatment (50-55°C for 3-5 minutes) is known to control decay attributed to fungi such as grey and black moulds caused by *Botrytis cinerea* and *Alternaria alternata*, respectively in many fresh fruits and vegetables (Fallik, *et al.*, 1996). Whenever heat is used on fresh produce, cool water mists or forced cold air should be provided to help return the fruits to their optimum temperature as soon as possible after completion of the treatment (Heyes and Bycroft, 2002).

2.2.3 Detrimental Effects of Hot Water Treatment

Although prestorage heat treatments are a promising alternative to chemical treatments, several aspects of the technique require continued research. Fine-tuning heating regime is necessary. For example avocados respond well to 36°C but at 38°C develop heat injury, typified by skin scald, surface pitting, flesh browning and sometimes a failure to ripen normally (Klein and Lurie, 1992).

Hot water treatments have to be used with a lot of precaution since if not assessed well to get correct temperature and time duration it can cause enough injury to rule out its use on most products (Mitchel and Kader, 1992). In broccoli, hot water treatment at 52°C for 3 minutes enhanced off odours and caused visual damage to flower buds (Forney and Jordan, 1998).

Jacobi *et al*, (1996) found that hot air treatment alone and storage at 22°C caused fruit injury in the form of skin browning and lenticel spotting as it was too stressful reducing fruit quality at market destination. Also, mangoes subjected to 46.5°C for 90 or 120 minutes followed by storage at 13°C showed severe browning of pulp adjacent to the seed and extensive darkening of lenticels at the end of 10 days storage (Nyanjage, *et al.*, 1999).

2.3 Modified atmosphere treatments

The terms controlled and modified atmosphere storage (CA and MA) implies addition or removal of gases resulting in an atmospheric composition different from that of normal air. Thus, the levels of carbon dioxide, oxygen, nitrogen and ethylene in the atmosphere may be manipulated. Controlled atmosphere storage generally refers to decreased oxygen and increased carbon dioxide concentration and implies precise control of these gases. Modified atmosphere storage is used when the composition of the storage atmosphere is not closely controlled (Wills, *et al.*, 1998). The effect of this method depends on the physiological activity of the product and the characteristics of the physical environment such as composition of the gas atmosphere, temperature and relative humidity (Gorris and Peppelenbos, 1992). This is generally used as an adjunct to low temperature storage but can be successfully used to substitute refrigeration for some commodities (Kader, *et al*, 1989).

Reduction of oxygen and elevation of carbon dioxide, whether intentional (modified or controlled atmosphere storage) or unintentional (restricted ventilation within a shipping container and/or a transport vehicle), can either delay or accelerate deterioration of fresh horticultural crops. The magnitude of these effects depends upon produce, cultivar, physiological age, oxygen (O_2) and carbon dioxide (CO_2) level, temperature, and duration of storage (Kader, *et al.*, 1989).

Respiration involves the consumption of carbohydrates and organic acids using atmospheric oxygen (O_2), and the consequent production of metabolic energy, heat, carbon dioxide (CO_2) and water vapour. Different species, varieties or cultivars of fruits and vegetables vary in their respiration rates (Gorris and Peppelenbos, 1992). Those that have high respiration rates such as okra tend to be most perishable while those with low respiration rates such as onions and potatoes tend to be least perishable (Sargent, *et al.*, 2000).

Okra is not stored in modified atmosphere storage commercially. At recommended storage temperatures, CO_2 concentrations of 4-10% can help maintain green colour and reduce discoloration and decay on damaged pods. Carbon dioxide concentrations higher than 10% can lead to development of off flavours. Low oxygen concentrations (3-5%) beneficially reduce respiration rates and thereby maintain quality of the produce (Wills, *et al.*, 1998).

Weight loss is very high in immature okra pods hence high relative humidity (95-100%) is needed to reduce dehydration, pod toughening and loss of fresh appearance. Modified atmosphere, a technique of sealing actively respiring produce in polymeric film packages to modify oxygen and carbon dioxide concentrations within the package atmosphere improve moisture retention, influence metabolism and activities of decay-causing microorganisms. The technique also reduces browning of damaged surfaces of produce thus increasing storability of a wide range of fresh produce. Due to high respiration rate, okra pods bleach and may develop off-flavours when stored in poorly ventilated containers for prolonged periods (over 24 hours). Due to excessive heating (heat of respiration), and high relative humidity (condensation) this promotes decay (Medlicott, 1990). In addition, temperature inside the package affects storability by influencing the film permeability and hence composition of O_2 and CO_2. Nevertheless,

cool chain handling of okra still remains the most appropriate method of extending its post harvest life. Modified environment may thus positively complement the influence of temperature in improving the postharvest performance of okra by changing the atmospheric gas composition (Cantwell and Trevor, 2002).

The effects of modified atmosphere (MA) are based on the often observed slowing of plant respiration in low O_2 environments (Pretel, *et al.*, 2000). There is about 21% O_2 in normal atmospheric air. As the concentration of O_2 inside the package falls to less than 10%, respiration rates begin to slow down. This suppression of respiration continues until O_2 reaches about 2-4% for most produce. If O_2 gets lower than 0.2% (depending on produce and temperature), fermentative metabolism replaces normal aerobic metabolism and off-flavours, off-odours and undesirable volatiles are produced (Thompson, 1996). Similarly, as CO_2 increases above the 0.03% found in air, respiration rates of some commodities are suppressed (Shewfelt, 1993b). In addition, elevated CO_2 suppresses plant tissue sensitivity to ethylene (Lopez *et al.*, 1998). For those products that tolerate high concentrations of CO_2, suppression of the growth of many bacteria and fungi results at greater than 10% CO_2 (Brackett, 1993).

The goal of modified atmosphere (MA) on fresh produce is to create an optimum package atmosphere with non-injurious levels of O_2 (low) and CO_2 (high) (Gorris and Peppelenbos, 1992). This is accomplished through the proper balance of several variables that affect package atmosphere. Controlled atmosphere storage is usually beneficial to okra pods at 7°C – 10°C with 95-100% relative humidity. However, the potential benefits of MA in okra are not well understood (Saltveit, 1997).

For commodities that tolerate high CO_2 levels, 15 to 20% CO_2-enriched air can be used as a fungicide to control decay-causing pathogens, such as *Botrytis cinerea* on strawberry, blueberry, blackberry, fresh fig and table grapes during transport. In modified atmosphere storage, antioxidant activity (flavinoids and vitamin C) decreases in spinach. Boiling the spinach after storage extracted 50% of total flavinoids and 60% vitamin C in the cooking water. The vitamin C content of the cooked tissue was higher in those samples stored in modified atmosphere packaging (How, 1993; Gill, *et al.*, 1997).

Serrano *et al.* (1997) found that modified atmosphere minimizes increases in putrescine and abscisic acid (ABA) levels caused by chilling injury in pepper fruit.

Chilling injury was reduced in mature green fruits stored at 2°C with modified atmosphere packaging, which led to less pronounced increases in amino-1-cyclopropane carboxylic acid (ACC), putrescine and ABA levels as compared to fruits stored without polypropylene films. Modified atmosphere storage is suitable for tropical and sub-tropical fruits and vegetables that are sensitive to chilling (Kader *et al.*, 1989).

There has emerged an increased appreciation that packaging can only deliver its promised benefits to fresh produce within a specific temperature range. In addition, an emphasis on shelf life extension has shifted to an emphasis on reduced chemical use (How,1993). As the marketplace for fresh-cut products becomes more competitive, quality sells more than shelf life (Cook, 1992). This has resulted in increased attention to maintaining low temperatures and rapid distribution. Such changes in perspective have helped realize the benefits that modern packaging films can provide (Thompson, 1996).

Modified atmosphere storage (MA) of fresh produce has posed difficult challenges for a packaging industry accustomed to barrier packaging designed to exclude atmospheric oxygen. Because fresh fruits and vegetables are still living, and still require oxygen for their metabolism, barrier flexible packaging has not been appropriate in most cases. Instead, packages whose gas transmission properties are precisely matched to the gas requirements of the product have become the norm (Pretel, *et al.*, 2000). Proper management of the raw materials prior to packaging and of the package during distribution and marketing are essential if the package is to deliver the desired value.
These two factors work in concert to maintain freshness, extend shelf life, ensure safety and promote sale. Neither low temperature nor MA can act alone to deliver full value to the customer packaging (Fernandez and Artes, 1997). The reason for this is that both treatments work together to slow the metabolism and aging of the product so that it stays fresher longer.

While high humidity in the storage environment is important for maintenance of high quality produce, free water on the surface of commodities common in modified atmosphere packaging can enhance germination and penetration by pathogens (Wills, *et al.*, 1998). When cold commodities are removed from storage and left at higher room temperatures, moisture from the surrounding warm air condenses on the colder product's surfaces (Sommer, 1992). A temporary increase in ventilation rate using a fan or

increasing exposure of the commodity to drier air can help to evaporate the condensed moisture and to reduce the chances of infection.

Poor postharvest handling of produce from the farm throughout the marketing chain results in huge losses due to mechanical damage and disease infection. However farmers can be trained to improve the quality of produce by adopting modern technologies in postharvest handling.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Experimental Material

The okra crop was grown at Egerton University, Tatoon Farm (Horticulture Research and Teaching Field), Kenya. The farm lies at a latitude of approximately 0°23' South, Longitude of 35°C 35' east and altitude of 2200 m above sea level. The mean temperature, humidity, evaporation rate and rainfall over a ten year period (1991-2000) are about 19.7°C, 62.5%, 3.9 mm/day and 907 mm/year, respectively (Egerton University Meteorological Station, 2000). The soil pH (H_2O) and (0.01M $CaCl_2$) at 0-30 cm depth is 6.3 and 5.4, respectively. The soils are Vintric Mollic Andosols. The postharvest experiment was conducted at the Department of Horticulture Laboratory.

3.2 Site preparation and crop management

3.2.1 Land Preparation: The area was ploughed and tilled and beds measuring 1.2 m wide and 20-30 cm high made. Drip irrigation tubes and polyethylene mulch were laid on the beds prior to planting and holes made on the mulching material according to plant spacing (Kemble, *et al.*, 1995)

3.2.2 Sowing: About 2 kg of seed ('Pusa Sawani') was used for planting the experiment plots. For maximum germination, seeds were soaked overnight and then only the swollen ones were planted at 1-3 cm deep (Jambhale and Nerker, 1990). Emergence took 7 days in optimal conditions, but can be delayed for up to 21 days by lower temperatures (Duzyaman, 1997).

3.2.3. Fertilization: At planting, about 120 kg NPK/ha (2gms/plant) was applied. Topdressings of CAN at 70 kg N/ha (68 gms/plant) was done when plants were 15 to 20 cm in height and again 2 to 3 weeks later (HCDA, 1996).

3.2.4 Mulching and Drip Irrigation: Okra is tolerant to water stress but yields will be reduced, particularly if stress occurs during flowering or pod filling stages (Duzyaman, 1997). Adequate water was therefore provided everyday for 4 hours throughout the cropping period in addition to the use of polyethylene mulch.

3.2.5 Pests and Diseases: Most common pests encountered were aphids and ants. These were scouted and controlled using endosulfan (Duzyaman, 1997) and other

recommended insecticides. Diseased plants were destroyed to prevent spreading. Diseases such as powdery mildew and leaf spot were sprayed with fungicides (HCDA, 1996).

3.2.6 Harvesting: Harvesting commenced within 10 weeks of planting, 4-7 days after the flower had opened. Well formed, straight, tender pods with a fresh appearance and a colour typical of the cultivar (generally bright green) and free of defects were harvested with at least 1cm long stalk. The okra was free from defects such as leaves, stems, broken pods, insect damage, and mechanical injury. The pods were handled carefully to prevent physical damage such as surface friction, impact and vibration bruising (Medlicott, 1990).

Rubber gloves were used to reduce skin irritations as okra was harvested manually. Hand removal of pods was difficult and hence the use of a sharp knife was necessary to avoid damaging the plant. Harvesting was carried out after every 2-3 days because pods developed rapidly. Non-harvested pods inhibit fruit set and development of pods higher on the plant and hence had to be removed regularly. Harvested pods were then put in plastic crates and immediately transferred to a cool room to dissipate field heat. Pods 5-8 cm in length, which are preferred by consumers, were used for the experiment. Pods were further sorted to select only those with good appearance (green, fresh, firm, tender tips and free from debris, no dark discoloration, chemical residue, disease, bird or insect damage), without seeds protruding through the skin (Perkins-Veazie and Collins, 1992).

3.3 Postharvest Treatments

The harvested and selected okra pods were subjected to hot water dipping treatments then packed into different packages and finally stored under different temperatures.

3.3.1 Hot Water Dipping

Three levels of water temperatures were used as hot water treatments at 50°C for one minute, 40°C for seven minutes and water at room temperature for 10 minutes (blank). Non-dipping was used as a control. Water temperatures were maintained with the help of two 30 litre insulated thermostatically controlled water bath filled with water

three quarter full (Fallik, *et al.*, 1996) for the required time. The treated pods were then placed on clean serviettes to air dry.

33.2 Packaging

Three levels of packaging were used consisting of perforated (punched) polyfilm bags, non-perforated polyfilm bags (0.03mm thickness) and non-packaged to modifying the storage atmosphere. Pods weighing 100g were put in the various packages and the non-packaged pods were placed on flat cartons (Wills et al., 1998).

3.3.3 Storage Temperature

Four levels of storage temperature, 4°C, 8.5°C, 13°C and room temperature storage were used for storing okra pods (Salunkhe and Desai, 1984). The temperatures of 4°C, 8.5°C and 13°C were attained in refrigerators while room temperatures were obtained by placing the pods on tables in the open. A summary of treatments is given in Table 1.

3.4 Experimental Design and Layout

The experimental design had - hot water treatment (4) storage temperature (4) packaging (3), replicated six times in a split split plot completely randomised design (SSPCRD). Hot water treatment being the main plot factor, storage temperature subplots factor and packaging as the sub-subplot factor. The pods were stored for a maximum period of three weeks (21 days). The experiment was repeated twice. The first trial ran from November 25th –December 15th and second trial from December 26th – January 15th. The statistical model and design layouts are shown.

Statistical model

Equation 1: $Y_{ijkl}=U+A_i+ E_i+B_j+AB_{ij}+E_{ij}+C_k+(AC)_{ik}+(BC)_{jk}+(ABC)_{ijk}+e_{ijk}$ **U**-Overall Mean, A_i- Hot Water Effect, E_i-Main Plot Error, B_j-Storage Temperature Effect, AB_{ij}-Interaction of Hot Water and Low Temperature Effect, E_{ij}-Low Temperature Effect, C_k-Packaging Effect (Sub Sub Plot), **AC**-Interaction of Hot Water and Packaging, **BC**-Interaction of Storage Temp and Packaging, **ABC**-Interaction of Hot Water, Low Temp and Packaging, e_{ijk}-Residual Effect Error

Table 1: Layout of split split plot in a completely randomised design

Hot water treatments	Storage temperature	Packaging
No water dipping (NHWD)	4 °C	FP
		P
		NP
	8.5 °C	FP
		P
		NP
	13 °C	FP
		P
		NP
	Room temperature (15-20°C)	FP
		P
		NP
Room temperature water dipping for10 minutes (RTWD)	4 °C	FP
		P
		NP
	8.5 °C	FP
		P
		NP
	13 °C	FP
		P
		NP
	Room temperature (15-20°C)	FP
		P
		NP
40 °C Hot Water Dipping for 7 minutes (40HWD)	4 °C	FP
		P
		NP
	8.5 °C	FP
		P
		NP
	13 °C	FP
		P
		NP
	Room temperature (15-20°C)	FP
		P
		NP
50 °C Hot Water Dipping for 1 minute (50HWD)	4 °C	FP
		P
		NP
	8.5 °C	FP
		P
		NP
	13 °C	FP
		P
		NP
	Room temperature (15-20°C)	FP
		P
		NP

Key

NP - Non-perforated polythene bag package
P - Perforated polythene bag package
FP -Free pods (Not packaged)

NHWD - No water dipping
RTWD - Room temperature water dipping
40HWD - 40°C hot water dipping
50HWD - 50°C hot water dipping

3.5 Variable Assessments

The variables described below were assessed first when the non-hot water treated and non-packaged pods stored at open room environment show signs of wilting or shrivelling. The assessment of weight loss and visual appearance were carried out on the 3rd day (excellent), 7th day (relatively good), 14th day (maximum) and 21st day (not published) of storage (Duzyaman, 1997).

3.5.1 Weight Loss

Weight of pods per bag were determined using an electric weighing balance and weight loss calculated as a percentage of the original weight at the start of the experiment. Weight loss = (weight of pods per bag / initial weight of pods) x100%.

3.5.2 Visual Appearance

Change from green skin colour of individual pods was evaluated using a hedonic scale as follows: 7 excellent (bright green), 5 – good (dull green), 3 – acceptable (yellowing) and 1 - not acceptable (dark). Loss in visual appearance was calculated per package.

3.5.3 Incidence of Decay

Incidence of decay was calculated as a percentage of the number of pods showing symptoms of decay to the total number of pods per bag at the end of 21 days. Incidence of decay = (No. of decayed pods per bag /No. of pods in a package) 100%.

3.5.4 Incidence of Chilling Injury

Incidence of chilling injury was determined at the end of 21 days and after exposing the produce to room conditions for the symptoms (discoloration, pitting, water-soaked lesions and increased decay) to be expressed. Incidence of chilling injury was calculated by counting the number of pods with symptoms as a percentage of the total number of pods per bag. Incidence of chilling injury = (No. of chilled pods per bag /No. of pods in a package) 100%.

3.5.5 Off odour

Off odour was evaluated using a hedonic scale of 7-Excellent, 5-good, 3-acceptable, and 1-not acceptable. Then percentage average divided by 7 and calculated per package. Off odour = (No of packages in scale /No of total packages) 100%.

3.5.6 Electrolyte Leakage

Electrolyte leakage was determined by rinsing cut pieces of okra with water. These pieces of 5 gm were then soaked in water for 15 minutes and the electroconductivity of the water taken using a Hanna electroconductivity meter to test for electron leakage.

3.6 Data Analysis

Data collected was subjected to analysis of variance (ANOVA) at $p \leq 0.05$ using Gen start (version 9) computer statistical software packages and the means separated by Duncan Multiple Range Test (DMRT).

CHAPTER FOUR

RESULTS

At the start of the experiment, pilot tests were done to establish the most feasible hot water treatment. One of the temperatures tested was 55°C for five minutes; it was severe on the pods and caused pod surface browning and disintegration on the third day. The second was 50°C for three minutes that was less severe but caused slight browning and surface disintegration in the non perforated packaged okra pods. The third and fourth temperatures were 40°C for 7 minutes and 50°C for 1 minute both of which did not damage the okra pods and hence were used for experimentation.

Effects of hot water dipping, storage temperature and packaging on weight loss

In both trials hot water dipping at 50°C for one minute suppressed weight loss most by 4% compared to the other treatments that were not significantly different. In trial 2, hot water dipping at 40°C for 7 minutes was not significantly different to dipping at 50°C for one minute but was significantly different from the other treatments. Highest weight loss was with pods stored at room temperature water dipping in both trials (Table 3).

Increase in storage temperature significantly increased weight loss in both trials. The lowest weight loss was storage temperature at 4°C followed by 8.5°C, 13°C and the highest at room temperature storage. At room temperature and 13°C storage temperature the weight loss was not significantly different in trial 2. In trial 1, 13°C storage temperature had a higher weight loss than at room temperature storage. Least weight loss was at 4°C storage temperature that was 15% lower than highest weight loss (Table 4).

Least weight loss of 0-6% was in non perforated packaging followed by perforated packaging with 7-35% while the highest weight loss was in free pod packaging at 50 – 80% of the original weight rendering the pods unsuitable for marketing as they were dried and shrivelled in both trials (Table 5).

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Table 3: Effect of hot water dipping on okra weight loss after 21 days of storage

Hot water treatment	Weight loss (%)	
	Trial 1	Trial 2
No water dipping	32.8 a*	33.6 ab*
Room temperature dipping	33.0 a	35.1 a
40°C for 7 minutes	34.3 a	31.9 bc
50°C for 1 minute	30.9 b	31.1 c

*Means followed by the same suffix are not significantly different in columns at DMRT $P \leq 0.05$

Table 4: Effect of storage temperature on okra weight loss after 21 days of storage

Storage temperature	Weight loss (%)	
	Trial 1	Trial 2
4°C	23.0 c*	22.5 c*
8.5°C	34.6 b	33.0 b
13°C	37.7 a	38.1 a
Room storage temperature	35.7 b	38.2 a

*Means followed by the same suffix are not significantly different in columns at DMRT $P \leq 0.05$

*Room temperature varied between 15-20°C

Table 5: Effect of packaging on okra weight loss after 21 days of storage

Packaging	Weight loss (%)	
	Trial 1	Trial 2
Free pod packaging	70.7 a*	71.7 a*
Perforated packaging	24.0 b	22.8 b
Non perforated packaging	3.5 c	4.4 c

*Means followed by the same suffix are not significantly different in columns at DMRT $P \leq 0.05$

Effects of hot water dipping and storage temperature on weight loss

At 4°C storage temperature weight loss was suppressed at all hot water treatments. At 50°C hot water dipping, weight loss was suppressed but only significantly in the room temperature storage. Highest weight loss was at 13°C and room temperature storage at all hot water treatments, but the differences were not significant (Figure 1a). At the storage temperature of 4°C, hot water dipping at 50°C significantly reduced weight loss compared to the other hot water treatments. At 8.5°C and 13°C storage temperatures

40°C and 50°C hot water dipping equally suppressed weight loss. Highest weight loss was at storage temperatures of 13°C in room hot water dipping. Hot water dipping at 50°C suppressed weight loss and hence the least weight loss was realised with hot water dipping at 50°C for one minute and storage temperature of 4°C in trial 2 under low temperature storage (Figure 1b).

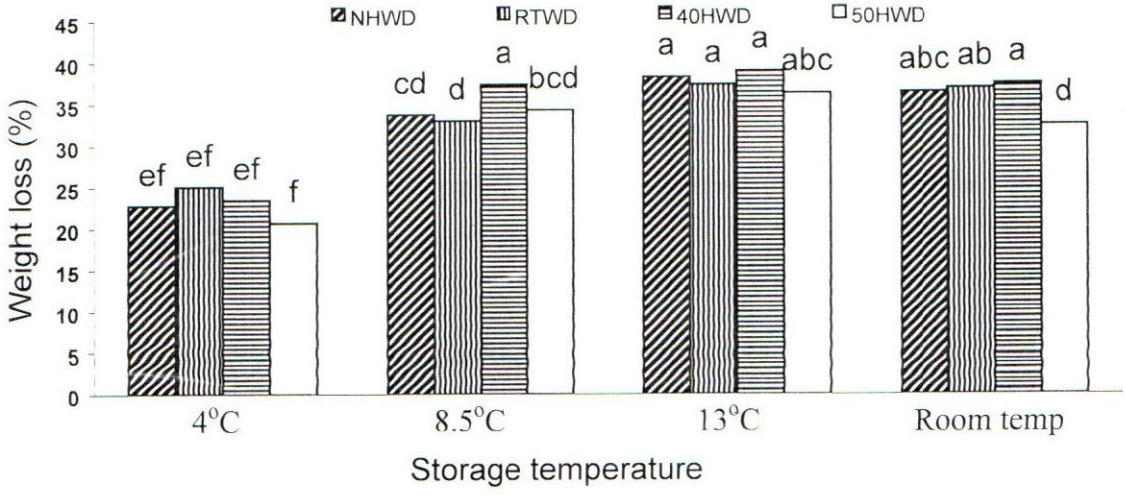


Figure 1a. Effects of hot water dipping and storage temperature on okra weight loss after 21 days of storage (Trial 1)

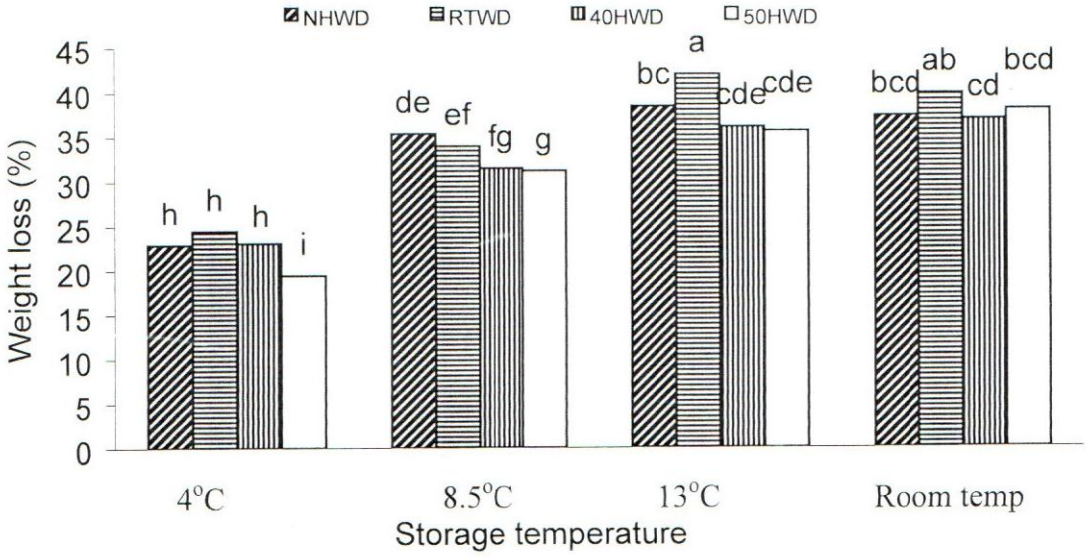


Figure 1b. Effects of hot water dipping and storage temperature on okra weight loss after 21 days of storage (Trial 2)

Effects of hot water dipping and packaging on weight loss

In free pod packaging the least weight loss was at 50°C. Highest weight loss was observed in non packaged pods dipped in water at room temperature. In non perforated packaging at all hot water treatments weight loss was most significantly suppressed. The highest weight loss suppression was with hot water dipping at 50°C for 1minute in non perforated packaging although this was not significantly different from the other hot water treatments in the same packaging (Figure 2a).

In free pod packaging weight loss was significantly suppressed at 50°C for 1 minute followed by 40°C for 7 minutes and the highest weight loss was at room hot water dipping in trial 2. In perforated packaging, hot water dipping at 40°C for 7 minutes and 50°C for one minute were not significantly different and prevented weight loss most compared to the other hot water treatments. The lowest weight loss was observed in storage under non perforated packaging at all hot water treatments (Figure 2b).

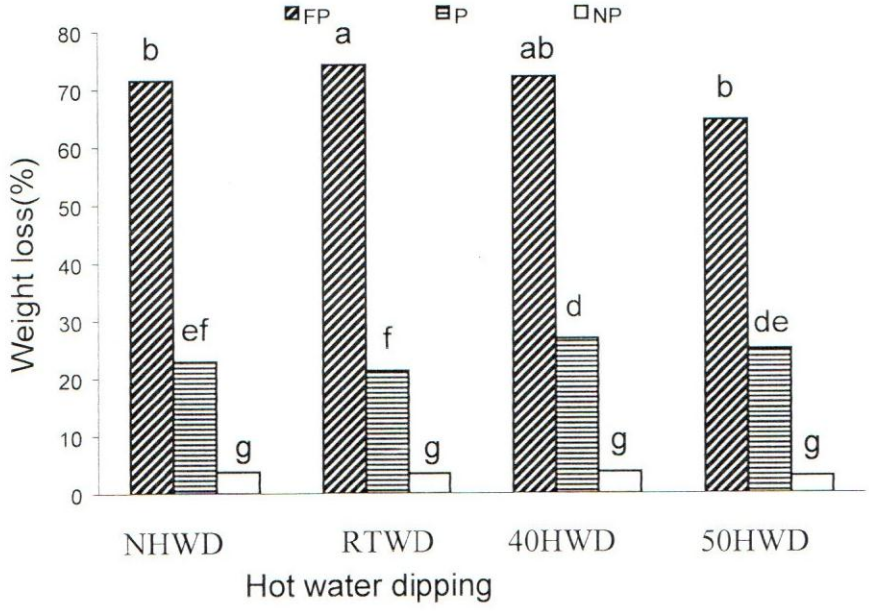


Figure 2a. Effects of hot water dipping and packaging on okra weight loss after 21 days of storage (Trial 1)

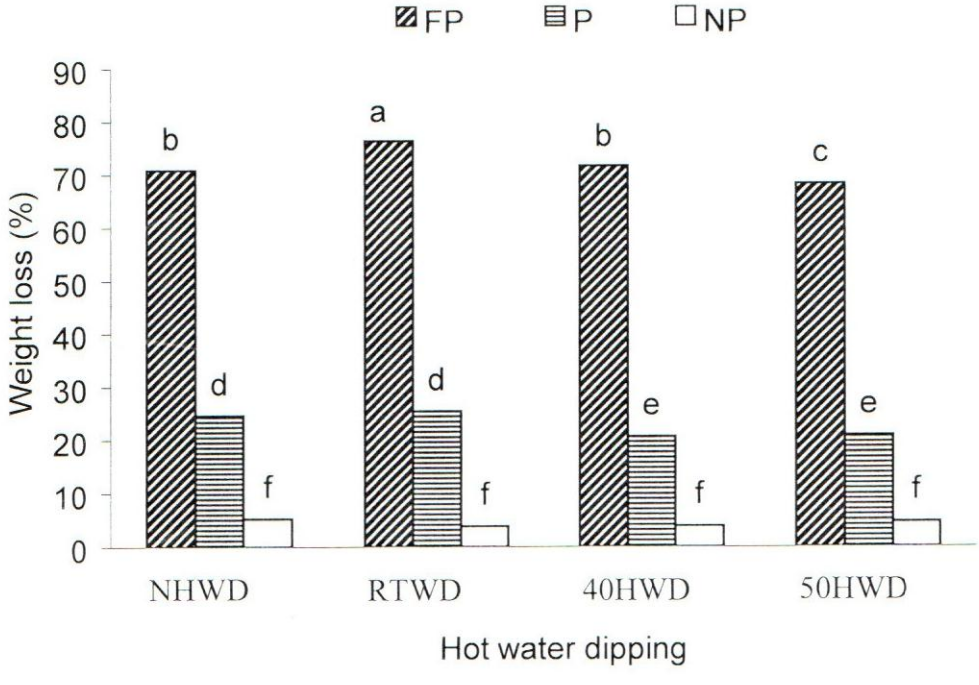


Figure 2b. Effects of hot water dipping and packaging on okra weight loss after 21 days of storage (Trial 2)

Effects of storage temperature and packaging on weight loss

There was a gradual increase in weight loss at every packaging level and with increase in storage temperature (Figure 3a). There, however, was an exception where room storage had a lower weight loss than 13°C storage temperature. Least weight loss was at 4°C storage temperature in non perforated packaging (Figure 3a). The same trend was observed in trial 2 (Figure 3b) except that the weight loss in room and 13°C storage temperatures were not significantly different. Greatest weight loss was observed with the room and 13°C storage temperature in free pod packaging. The least weight loss was recorded in 4°C storage temperature in non perforated packaging in trial 2, which was not different from non perforated packaging at 8.5°C (Figure 3b).

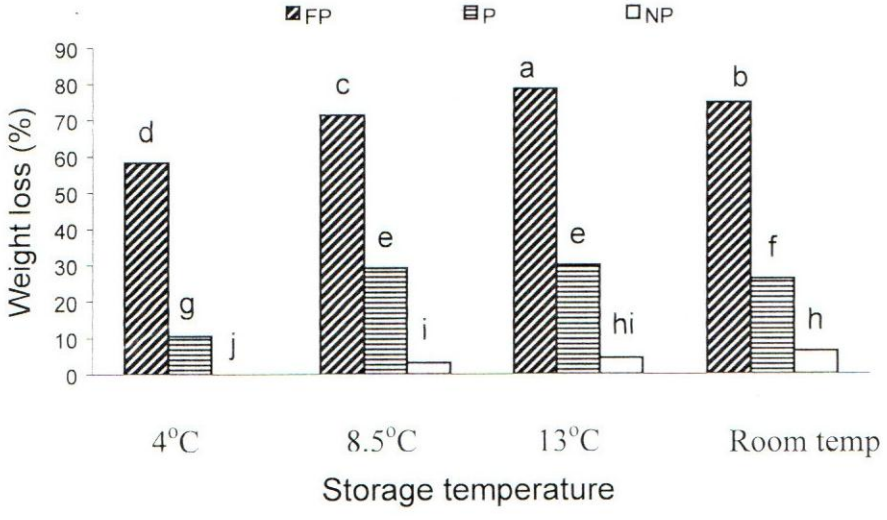


Figure 3a. Effects of storage temperature and packaging on okra weight loss after 21 days of storage (Trial 1)

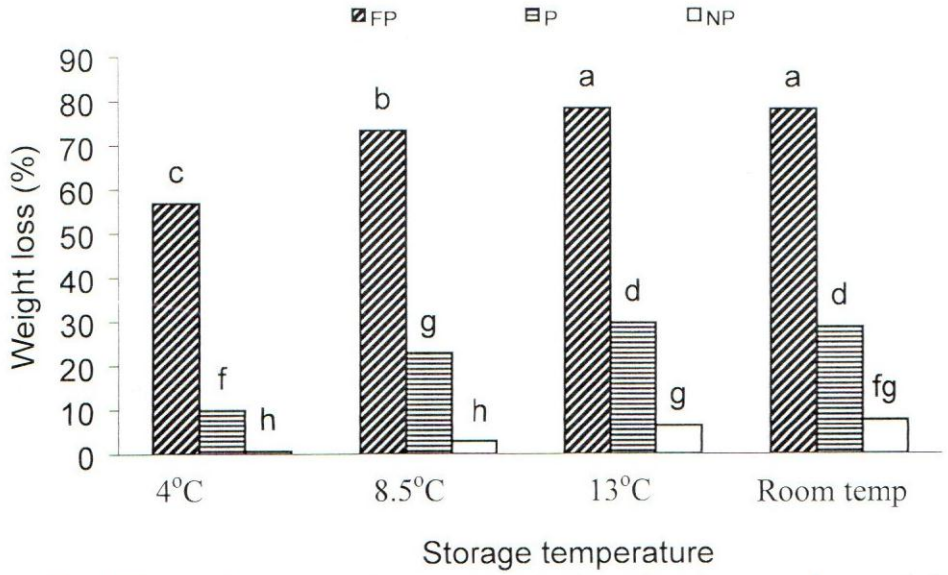


Figure 3b. Effects of storage temperature and packaging on okra weight loss after 21 days of storage (Trial 2)

Effects of hot water dipping, storage temperature and packaging on weight loss

Highest weight loss was at room temperature, hot water dipping in room temperature storage and in free pod packaging. These losses were, however, not significantly different from NHWD, 13°C, FP; RTWD, 13°C, FP; 40HWD 13°C, FP and 50HWD, 13°C, FP storage combinations. Non perforated packaging at all storage temperatures and hot water treatments had on the overall low weight losses and were not significantly different. All hot water treatments at 4°C storage temperature and non perforated packaging had lowest weight loss with no loss in trial 1 (Table 6a). In trial 2 highest weight loss was at RTWD in room temperature storage and in free pod packaging. Least weight loss was at room hot water dipping at storage temperature of 4°C and in non perforated packaging although this was not significantly different from storage at 4°C at all hot water treatments in non perforated packaging and storage at 8.5°C at all hot water treatments, except NHWD when packaged in non perforated packaging. Different packaging levels had significantly different weight loss suppression (Table 6b). Packaging treatment when compared to the other treatments had more effect on weight suppression in both trials. The overall means indicate that the most effective weight suppression treatment combination was observed in hot water dipping at 50°C for 1 minute, in 4°C storage temperature and in non perforated packaging.

Table 6a. Interactive effects of hot water dipping, storage temperature and packaging on okra weight loss (%)after 21 days of storage (Trial 1)

Hot water dipping	Storage temperature	Weight loss (%)		
		No package Free pods	Perforated polythene	Non perforated polythene
No water dipping	4°C	60.7ef[z]	7.5mno	0.2p
	8.5°C	73c	24.7jk	3.3op
	13°C	79.7ab	30.5hi	4.5nop
	Room temperature[y]	73c	29.0ijk	7.2mno
Room temperature water dipping	4°C	64.8de	10.3lmn	0.0p
	8.5°C	72.5c	23.5k	2.8op
	13°C	79.0ab	27.7ijk	5.2nop
	Room temperature	80.7a	23.8jk	6.0mnop
40°C Hot water dipping	4°C	59.2f	11.2lm	0.0p
	8.5°C	72.7c	35.7h	3.7op
	13°C	79.3ab	32.7hi	4.8nop
	Room temperature	74.7bc	27.7ijk	6.7mno
50°C Hot water dipping	4°C	48.5g	13.5l	0.0p
	8.5°C	67.2d	32.7hi	1.0op
	13°C	76.0abc	29.3ij	3.5op
	Room temperature	67.3d	24.2jk	5.5mnop

[z]Means followed by the same suffix are not significantly different in all columns at DMRT $P \leq 0.05$

[y]Room temperature varied between 15-20°C

Table 6b. Interactive effects of hot water dipping, storage temperature and packaging on okra weight loss after 21 days of storage (Trial 2)

Hot water dipping	Storage temperature	Weight loss (%)		
		No package Free pods	Perforated polythene	Non perforated polythene
No water dipping	4°C	59.5g[z]	9.0pq	0.2uv
	8.5°C	74.2cde	28.0jklm	4.0qrstu
	13°C	76.5cde	31.8j	7.2pqrs
	Room temperature[y]	73.2cde	29.5jk	19.7pq
Room temperature water dipping	4°C	64.3f	9.0pq	0.0v
	8.5°C	74.7cde	24.5lmn	2.8rstuv
	13°C	82.7ab	37.5i	6.0qrst
	Room temperature	83.3a	30.2jk	6.3qrs
40°C Hot water dipping	4°C	59.3g	9.2pq	0.7tuv
	8.5°C	71.8e	20.3no	2.3rstuv
	13°C	76.7cde	26.2klm	5.7qrstu
	Room temperature	78.2bc	26.3klm	6.7qrs
50°C Hot water dipping	4°C	44.2h	12.3p	1.8stuv
	8.5°C	72.5de	18.7o	2.5rstuv
	13°C	77.7bcd	23.0mno	6.5qrs
	Room temperature	78.0bcd	28.7jkl	7.8pqr

[z]Means followed by the same suffix are not significantly different in all columns at DMRT $P \leq 0.05$

[y]Room temperature varied between 15-20°C

Interactive effects of hot water dipping, storage temperature and packaging on chilling injury

Incidence of chilling injury was least under hot water treatment of 50°C for 1 minute followed by 40°C for 7 minutes and then room and non hot water dipping though these were not significantly different in trial 1. In trial 2, chilling injury was significantly suppressed in hot water dipping at 50°C for one minute compared to the other hot water treatments (Table 7).

Chilling injury did not occur in storage at 13°C and room storage temperatures. Chilling injury was more severe at 4°C storage temperature than at 8.5°C in trial 2 but was not significantly different in trial 1 (Table 8).

Chilling injury incidence was suppressed most in perforated packaging followed by non perforated packaging. The highest incidence chilling injury was recorded in the free pod packaging in trial 2 but in trial 1 there was no significant difference. This may be explained by the fact that trial 2 used older plant pods, which had hardier pods than in trial 1 (Table 9).

Table 7: Effect of hot water dipping on okra chilling injury after 21 days of storage

Hot water treatment	Incidence of chilling injury (%)	
	Trial 1	Trial 2
No hot water dipping	50.0 a*	50.0 a*
Room temperature dipping	50.0 a	50.0 a
40°C for 7 minutes	49.4 a	50.0 a
50°C for 1 minute	47.9 a	43.1 b

*Means followed by the same suffix are not significantly different in columns at DMRT $P \leq 0.05$

Table 8: Effect of storage temperature on okra chilling injury after 21 days of storage

Storage temperature	Incidence of chilling injury (%)	
	Trial 1	Trial 2
4°C	98.6 a*	100 a*
8.5°C	98.7 a	93.1 b
13°C	0.0 b	0.0 c
Room storage temperature	0.0 b	0.0 c

*Means followed by the same suffix are not significantly different in columns at DMRT $P \leq 0.05$

*Room temperature varied between 15-20°C

Table 9: Effect of packaging on okra chilling injury (%) after 21 days of storage

Packaging	Incidence of chilling injury (%)	
	Trial 1	Trial 2
Free pod packaging	50.0 a*	50.0 a*
Perforated packaging	48.1 a	46.5 c
Non perforated packaging	49.9 a	48.3 b

*Means followed by the same suffix are not significantly different at DMRT $P \leq 0.05$

Effects of hot water dipping and storage temperature on okra chilling injury

At 13°C and room storage temperatures there was no chilling injury. A combination of hot water treatment at 40°C and storage temperature at 8.5°C reduced incidence of chilling injury but not significantly. The lowest incidence of chilling injury was in hot water dipping at 50°C for one minute at 4°C storage temperatures (Figure 4a).

A repeat experiment (Figure 4b) indicated that okra pods at 50°C hot water dipping for 1 minute suppressed chilling injury at 8.5°C storage temperature. The results suggest that the most effective treatment was storing pods at 13°C and room storage.

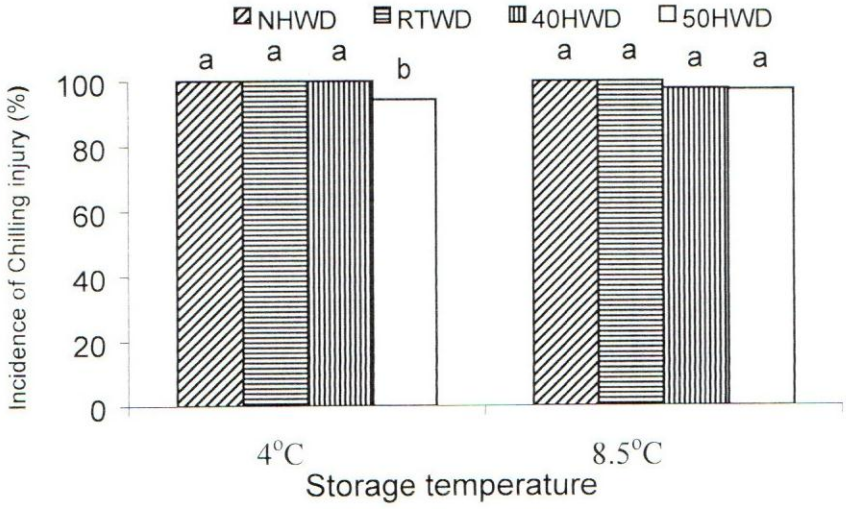


Figure 4a. Effect of hot water dipping and storage temperature on chilling injury of okra after 21 days of storage (Trial 1)

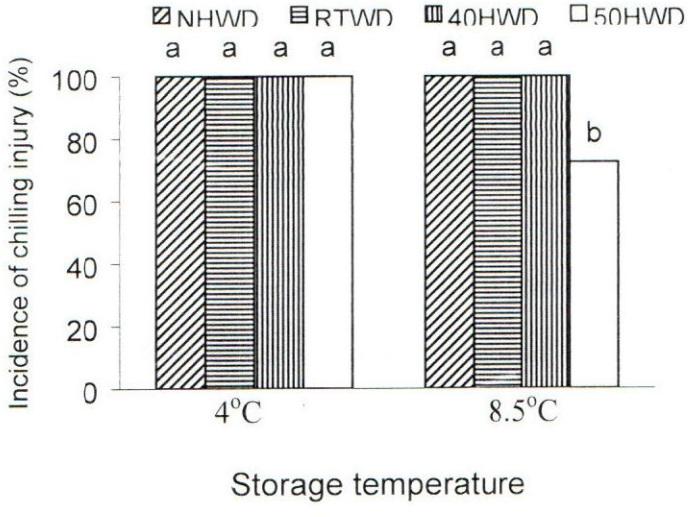


Figure 4b. Effect of hot water dipping and storage temperature on chilling injury of okra after 21 days of storage (Trial 2)

Effect of hot water dipping and packaging on chilling injury

In Trial 1, hot water treatment at 40°C for 7 minutes prevented chilling injury in perforated packaging better than in free pod or non perforated packaging (Figure 5a). Hot water dipping at 50°C for 1 minute led to a less extent suppressed chilling injury in non perforated packaging insignificantly but significantly reduced incidence of chilling injury in perforated packaging (Figure 5a).

In Trial 2, hot water dipping at 50°C significantly enhanced suppression of chilling injury in non perforated and perforated packages but more so in perforated packaging (Figure 5b). For chilling injury protection use of perforated packaging and hot water at 50°C for 1 minute demonstrated the best results.

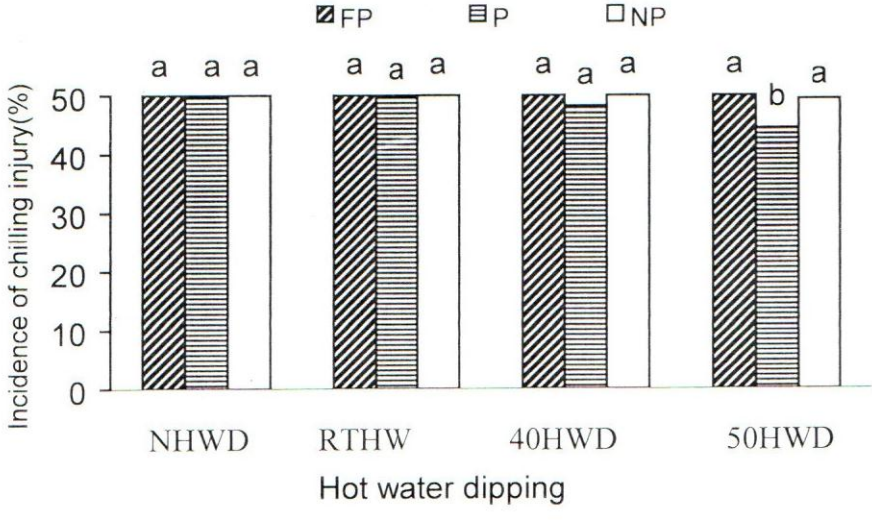


Figure 5a. Effect of hot water dipping and packaging on chilling injury of okra after 21 days of storage (Trial 1)

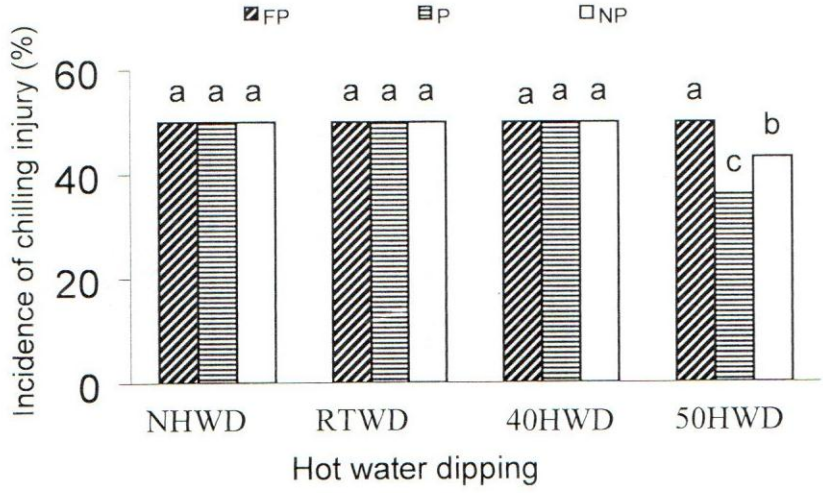


Figure 5b. Effect of hot water dipping and packaging on chilling injury of okra after 21 days of storage (Trial 2)

Effect of storage temperature and packaging on chilling injury

Okra stored at 13°C and room temperatures had no chilling injury. At 4°C and 8.5°C storage temperatures chilling injury was significantly suppressed in perforated packaging (Figure 6a). Similar results were observed in a repeat experiment only that at 8.5°C storage temperature the incidence of chilling injury was reduced in perforated and non perforated packaging but even better in perforated packaging (Figure 6b).

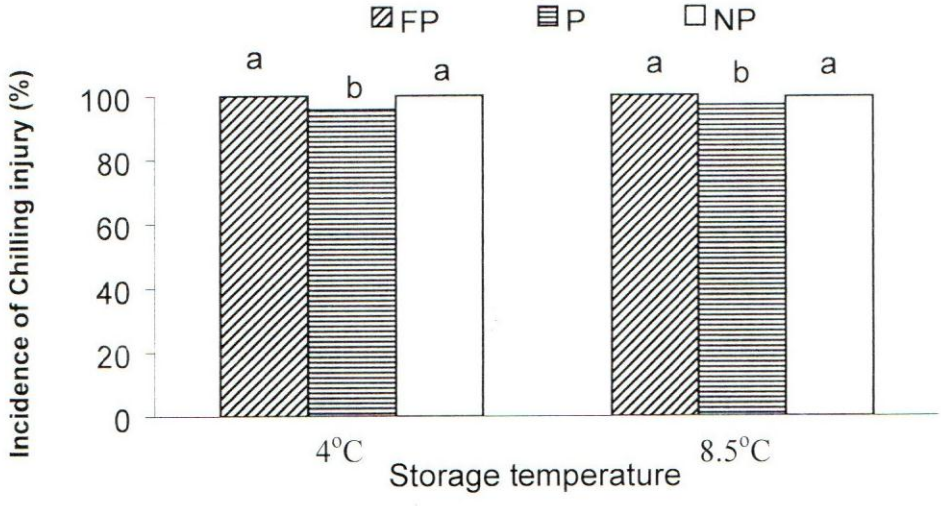


Figure 6a. Effect of storage temperature and packaging on chilling injury of okra after 21 days of storage (Trial 1)

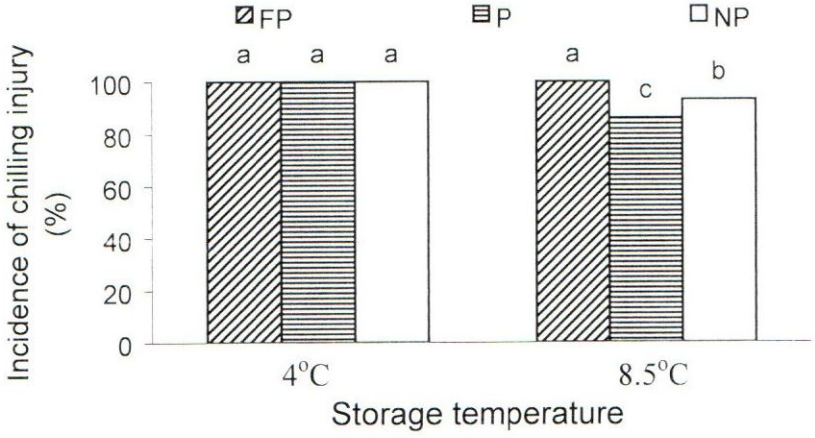


Figure 6b. Effect of storage temperature and packaging on chilling injury of okra after 21 days of storage (Trial 2)

Interactive effects of hot water dipping, storage temperature and packaging on chilling injury

Hot water dipping at 40°C and 50°C significantly alleviated chilling injury. This is demonstrated in the case of pods put through 40°C hot water dipping, kept in perforated packaging and stored at 8.5°C temperature. Hot water dipping at 50°C was even more effective and suppressed chilling injury at 4°C storage temperature for pods in perforated packaging by 17 %. Storage temperature of 8.5°C had chilling injury suppressed in both perforated and non perforated packaging. Best chilling injury suppression was observed with pods in perforated packaging and hot water dipping at 50°C for 1 minute and stored at 4°C. (Table 10a). Chilling injury was significantly suppressed in pods treated in hot water dipping at 50°C in non perforated packaging but was even better in perforated packaging. Best chilling injury suppression in Trial 2 was at 50°C hot water treatment, kept at 8.5°C storage temperature and in perforated packaging (Table 10b). To avoid chilling injury in okra pods storage temperature should be at either 13°C and room storage.

Table 10a. Interactive effects of hot water dipping, storage temperature and packaging on chilling injury of okra after 21 days of storage (Trial 1)

Hot water dipping	Storage temperature	Incidence of chilling injury (%)		
		No package (Free pods)	Perforated polythene	Non perforated polythene
No water dipping	4°C	100.0a[z]	100.0a	100.0a
	8.5°C	100.0a	100.0a	100.0a
	13°C	0.0e	0.0e	0.0e
	Room temperature[y]	0.0e	0.0e	0.0e
Room temperature water dipping	4°C	100.0a	100.0a	100.0a
	8.5°C	100.0a	100.0a	100.0a
	13°C	0.0e	0.0e	0.0e
	Room temperature	0.0e	0.0e	0.0e
40°C Hot water dipping	4°C	100.0a	100.0a	100.0a
	8.5°C	100.0a	92.9c	100.0a
	13°C	0.0e	0.0e	0.0e
	Room temperature	0.0e	0.0e	0.0e
50°C Hot water dipping	4°C	100.0a	82.9d	100.0a
	8.5°C	100.0a	94.5bc	97.6ab
	13°C	0.0e	0.0e	0.0e
	Room temperature	0.0e	0.0e	0.0e

[z]Means followed by the same suffix are not significantly different in all columns at DMRT $P \leq 0.05$

[y]Room temperature varied between 15-20°C

Table 10b. Interactive effects of hot water dipping, storage temperature and packaging on chilling injury of okra (Trial 2)

Hot water dipping	Storage temperature	Chilling injury %		
		No package (Free pods)	Perforated polythene	Non perforated polythene
No water dipping	4°C	100.0a[z]	100.0a	100.0a
	8.5°C	100.0a	100.0a	100.0a
	13°C	0.0d	0.0d	0.0d
	Room temperature[y]	0.0d	0.0d	0.0d
Room temperature water dipping	4°C	100.0a	100.0a	100.0a
	8.5°C	100.0a	100.0a	100.0a
	13°C	0.0d	0.0d	0.0d
	Room temperature	0.0d	0.0d	0.0d
40°C Hot water dipping	4°C	100.0a	100.0a	100.0a
	8.5°C	100.0a	100.0a	100.0a
	13°C	0.0d	0.0d	0.0d
	Room temperature	0.0d	0.0d	0.0d
50°C Hot water dipping	4°C	100.0a	100.0a	100.0a
	8.5°C	100.0a	44.2c	72.7b
	13°C	0.0d	0.0d	0.0d
	Room temperature	0.0d	0.0d	0.0d

[z]Means followed by the same suffix are not significantly different in all columns at DMRT $P \leq 0.05$

[y]Room temperature varied between 15-20°C

4.1.3 Effects of hot water dipping, storage temperature and packaging on incidence of decay

Hot water dipping at 50°C significantly reduced decay incidence of okra pods in both trials compared to the other treatments. In trial one, the lowest incidence of decay was observed at 50°C, 40°C and room hot water dipping while the highest incidence of decay was at non hot water dipping. This trend was similar in the repeat experiment only that higher incidence of decay was recorded in room hot water dipping (Table 11).

There was no decay at 4°C storage temperature. The highest recorded incidence of decay was at the storage temperature of 8.5°C in both trials. In trial, 1 room storage had

lower incidence of decay than those pods in 13°C storage temperature and vice versa in trial 2 (Table 12).

Free pod packaging had no pods showing decay. Perforated packaging had significantly less incidence of decay than non perforated in trial 1 but in trial 2 there was less decay in non perforated packaging though this difference was not significant (Table 13).

Table 11: Effect of hot water dipping on okra decay after 21 days of storage

Hot water treatment	Incidence of decay (%)	
	Trial 1	Trial 2
No hot water dipping	28.6 a*	22.9 ab*
Room temperature dipping	26.0 a	26.0 a
40°C for 7 minutes	22.6 a	26.0 a
50°C for 1 minute	10.0 b	19.1 b

*Means followed by the same suffix are not significantly different in columns at DMRT $P \leq 0.05$

Table 12: Effect of storage temperature on okra decay after 21 days of storage

Storage temperature	Incidence of decay (%)	
	Trial 1	Trial 2
4°C	0.0 d*	0.0 c*
8.5°C	52.4 a	60.2 a
13°C	22.2 b	16.8 b
Room storage temperature	12.7 c	17.0 b

*Means followed by the same suffix are not significantly different in columns at DMRT $P \leq 0.05$

*Room temperature varied between 15-20°C

Table 13: Effect of packaging on okra decay after 21 days of storage

Packaging	Incidence of decay (%)	
	Trial 1	Trial 2
Free pod packaging	0.0 c*	0.0 b*
Perforated packaging	30.1 b	36.2 a
Non perforated packaging	35.4 a	34.3 a

*Means followed by the same suffix in columns are not significantly different at DMRT $P \leq 0.05$

Effect of hot water dipping and storage temperature on decay incidence

Pods kept at 4°C storage temperature at all hot water treatments in both trials recorded no decay. However pods stored at 8.5°C had the highest pod decay in comparison to the other storage temperatures. There was no significant difference in the incidence of decay for pods in 8.5°C storage temperature, no hot water dipping, room temperature water dipping and 40°C hot water dipping. At 13°C storage temperature, 40°C and 50°C hot water dipping had significantly less pod decay. Under room storage other hot water treatments were not significantly different except for pods treated at 50°C hot water dipping, which had significantly less decayed pods (Figure 7a). These observations indicate that at all storage temperatures hot water dipping at 50°C reduced incidence of decay.

At 8.5°C and 13°C storage temperatures only hot water dipping at 50°C significantly lowered incidence of decay. At room storage temperature there was no significant difference among the hot water treatments but decay incidence was greatly reduced compared to the other storage temperatures (Figure 7b).

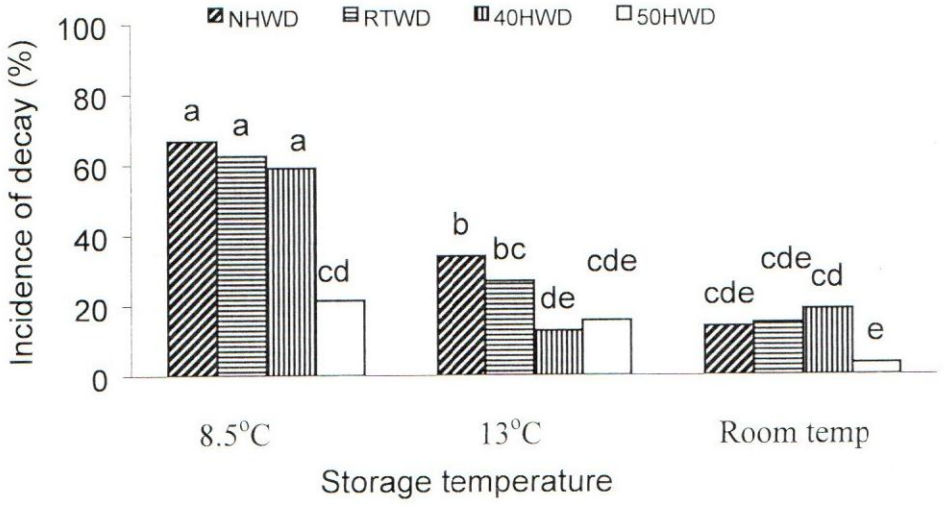


Figure 7a. Effects of hot water dipping and storage temperature on okra decay after 21 days of storage (Trial 1)

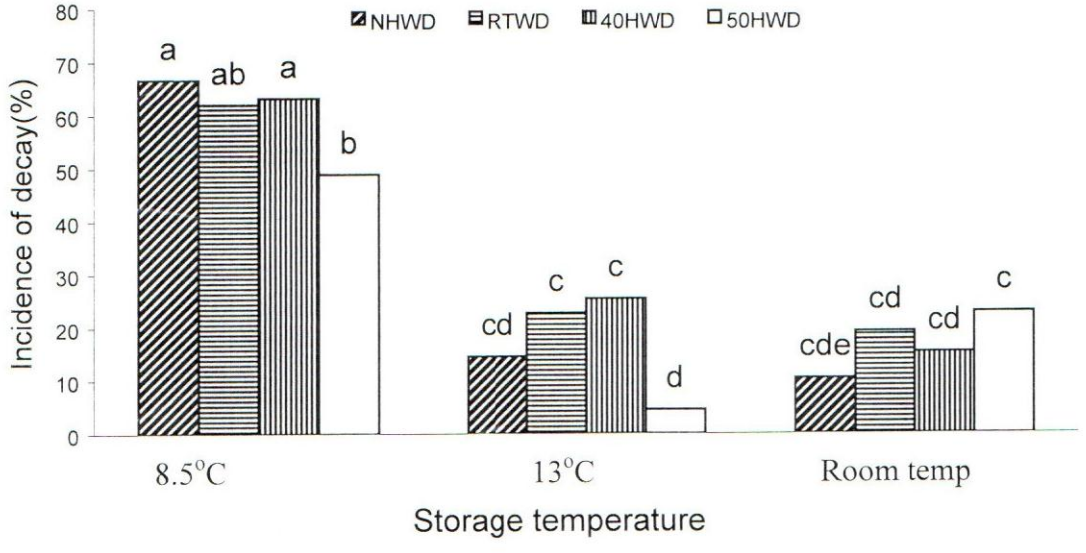


Figure 7b. Effects of hot water dipping and storage temperature on okra decay after 21 days of storage (Trial 2)

Effects of hot water dipping and packaging on decay incidence

The incidence of decay was generally high for pods without hot water treatment and those treated through room temperature water dipping. The least incidence of decay occurred in 50°C hot water dipping. In all hot water treatments there was no decay for pods under free pod packaging. In the no hot water dipping and room hot water dipping, perforated and non perforated packaging had no significant difference in incidence of pod decay. At 40°C and 50°C hot water treatment, perforated packaging had significantly lower incidence of decay than non perforated packaging (Figure 8a), indicating that hot water dipping with perforated packaging suppressed decay.

A repeat experiment (Figure 8b) showed no decay in free pod packaging. In non hot water dipping treatment, non perforated packaging had significantly less decayed pods than perforated packaging and with room temperature water dipping they had no significant difference in incidence of decay. Under 40°C hot water dipping and in perforated packaging pods had significantly less decayed pods. Also under 50°C hot water dipping in non perforated packaging there were less decayed pods than perforated packaging though not significantly different (Figure 8b). Generally least decay was under 50°C hot water dipping in perforated packaging for trial 1 and in non perforated packaging in trial 2 except free pod packaging, which had unmarketable pods.

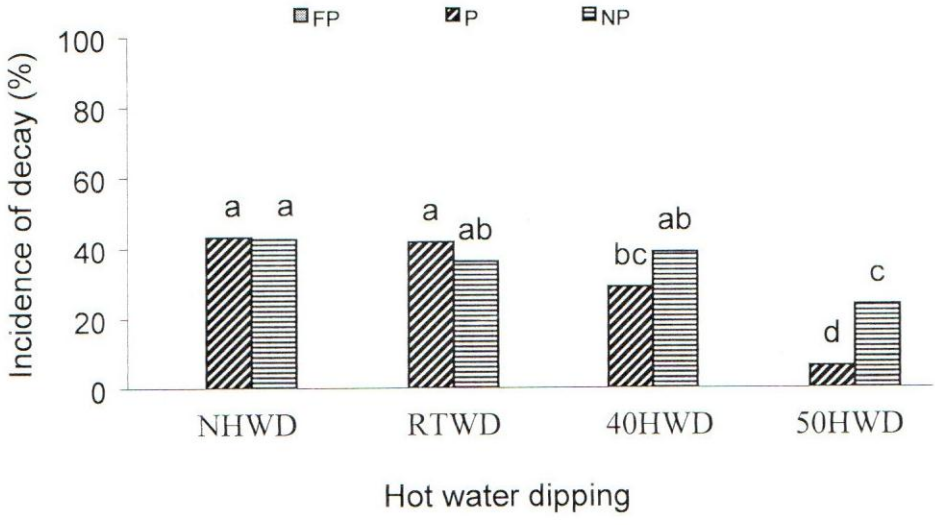


Figure 8a. Effects of hot water dipping and packaging on okra decay after 21 days of storage (Trial 1)

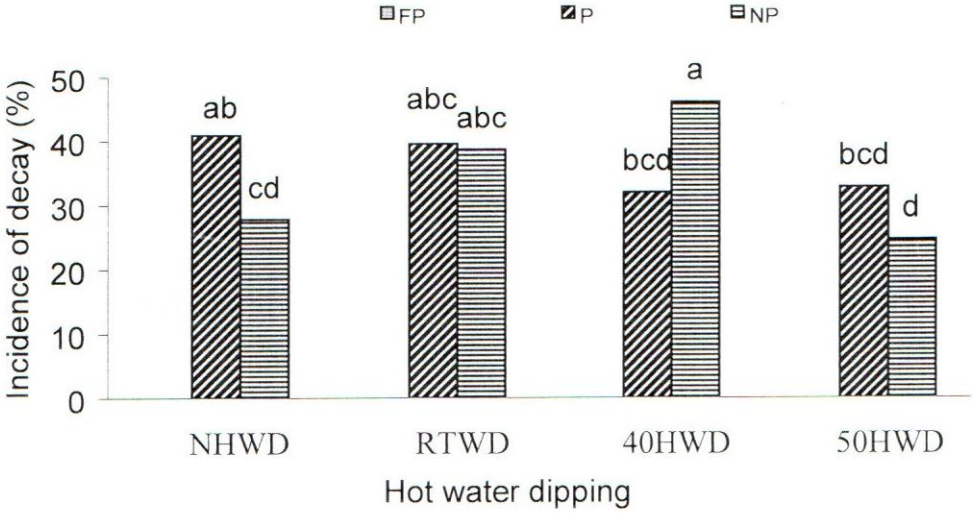


Figure 8b. Effects of hot water dipping and packaging on okra decay after 21 days of storage (Trial 2)

Effects of storage temperature and packaging on decay incidence

Pods stored at 4°C and in free pod packaging had no decay. At 8.5°C storage temperature, the incidence of decay was highest but those pods in perforated packaging had less decay than non-perforated packaging. Pods stored at 13°C, in room storage temperatures and perforated packaging had less decay. Least decay of pods after 4°C was observed in pods stored at room temperature in perforated packaging (Figure 9a). However, there was no decay of pods at 4°C storage temperatures and free pod packaging in trial 2. In the different temperatures there was no significant difference between perforated and non perforated packaging (Figure 9b). Least decay was however at 13°C storage temperature in non perforated packaging.

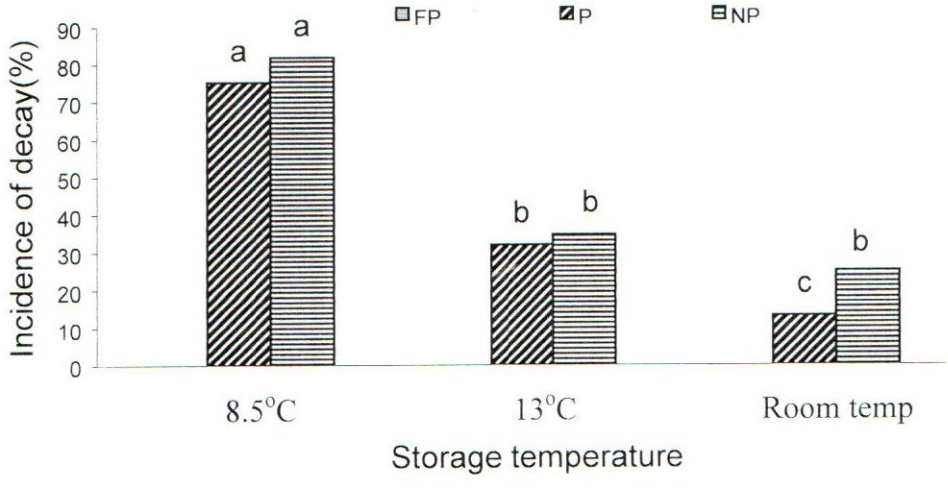


Figure 9a. Effects of storage temperature and packaging on okra decay after 21 days of storage (Trial 1)

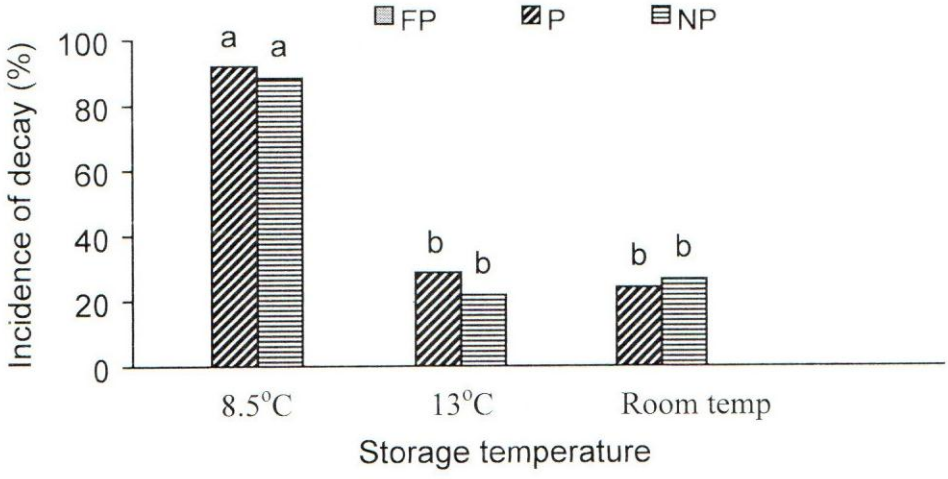


Figure 9b. Effects of storage temperature and packaging on okra decay after 21 days of storage (Trial 2)

Interactive effects of hot water dipping, storage temperature and packaging on decay

Pods stored under low temperatures of 4°C had no decay. Unfortunately these pods were frozen and hence unsuitable for sale in the fresh market after three weeks of storage. Free packaged pods also had no decay but were dry and shrivelled reducing their quality. Hot water dipping at 50°C prevented pod decay most compared to the other hot water treatments. Hot water dipping, perforated packaging and storage temperatures of 13°C and room storage reduced decay significantly. At 50°C hot water dipping, 13°C in perforated packaging and room storage temperatures in perforated and non perforated packaging had the least decay and also the most marketable pods (Table 14a). The same trend was observed in trial 2 with most marketable pods at 50°C HWD stored at 13°C temperature and packed in perforated and non perforated packaging. A similar observation was made for 40°C hot water dipping in room temperature storage and in perforated packaging. Most decay in both trials was in RTWD stored at 8.5°C storage temperature and also NHWD stored at 8.5°C in perforated and non perforated packaging, indicating that these conditions are unsuitability for okra storage (Table14b). Lowest decay after free pod packaging and 4°C storage temperature in trial 1 was 50°C hot water dipping at room temperature storage in perforated packaging. In trial two the lowest

decay incidence was in 50°C hot water dipping stored at 13°C in non perforated packaging.

Table 14a.Interactive effects of hot water dipping, storage temperature and packaging on okra decay after 21 days of storage (Trial 1)

Hot water dipping	Storage temperature	Incidence of decay (%)	
		Perforated polythene	Non perforated polythene
No water dipping	4°C	0.0i[z]	0.0i
	8.5°C	100.0a	100.0a
	13°C	63.3b	38.2cde
	Room temperature[y]	9.4fghi	32.2cde
Room temperature water dipping	4°C	0.0i	0.0i
	8.5°C	97.6a	89.6a
	13°C	49.6bc	30.8cdef
	Room temperature	20.0defghi	24.6defgh
40°C Hot water dipping	4°C	0.0i	0.0i
	8.5°C	86.7a	90.7a
	13°C	9.4fghi	28.5cdefg
	Room temperature	19.4defghi	36.7cde
50°C Hot water dipping	4°C	0.0i	0.0i
	8.5°C	16.5efghi	47.4bc
	13°C	5.6hi	41.1cd
	Room temperature	3.3hi	6.7ghi

[z]Means followed by the same suffix are not significantly different in all columns at DMRT $P \leq 0.05$

[y]Room temperature varied between 15-20°C

Table 14b. Interactive effects of hot water dipping, storage temperature and packaging on okra decay after 21 days of storage (Trial 2)

Hot water dipping	Storage temperature	Incidence of decay (%)	
		Perforated polythene	Non perforated polythene
No water dipping	4°C	0.0h[z]	0.0h
	8.5°C	100.0a	100.0a
	13°C	36.7de	7.2fgh
	Room temperature[y]	27.0defg	4.2fgh
Room temperature water dipping	4°C	0.0h	0.0h
	8.5°C	100.0a	86.0ab
	13°C	38.9de	29.5def
	Room temperature	19.0efgh	38.9de
40°C Hot water dipping	4°C	0.0h	0.0h
	8.5°C	89.5ab	100.0a
	13°C	28.8def	47.7cd
	Room temperature	9.2fgh	36.8de
50°C Hot water dipping	4°C	0.0h	0.0h
	8.5°C	78.6ab	68.1bc
	13°C	10.7fgh	2.8gh
	Room temperature	41.5de	27.1defg

[z]Means followed by the same suffix are not significantly different in all columns at DMRT $P \leq 0.05$

[y]Room temperature varied between 15-20°C

4.1.4 Effects of hot water dipping, storage temperature and packaging on electrolyte leakage

In both trials of the experiment, the lowest electrolyte leakage was in 50°C hot water dipping, 40°C hot water dipping and non hot water dipping. The highest electrolyte leakage was observed in room hot water dipping. The results were significantly different in trial 1 but not in trial 2 (Table 15). Pods with least electrolyte leakage indicated that they also had least damage caused by storage duration and treatments.

Highest electrolyte leakage was in pods stored at 4°C trial 1 due to chilling injury. In trial two the highest electrolyte leakage in pods was at 8.5°C storage. The high incidence of electrolyte leakage in both cases may be attributed to rotting caused by decay and chilling injury. In trial 1 lowest electrolyte leakage was at room storage and that of trial 2 was at 13°C storage temperature indicating these storage temperatures were not detrimental to the pods (Table 16).

Highest electrolyte leakage was in free pod packaging followed by non perforated packaging. The least electrolyte leakage was in perforated packaged pods in both trials (Table 17). Perforated packaging, therefore gave the lowest injury to cell membrane.

Table 15: Effect of hot water dipping on okra electrolyte leakage after 21 days of storage

Hot water treatment	Electrolyte leakage ($EC.m^S/cm$)	
	Trial 1	Trial 2
No hot water dipping	5.5 b*	8.8 a*
Room temperature dipping	6.6 a	9.0 a
40°C for 7 minutes	5.6 b	8.4 a
50°C for 1 minute	4.9 b	7.9 a

*Means followed by the same suffix are not significantly different in columns at DMRT $P \leq 0.05$

Table 16: Effect of storage temperature on okra electrolyte leakage after 21 days of storage

Storage temperature	Electrolyte leakage ($EC.m^S/cm$)	
	Trial 1	Trial 2
4°C	12.7 a*	11.9 a*
8.5°C	4.6 b	12.0 a
13°C	2.7 c	4.6 c
Room storage temperature	2.5 c	5.6 b

*Means followed by the same suffix are not significantly different in columns at DMRT $P \leq 0.05$

Table 17: Effect of packaging on okra electrolyte leakage (%) after 21 days of storage

Packaging	Electrolyte leakage ($EC.m^S/cm$)	
	Trial 1	Trial 2
Free pod packaging	6.5 a*	9.1 a*
Perforated packaging	5.0 b	8.0 a
Non perforated packaging	5.3 b	8.5 a

*Means followed by the same suffix are not significantly different at DMRT $P \leq 0.05$

*Room temperature varied between 15-20°C

Effects of hot water dipping and storage temperature on electrolyte leakage

Storage temperature of 4°C generally had the highest electrolyte leakage while room hot water dipping allowed significantly higher electrolyte leakage than the other hot water treatments. At 8.5°C storage temperature, hot water dipping at 50°C had a significantly lower electrolyte leakage than the other hot water treatments. At 13°C storage temperature and at all hot water treatments electrolyte leakage was generally low and was not significantly different. A combination of room temperature storage, no hot water dipping and 50°C hot water dipping had significantly lower electrolyte leakage than the other hot water treatments. The lowest electrolyte leakage was in pods treated under 50°C hot water dipping stored at 8.5°C, room storage temperature also in all hot water treatments at 13°C and no hot water dipping at room temperature storage (Figure 10a).

In trial 2, 8.5°C storage temperature had a higher electrolyte leakage than at 4°C storage temperature due to increased decay in trial 2. (Figure 10b). In the later case, pods were older and had more latent infection from the farm. The lowest electrolyte leakage was at both 13°C and room temperature storage. However, 13°C had lower electrolyte leakage at 50°C hot water dipping although the difference was not significant (Figure 10b). In both trials, it is evident that electrolyte leakage was more affected by storage temperature than the hot water treatments.

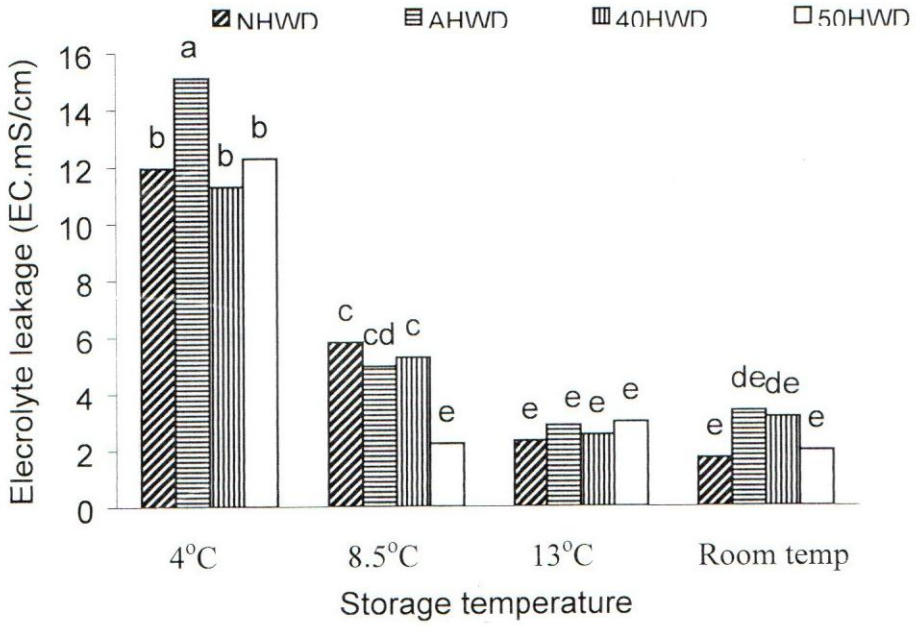


Figure 10a. Effects of hot water dipping and storage temperature on electrolyte leakage of okra after 21 days of storage (Trial 1)

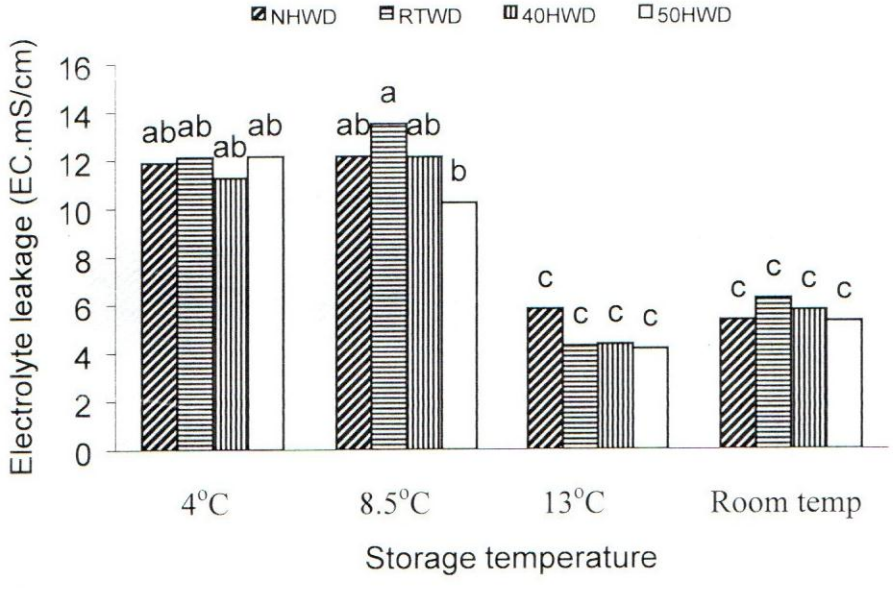


Figure 10b. Effects of hot water dipping and storage temperature on electrolyte leakage of okra after 21 days of storage (Trial 2)

Effects of hot water dipping and packaging on electrolyte leakage

In all hot water treatments, the highest electrolyte leakage was observed in free packaged pods while pods with the lowest electrolyte leakage were in perforated packaging with an exception of room temperature water dipping. Lowest electrolyte leakage was at 50°C hot water dipping in perforated but not significantly different from non perforated packaging at the same hot water treatment. Hot water dipping at 40°C and 50°C reduced electrolyte leakage when combined with packaging and this improved pod quality (Figure 11a).

In trial 2 (Figure 11b), the highest electrolyte leakage was in free pod packaging and lowest in perforated packaging. Use of hot water dipping at 50°C in perforated packaging reduced electrolyte leakage significantly in free and perforated packaging. Lowest electrolyte leakage was at 50°C hot water dipping in perforated packaging, however this was not significantly different from pods treated to 40°C hot water dipping in perforated packaging.

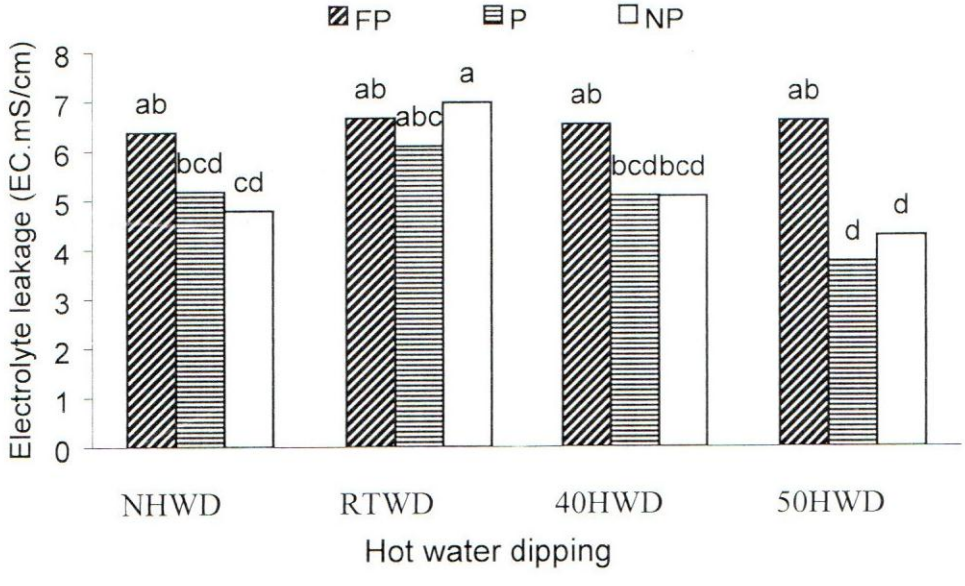


Figure 11a. Effects of hot water dipping and packaging on electrolyte leakage of okra after 21 days of storage (Trial 1)

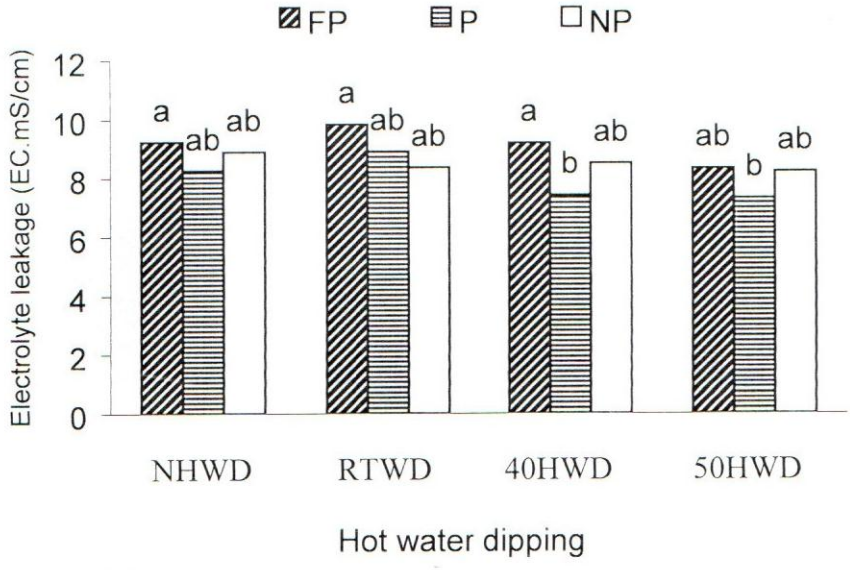


Figure 11b. Effects of hot water dipping and packaging on electrolyte leakage of okra after 21 days of storage (Trial 2)

Effects of storage temperature and packaging on electrolyte leakage

Regardless of packaging, storage temperature at 4°C had the highest electrolyte leakage. In free pod packaging, least electrolyte leakage was at room storage temperature. In perforated and non perforated packages the least electrolyte leakage was at 13°C storage temperature though not significantly different from room storage temperature (Figure 12a). This suggested that packaging at higher storage temperatures greatly reduced electrolyte leakage.

In trial two, the lowest electrolyte leakage in free pod packaging was observed with the room storage temperature while for perforated and non perforated packaging it was at 13°C storage temperature. Perforated and non perforated packaging placed at 13°C storage temperature prevented electrolyte leakage and provided the best pod quality (Figure 12b).

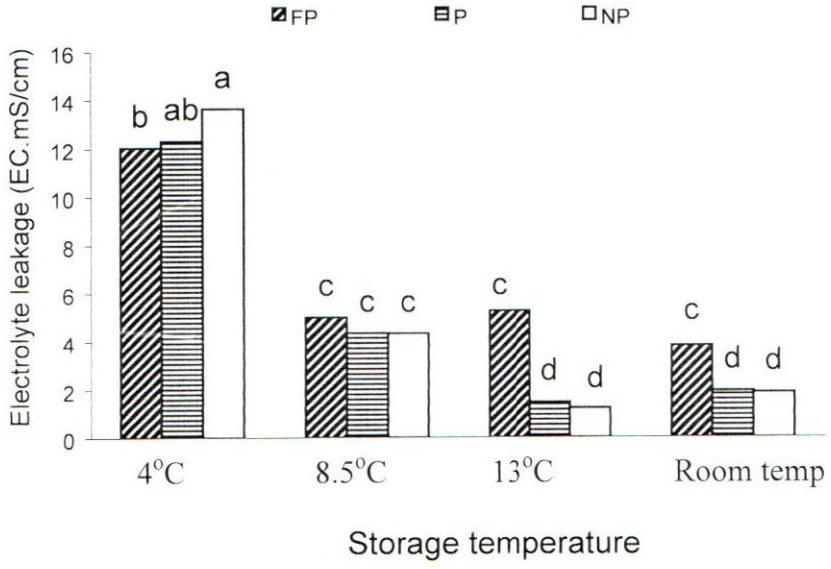


Figure 12a. Effects of storage temperature and packaging on electrolyte leakage of okra after 21 days of storage (Trial 1)

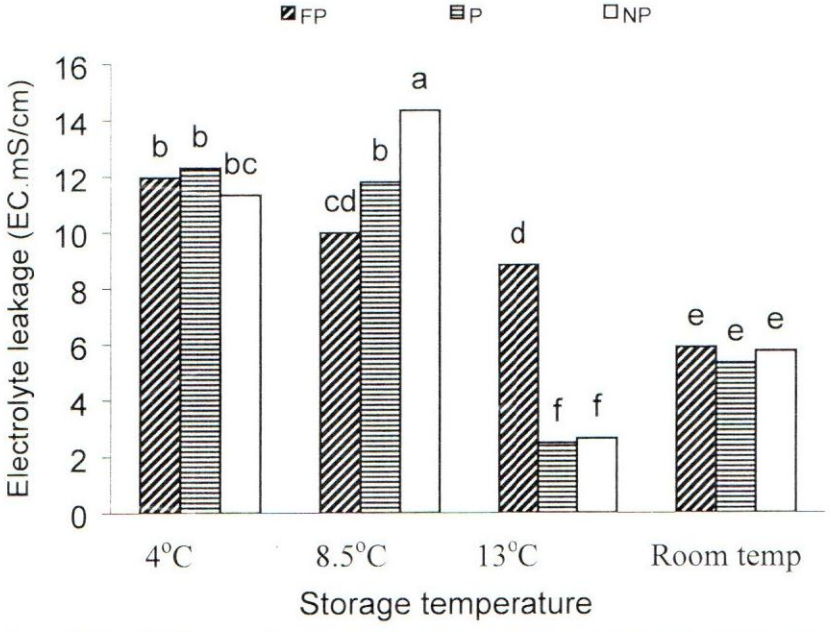


Figure 12b. Effects of storage temperature and packaging on electrolyte leakage of okra after 21 days of storage (Trial 2)

Interactive effects of hot water dipping, storage temperature and packaging on electrolyte leakage

Highest electrolyte leakage was observed in pods placed at 4°C storage temperature due to chilling injury in non perforated packaging and room hot water dipping. The best treatment combination was in hot water dipping at 50°C under room storage temperatures in perforated packaging (Table 18a). In trial two storage at 8.5°C had the highest electrolyte leakage due to decay and chilling injury in non perforated packaging and in room hot water dipping. The best treatment was at 50°C hot water dipping, 13°C storage temperature in perforated and non perforated packaging. In the same trial the best treatment was in 13°C storage temperature in 40°C hot water dipping perforated and non perforated packaging, and also in 13°C storage temperature in room temperature water dipping and non perforated packaging (Table 18b).

Table 18a. Interactive effects of hot water dipping, storage temperature and packaging on electrolyte leakage of okra after 21 days of storage (Trial 1)

Hot water dipping	Storage temperature	Electrolyte leakage ($EC.m^S/cm$)		
		No package (Free pods)	Perforated polythene	Non perforated polythene
No water dipping	4°C	12.0bc[z]	12.1bc	11.8bc
	8.5°C	6.0efg	6.2ef	53efghi
	13°C	4.6fghijk	1.4klm	1.0lm
	Room temperature[y]	3.0fghijklm	1.0lm	1.2lm
Room temperature water dipping	4°C	12.6bc	13.3bc	19.5a
	8.5°C	3.4fghijklm	5.8efg	5.7efg
	13°C	5.5efgh	2.0ijklm	1.1lm
	Room temperature	5.2efghi	3.3fghijklm	1.6jklm
40°C Hot water dipping	4°C	10.1cd	12.5bc	11.4bc
	8.5°C	8.0de	3.5fghijklm	4.3fghijkl
	13°C	5.0efghij	1.6jklm	1.0lm
	Room temperature	3.1fghijklm	2.8fghijklm	3.6fghijklm
50°C Hot water dipping	4°C	13.5b	11.4b	12.0bc
	8.5°C	2.7ghijklm	1.9ijklm	2.1hijklm
	13°C	6.1efg	2.0lm	1.8jklm
	Room temperature	4.0fghijklm	0.7m	1.2lm

[z]Means followed by the same suffix are not significantly different in all columns at DMRT $P \leq 0.05$

[y]Room temperature varied between 15-20°C

Table 18b. Interactive effects of hot water dipping, storage temperature and packaging on electrolyte leakage of okra after 21 days of storage (Trial 2)

Hot water dipping	Storage temperature	Electrolyte leakage ($EC.m^S/cm$)		
		No packaging (Free pods)	Perforated polythene	Non perforated polythene
No water dipping	4°C	12.0bcdef[z]	12.1bcdef	11.7bcdef
	8.5°C	10.9cdefg	11.8bcdef	13.8abc
	13°C	10.3cdefgh	2.6nop	4.6klmnop
	Room temperature[y]	4.0lmnop	6.5ijklm	5.6jklmno
Room temperature water dipping	4°C	12.7bcde	13.0bcd	10.8cdefg
	8.5°C	11.8bcdef	12.2bcdef	16.5a
	13°C	7.3ghijk	L3.6mnop	1.9p
	Room temperature	7.5ghijk	6.9hijklm	4.2klmnop
40°C Hot water dipping	4°C	9.9defghi1	2.8bcd	11.2cdef
	8.5°C	10.4cdefgh	11.1cdef	14.9ab
	13°C	9.0efghij	1.9p	2.1op
	Room temperature	7.6ghijk	3.9lmnop	5.7jklmn
50°C Hot water dipping	4°C	13.4abcd	11.4bcdef	11.7bcdef
	8.5°C	6.9hijklm	12.0bcdef	11.8bcdef
	13°C	8.6fghij	1.9p	2.0p
	Room temperature	4.4klmnop	3.9lmnop	7.5ghijkl

[z]Means followed by the same suffix are not significantly different in all columns at DMRT $P \leq 0.05$

[y]Room temperature varied between 15-20°C

4.1.5 Effects of hot water dipping, storage temperature and packaging on off odour

Least off odour was recorded in pods treated at 50°C hot water dipping while the worst odour recorded in trial 1 were pods treated in room hot water dipping. In trial 2 worst pods were those in no hot water dipping. This showed that off odour was prevented by hot water dipping especially at 50°C in both trials (Table 19).

Worst odour was in pods stored at 8.5°C storage temperature. This treatment also had the highest decay incidence. Least off odour was at 4°C since these pods were frozen and thus not marketable. The best marketable pods in trial 1 came from pods kept at room

storage temperature and in trial 2 from pods stored at 13°C storage temperature (Table 20).

Least off odour was found in those pods in free pod packaging although the pods were dry and shrivelled. The package that best reduced off odour was the perforated and worst odour was in non perforated as shown in both experimental trials (Table 21).

Table 19 Effect of hot water treatment on off odour of okra after 21 days of storage

Hot water treatment	Index of off odour	
	Trial 1	Trial 2
No hot water dipping	3.9 b*	4.0 a*
Room temperature dipping	3.9 b	4.0 a
40°C for 7 minutes	4.1 b	3.9 a
50°C for 1 minute	4.6 a	4.1 a

*Means followed by the same suffix are not significantly different in columns at DMRT $P \leq 0.05$

Table 20 Effect of storage temperature on off odour of okra after 21 days of storage

Storage temperature	Index of off odour	
	Trial 1	Trial 2
4°C storage temperature	5.0 a*	5.0 a*
8.5°C storage temperature	2.8 c	2.5 c
13°C storage temperature	4.3 b	4.4 b
Room storage temperature*	4.5 b	4.1 b

*Means followed by the same suffix are not significantly different in columns at DMRT $P \leq 0.05$

Table 21: Effect of packaging on off odour of okra after 21 days of storage

Packaging	Index of off odour	
	Trial 1	Trial 2
Free pod packaging	5.0 a*	5.0 a*
Perforated packaging	3.9 b	3.6 b
Non perforated packaging	3.5 c	3.5 b

* Means followed by the same suffix are not significantly different at DMRT $P \leq 0.05$

Effects of hot water treatment and storage temperature on off odour

In all the hot water treatments, 4°C storage temperatures had no off odour as pods were frozen. Pods with the highest off odour were those stored at 8.5°C storage temperature. Hot water dipping reduced number of non acceptable pods especially at the 8.5°C storage temperature. Best pods were at 50°C hot water dipping at room storage temperatures (Figure 13a). In trial two the trend was similar and the only difference was that best pods were at 50°C hot water dipping at 13°C storage temperature (Figure 13 b).

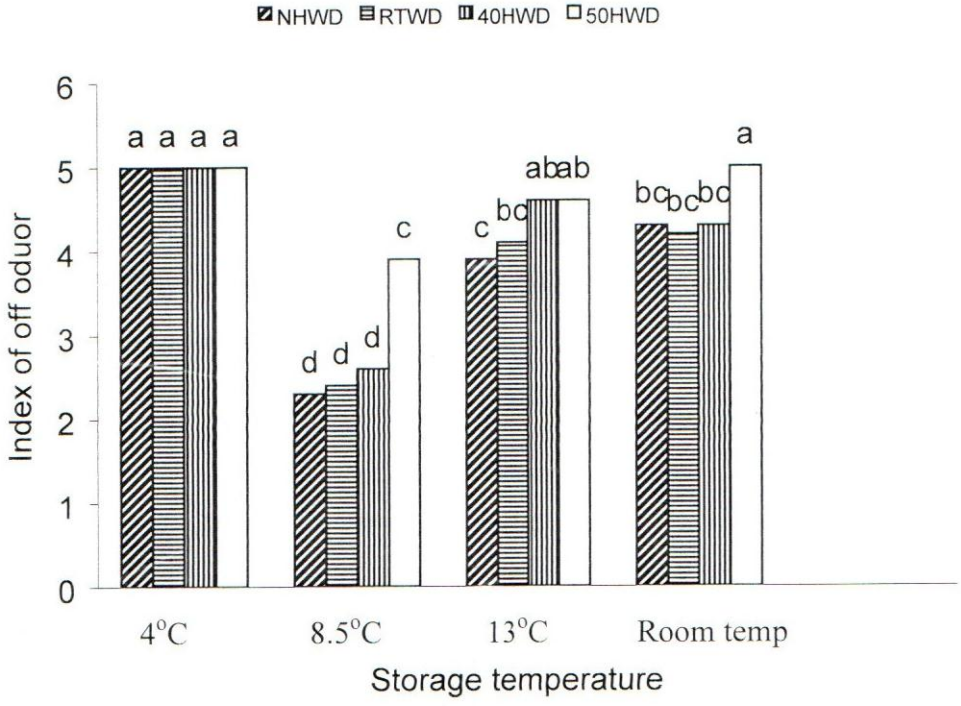


Figure 13a. Effects of hot water dipping and storage temperature on off oduor of okra after 21 days of storage (Trial 1)

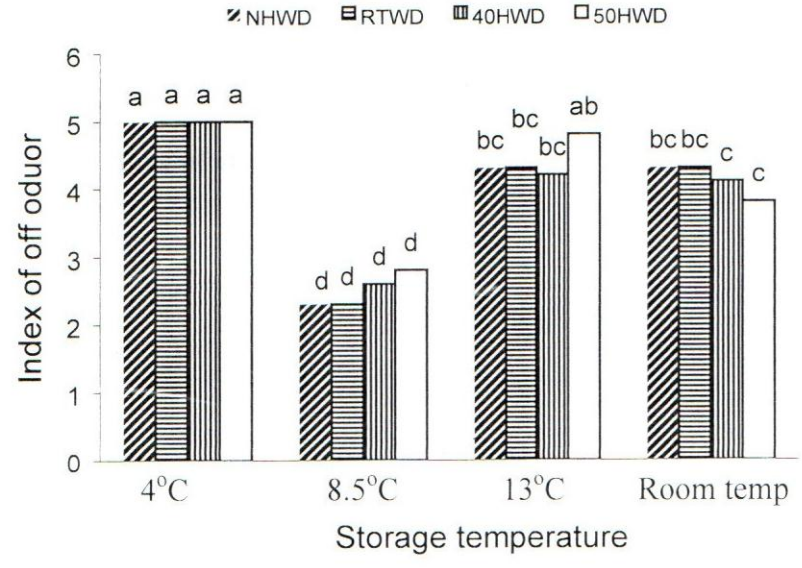


Figure 13b. Effects of hot water dipping and storage temperature on off oduor of okra after 21 days of storage (Trial 2)

Effects of hot water dipping and packaging on off odour

In all hot water treatments, least off odour was more prevalent with pods in free pod packaging as these pods were shrivelled and dry. Worst pods were in the non perforated packaging. Hot water dipping at 50°C in perforated packaging produced better results in reducing off odour and therefore more acceptable pods with an exception of free pods (Figure 14a and 14b). The best odour was produced in perforated packaging and hot water dipped pods at 50°C.

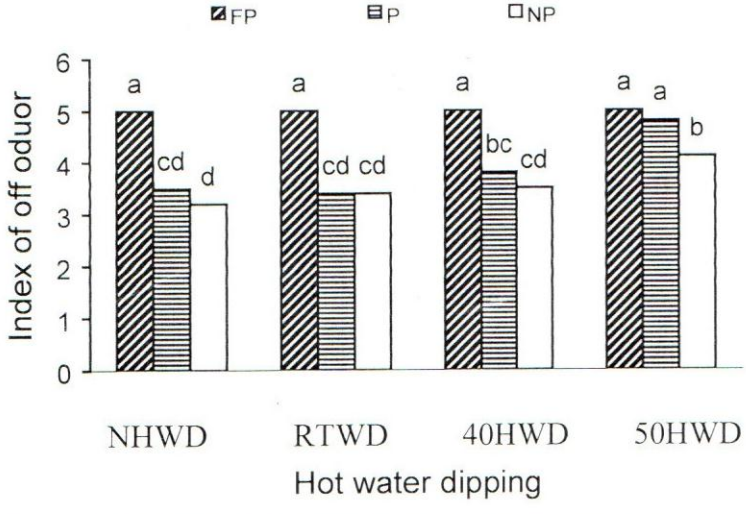


Figure 14a. Effects of hot water dipping and packaging on off oduor of okra after 21 days of storage (Trial 1)

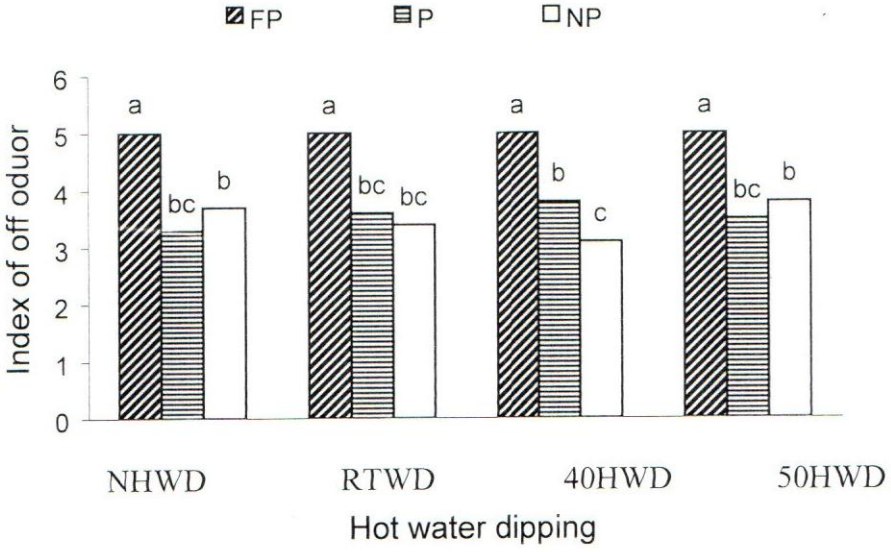


Figure 14b. Effects of hot water dipping and packaging on off oduor of okra after 21 days of storage (Trial 2)

Effects of storage temperature and packaging on off odour

In all packaging treatments, storage temperature of 4°C produced no off odour since the pods were frozen. Storage at 8.5°C had the worst off odour. Best marketable pods with least off odour were from room storage conditions in perforated packaging (Figure 15a). Figure 15b confirms the same results in the case of trial two, only that the best pods were from the 13°C storage temperature treatment in non perforated packaging.

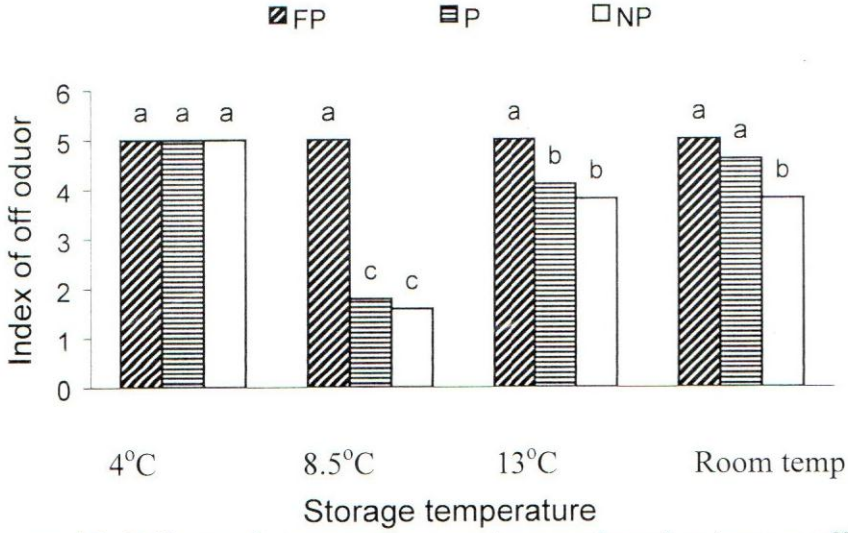


Figure 15a Effects of storage temperature and packaging on off oduor of okra after 21 days of storage (Trial 1)

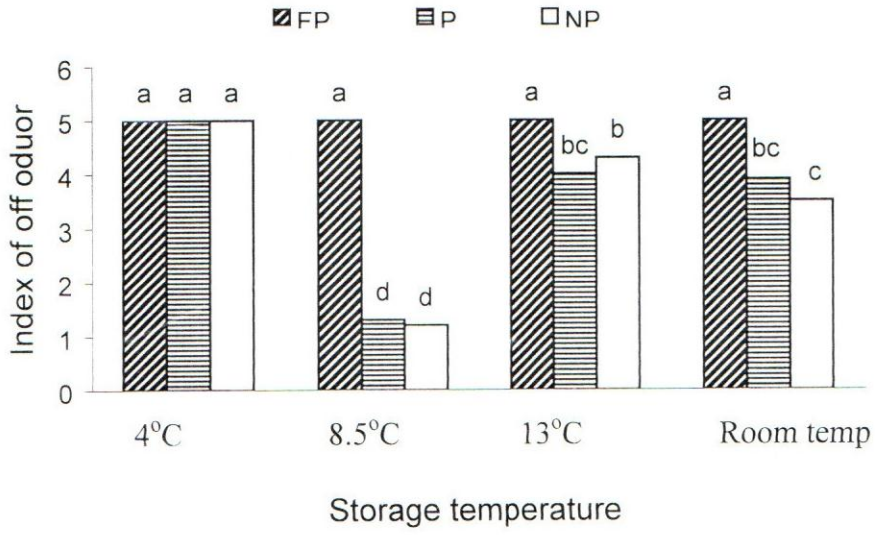


Figure 15b. Effects of storage temperature and packaging on off oduor of okra after 21 days of storage (Trial 2)

Interactive effects of hot water dipping, storage temperature and packaging on off odour

There was no off odour in pods stored in the 4°C storage temperature and in free pod packaging. The pods at 4°C were frozen and in free pod packaging were dry and hence did not decay. The best storage with least off odour were with pods under room storage conditions in perforated and non perforated packaging and treated in hot water dipping at 50°C (Table 22a). Worst combination was that of 8.5°C storage temperature at all hot water treatments except 50°C hot water dipping in trial 1. In trial 2 it was 8.5°C storage temperature at all hot water treatments. Trial two shows similar results, but the best treatment was with pods treated under 50°C hot water dipping, 13°C storage temperature and in non perforated packaging (Table 22b).

Table 22a. Interactive effects of hot water dipping, storage temperature and packaging on off oduor of okra after 21 days (Trial 1)

Hot water dipping	Storage temperature	Index of off odour		
		No package (Free pods)	Perforated polythene	Non perforated polythene
No water dipping	4°C	5.0a[z]	5.0a	5.0a
	8.5°C	5.0a	1.0f	1.0f
	13°C	5.0a	3.0de	3.0de
	Room temperature[y]	5.0a	4.7a	3.0de
Room temperature water dipping	4°C	5.0a	5.0a	5.0a
	8.5°C	5.0a	1.0f	1.3f
	13°C	5.0a	3.3cde	4.0abc
	Room temperature	5.0a	4.3ab	3.3cde
40°C Hot water dipping	4°C	5.0a	5.0a	5.0a
	8.5°C	5.0a	1.3f	1.3f
	13°C	5.0a	4.7a	4abc
	Room temperature	5.0a	4.3ab	3.7bcd
50°C Hot water dipping	4°C	5.0a	5.0a	5.0a
	8.5°C	5.0a	4.0abc	2.7e
	13°C	5.0a	5.0a	3.7bcd
	Room temperature	5.0a	5.0a	5.0a

[z] Means followed by the same suffix are not significantly different in all columns at DMRT $P \leq 0.05$

[y]Room temperature varied between 15-20°C

Table 22b. Interactive effects of hot water dipping, storage temperature and packaging on off oduor of okra after 21 days (Trial 2)

Hot water dipping	Storage temperature	Index of off odour		
		No package (Free pods)	Perforated polythene	Non perforated polythene
No water dipping	4°C	5.0a[z]	5.0a	5.0a
	8.5°C	5.0a	1.0f	1.0f
	13°C	5.0a	3.7bcde	4.3abc
	Room temperature[y]	5.0a	3.7bcde	4.3abc
Room temperature water dipping	4°C	5.0a	5.0a	5.0a
	8.5°C	5.0a	1.0f	1.0f
	13°C	5.0a	4.0abcd	4.0abcd
	Room temperature	5.0a	4.3abc	3.7bcde
40°C Hot water dipping	4°C	5.0a	5.0a	5.0a
	8.5°C	5.0a	1.7f	1.0f
	13°C	5.0a	4.0abcd	3.7bcde
	Room temperature	5.0a	4.7ab	2.7e
50°C Hot water dipping	4°C	5.0a	5.0a	5.0a
	8.5°C	5.0a	1.7f	1.7f
	13°C	5.0a	4.3abc	5.0a
	Room temperature	5.0a	3.0de	3.3cde

[z]Means followed by the same suffix are not significantly different in all columns at DMRT $P \leq 0.05$

[y]Room temperature varied between 15-20°C

4.1.6 Effects of hot water dipping, storage temperature and packaging on visual appearance

Best visual appearance was significant in pods treated with hot water dipping at 50°C followed by those with 40°C hot water dipping. Worst looking pods were from non hot water dipping treatment. Same results were observed in both trials (Table 23). During the experiment, hot water dipping at 40°C and 50°C reduced the characteristic blackening on the ridges of the okra pods as they stood out from the other pods.

Table 25 Effect of packaging on okra visual appearance after 21 days of storage

Packaging	Index of visual appearance	
	Trial 1	Trial 2
Free pod packaging	3.0 b*	2.8b*
Perforated packaging	4.3 a	3.8a
Non perforated packaging	4.2 a	3.8a

* Means followed by the same suffix are not significantly different at DMRT $P \leq 0.05$

Effects of hot water dipping and storage temperature on visual appearance

The best visual appearance was observed in pods stored at room and 13°C storage temperatures. Storage temperature at 8.5°C had the worst visual appearance but at 50°C hot water dipping visual appearance was improved slightly in comparison to the other hot water treatments. At 13°C storage temperature, 40°C and 50°C hot water dipping maintained good visual appearance. The best visual appearance was maintained at room storage temperature in 50°C hot water dipping (Figure 16a).

In trial two (Figure 16b) hot water dipping and higher storage temperatures maintained visual appearance but the best pods were observed at 13°C storage temperature in 50°C hot water dipping.

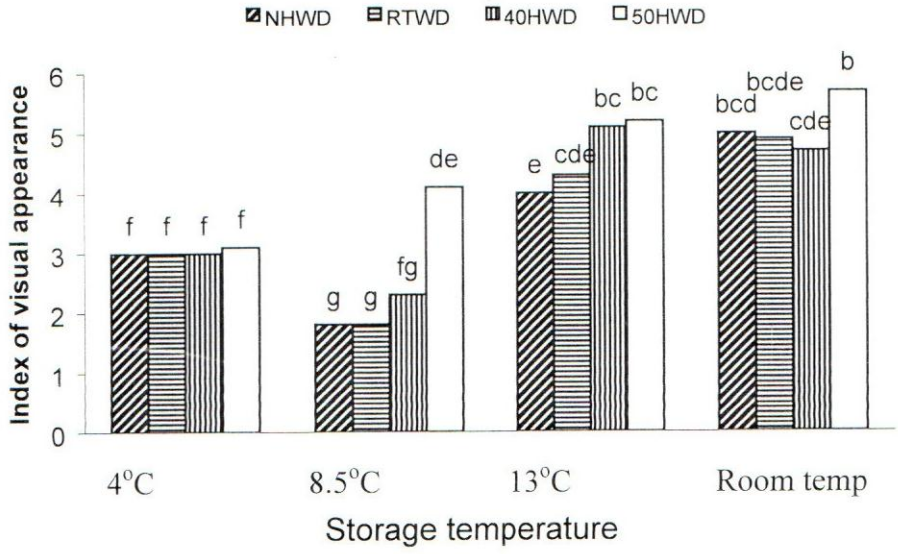


Figure 16a. Effects of hot water dipping and storage temperature on visual appearance of okra after 21 days of storage (Trial 1)

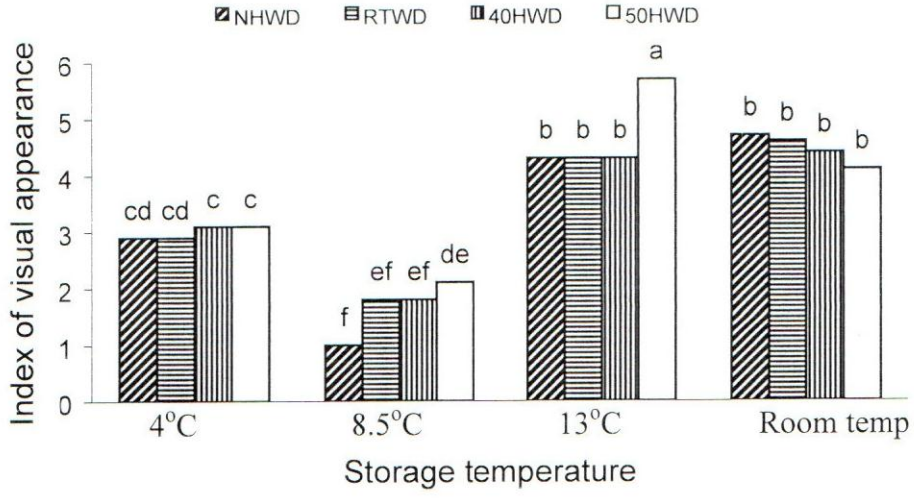


Figure 16b. Effects of hot water dipping and storage temperature on visual appearance of okra after 21 days of storage (Trial 2)

Effects of hot water dipping and packaging on visual appearance

Generally hot water dipping at 40°C and 50°C enhanced visual appearance at all packaging levels. The worst packaging treatment was in free pod packaging at all hot water treatments. The best visual appearance was observed at 50°C hot water treatment in perforated packaging (Figure 17a). In trial two the trend was the same but the best visual

appearance was at 50°C hot water dipping in non perforated packages although this was not significantly different from perforated packaging at the same hot water treatment and 40°C hot water dipping in perforated packaging (Figure 17b).

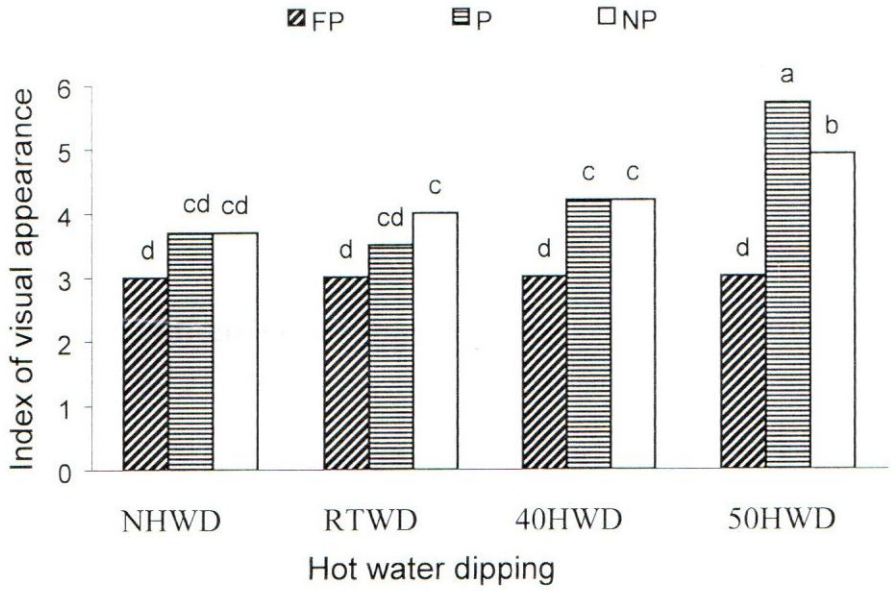


Figure 17a. Effects of hot water dipping and packaging on visual appearance of okra after 21 days of storage (Trial 1)

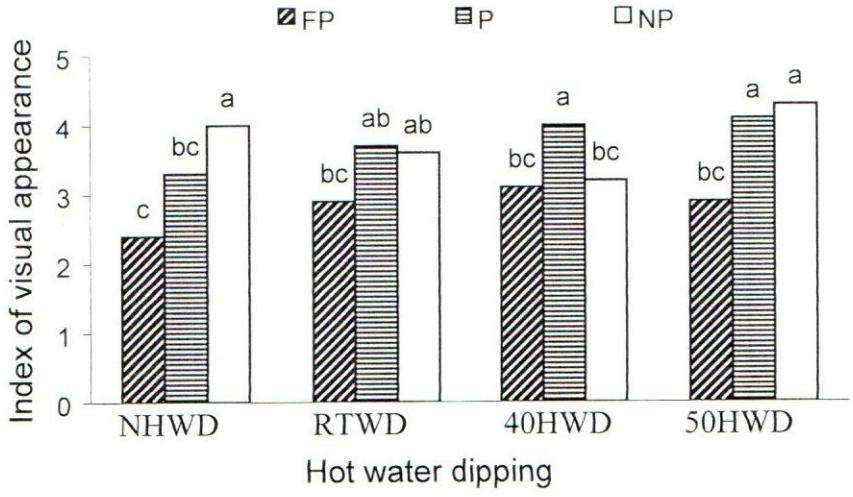


Figure 17b. Effects of hot water dipping and packaging on visual appearance of okra after 21 days of storage (Trial 2)

Effects of storage temperature and packaging on visual appearance

The best visual appearance was in room storage temperature in perforated packaging (Figure 18a). In both trials the worst visual appearance was in 8.5°C storage temperature. In trial 2 the trend was similar only that the best pods were obtained at 13°C storage temperature in non perforated packaging although not significantly different from pods in perforated packaging and also those in room temperature storage in perforated and non perforated packaging (Figure 18b).

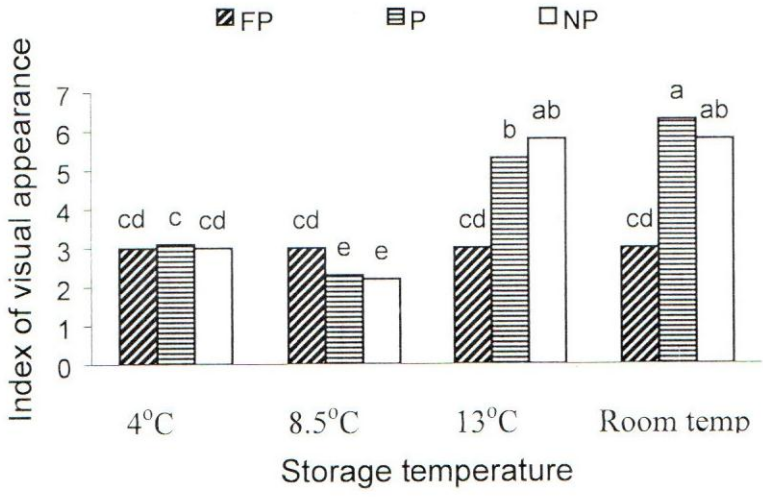


Figure 18a. Effects of storage temperature and packaging on visual appearance of okra after 21 days of storage (Trial 1)

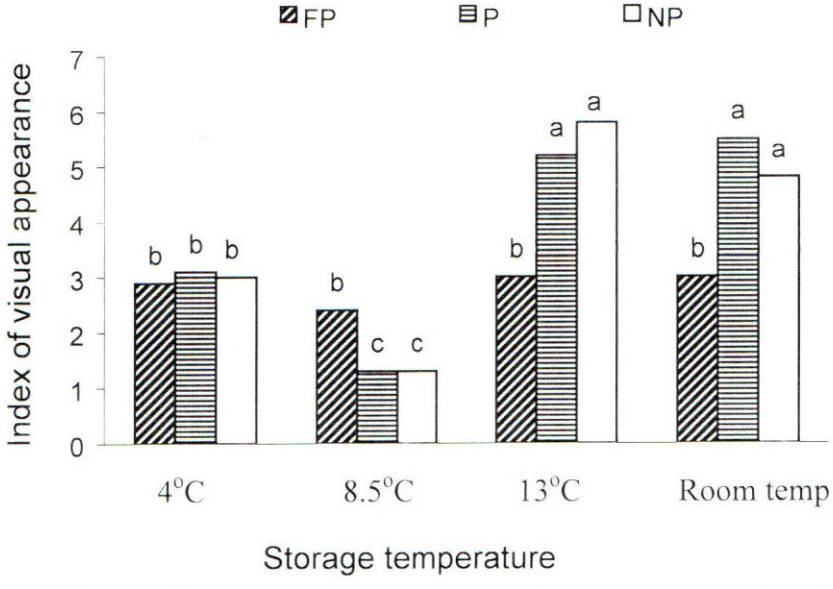


Figure 18b. Effects of storage temperature and packaging on visual appearance of okra after 21 days of storage (Trial 2)

Interactive effects of hot water dipping, storage temperature and packaging on visual appearance

The worst pods were those not dipped in hot water and those in room temperature water dipping, in perforated and non perforated packaging at 8.5°C storage temperature. Optimal visual appearance was at room storage temperature at 50°C hot water dipping in perforated and non perforated packaging and storage at 13°C in perforated packaging treated in 50°C hot water dipping (Table 26a). In trial two, the worst pods were at 8.5°C storage temperature at all hot water treatment levels except those in 50°C hot water dipping. The best pods were observed in 50°C hot water dipping treatment, stored at 13°C and in perforated and non perforated packaging (Table 26b).

Table 26a. Interactive effects of hot water dipping, storage temperature and packaging on visual appearance of okra after 21 days of storage (Trial 1)

Hot water dipping	Storage temperature	Index of visual appearance		
		No package (Free pods)	Perforated polythene	Non perforated polythene
No water dipping	4°C	3.0hi[z]	3.0hi	3.0hi
	8.5°C	3.0hi	1.0j	1.3j
	13°C	3.0hi	4.3efgh	4.7defg
	Room temperature[y]	3.0hi	6.3abc	5.7abcde
Room temperature water dipping	4°C	3.0hi	3.0hi	3.0hi
	8.5°C	3.0hi	1.0j	1.3j
	13°C	3.0hi	4.0fgh	6.0abcd
	Room temperature	3.0hi	6.0abcd	5.7abcde
40°C Hot water dipping	4°C	3.0hi	3.0hi	3.0hi
	8.5°C	3.0hi	2.0ij	2.0ij
	13°C	3.0hi	5.7abcde	6.7ab
	Room temperature	3.0hi	6.0abcd	5.0cdef
50°C Hot water dipping	4°C	3.0hi	3.3ghi	3.0hi
	8.5°C	3.0hi	5.3bcdef	4.0fgh
	13°C	3.0hi	7.0a	5.7abcde
	Room temperature	3.0hi	7.0a	7.0a

[z]Means followed by the same suffix are not significantly different in all columns at DMRT $P \leq 0.05$

[y]Room temperature varied between 15-20°C

Table 26b. Interactive effects of hot water dipping, storage temperature and packaging on visual appearance of okra after 21 days of storage (Trial 2)

Hot water dipping	Storage temperature	Index of visual appearance		
		No package (Free pods)	Perforated polythene	Non perforated polythene
No water dipping	4°C	3.0fghi[z]	3.0fghi	3.0fghi
	8.5°C	1.0j	1.0j	1.0j
	13°C	3.0fghi	3.7defg	6.3ab
	Room temperature[y]	3.0fghi	5.3bcd	5.7abc
Room temperature water dipping	4°C	2.7fghi	3.0fghi	3.0fghi
	8.5°C	3.0fghi	1.0j	1.3ij
	13°C	3.0fghi	4.7bcde	5.3bcd
	Room temperature	3.0fghi	6.0ab	4.7bcde
40°C Hot water dipping	4°C	3.3efgh	3.0fghi	3.0fghi
	8.5°C	3.0fghi	1.3ij	1.0j
	13°C	3.0fghi	5.3bcd	4.7bcde
	Room temperature	3.0fghi	6.3ab	4.0def
50°C Hot water dipping	4°C	3.0fghi	3.3efgh	3.0fghi
	8.5°C	2.7fghi	1.7hij	2.0ghij
	13°C	3.0fghi	7.0a	7.0a
	Room temperature	3.0fghi	4.3cdef	5.0bcd

[z]Means followed by the same suffix are not significantly different in all columns at DMRT $P \leq 0.05$

[y]Room temperature varied between 15-20°C

CHAPTER FIVE

DISCUSSION

5.0 Senescence and Shelf life

Some okra pods placed in the open were dried and shriveled; others in polyfilm bags were rotten after 21 days of storage. Ripening and senescence that leads to fruit deterioration in storage can explain this. The continued responsiveness of climacteric fruit to ethylene during and after ripening is one reason why senescing occurs (Thompson, 1996). Hence the need to inhibit or slow down the senescing process for extended shelf life.

Senescing fruit usually has enhanced softness which could be partly due to weight loss, as a result of active wound induced synthesis or passive activation of pre-existing catalytically quiescent enzyme stimulation of hydrolytic enzymes especially upon tissue wounding. Several authors have reported enhanced activity of pectin hydrolyses and increased pectin depolymerisation upon tissue wounding (Huber et al., 2005) Tissue wounding in okra could have been caused by harsh storage temperature, hot water treatment as well as mechanical damage at harvest.

Evidence gathered supports membrane damage as the key event leading to a cascade of biochemical reactions culminating in tissue deterioration and economic loss. Biophysical changes in membrane lipids and enzymatic and non-enzymatic peroxidation lead to altered membrane properties and result in ion leakage and cellular decompartmentation. Damage to cell membranes that increases ion leakage and water loss has been attributed in part to changes in lipoxygenase activity. Electrolyte leakage from tomato fruit increased as ripening progressed. Cell membrane changes leading to cell death as induced in part by both lipoxygenase and the reactive oxygen that increases as fruit ripens. Disruption of cell membranes could result in mixing of cell contents leading to further injury causing deterioration (Kissinger et al., 2005)

To alleviate or reduce this senescing processes in okra various methods such as packaging, different storage temperatures and hot water dipping were used as discussed.

5.1 Hot Water Dipping

In considering single treatments hot water dipping at 50°C for one minute was more effective in enhancing pod quality than the 40°C hot water dipping for seven minutes (Table 11). This is because at higher temperatures for shorter durations there is least impact on fruit quality than lower temperatures for longer periods (Cantwell de Trejo, 1998). Pods not dipped in hot water and those dipped in room temperature water did poorly. Furthermore the 50°C hot water treatment was better in suppressing weight loss compared to the other hot water treatments. This could be attributed to stress proteins, dehydrins, which are produced during hot water treatment. As reported by Neven and Drake (1998), these proteins along with other physiological mechanisms help the fruit to prevent water loss and withstand environmental stress. Hot water treated pods had best visual appearance with least blackening on the ridges, a characteristic found in stored okra pods. It is possible that okra pods respond to heat shock by producing unique heat shock proteins (hsp) that help prevent further stress. Induction of the synthesis of hsp is accompanied by reduction in the synthesis of other proteins, such as the suppression of PAL (phenylalanine ammonia lyase) reducing phenolic compounds that cause browning in wounded lettuce tissue and other produce (Saltveit, 1998). This would in turn reduce shelf life and marketability, which could explain the good visual appearance in the pods treated with hot water as blackening was greatly inhibited thus resulting in a very good green colour.

Similar work by Woolf, *et al.* (1995) found that hsp usually confer tolerance at low temperatures as reduction in chilling injury was related to increased levels of hsp that reduced symptoms. Furthermore, research by Collins (2003) has shown that synthesis of hsp continued upto 9 days after the heat shock and as their synthesis gradually declined the tissue becomes correspondingly less tolerant to chilling This can explain the reduced chilling injury at 50°C for 1 minute in the 4°C and 8.5°C refrigeration on day 21. Although chilling injury was not much by day 14, the tolerance started declining on the following week of storage.

Decay was reduced by 18% in hot water treatment at 50°C for one minute when compared to highest decay incidence found in the no hot water dipping treatment. This

could possibly suggest that pods usually have latent infection from the farm and the hot water treatment decreased microorganism population. This is likely so because Sommer (1992) clearly showed that disease incidence and severity depends on the number of fungus spores or pathogen population present.

The present study also showed that decay reduction was by about 6% in pods picked from older plants indicating more latent infection than those from young plants. Fruits, especially those for export are harvested at a stage of maturity where the fungus has not penetrated the fruit but is firmly fixed to its surface at the resistant aspersoria stage. Postharvest treatment with a fungicide is generally reported to be ineffective in controlling fungal diseases but immersing fruits in hot water can give good disease control (Thompson, 1996).

Hot water dipping at 50°C reduced decay more than the other treatments. Off oduor was consequently reduced by hot water dipping at 50°C as this is usually caused by decay. Electrolyte leakage was also inhibited as this is also caused by decay and chilling injury. The 50°C hot water treatment had the best results in inhibiting electrolyte leakage. Heat treatment induced hsp probably suppressed oxidative activity and maintained membrane stability and hence enhanced pod quality.

Weight loss was prevented and chilling injury suppressed in pods dipped at 50°C hot water temperature. This is possibly due to the hot water treated fruits loosing less weight as a result of melting of natural surface wax, which seals natural openings and invisible cracks on produce, therefore, increasing resistance to chilling injury. Short hot water rinse and brush technique is commercially used on peppers, melons, mangoes, sweet corn, litchi and tomatoes among others. Wang (2001) reports that this technology had reduced postharvest losses in Israel to less than 2% saving the country $ 15 million and increasing markets to USA and Europe. The same experience is likely with okra pods.

5.2 Storage temperature

Results show that there was no chilling injury in okra at 13°C and room storage temperatures. Decay was also relatively reduced at room and 13°C storage temperature. In trial one decay was reduced by 40% while a repeat experiment had decay reduced by 43%. The best storage condition was the room temperature storage, which had a

maximum and minimum temperature of between 15°C to 18°C, the 13°C storage temperature following closely. Okra pods, like other tropical fruits, should be stored at a temperature above 13°C. Electrolyte leakage was reduced at 13°C storage temperature followed by room temperature storage. Off odour at 13°C and room storage temperature was exceptionally good. Best visual appearance was at room temperature storage and was not different from the 13°C storage. At this temperature range and in combination with perforated packaging and hot water treatment, decay, electrolyte leakage and off odour were controlled.

Visual appearance was optimal and there was no chilling injury. Weight loss was, however, high but not too much to reduce marketability especially due to packaging. This suggests that in very hot production areas with temperatures above 25°C, refrigerators are not a necessity and all that is required is an insulated store built of special cooling material. This approach saves the need for electricity. At 4°C storage temperature, the okra pods were frozen and hence showed no decay, but there was severe chilling injury though a little tolerance was seen initially in the 50°C hot water treated pods. Pods can therefore be stored at 4°C for only a very brief period when hot water treated but this is apparently uneconomical, as refrigerators and electricity will be used. At 8.5°C storage temperature the 50°C hot water treatment prevented chilling injury upto the 14th day after which pods started showing symptoms though less severe than in the 4°C treatments. Storage at 8.5°C was very susceptible to decay chilling injury, and hence the very high electrolyte leakage at 4°C and 8.5°C. This could be an indication that the pod membrane was damaged, therefore, causing solute leakage. Thompson (1996) reported that the lower the temperature the longer the storage duration. For okra this does not agree with Thompson's observations since results showed that the optimal temperature is between 13°C and 18°C where the best quality of pods was achieved, as okra is a tropical vegetable.

5.3 Packaging

Packaged okra pods had less weight loss and good visual appearance when compared to free pod packaging. Packaging might have improved moisture retention, and reduced exposure to microorganisms and contaminants. Perforated packaging had better

storing ability than non perforated packaging. Similar findings have been made with bell peppers stored in perforated packaging which had a lower decay incidence than in non perforated packaging (Yehoshua et al., 1998). It was also found that pods in perforated packaging had less off odour than those in non perforated packaging. This finding is also similar to a study carried out on parsley where perforated packaging retained flavour and aroma better than in non perforated packaging (Heyes, 2004). In storage, ventilation is very important to avoid build up of carbon dioxide and heat as non perforation permits slow gas exchange combined with vapour and heat build up leading to rapid deterioration.

Electrolyte leakage was reduced in perforated packaging in comparison to the other packaging methods. Chilling injury was most reduced by packaging in perforated polythene. A most likely explanation could be that electrolyte leakage and carbon dioxide increased proportionally with chilling injury incidence and storage duration therefore reducing chilling injury in the perforated packaging. Storing okra pods in packages was very helpful since pods not packaged dried out long before the 21st day.

The best packaging was perforated as it gave good ventilation and hence had less decay and chilling of the pods. Perforated packaging can accumulate carbon dioxide to levels within the fungistatic range unlike non perforated packages that have a high relative humidity, high reduction of weight loss would aggravate decay. In support of this observation, the non perforated pods had higher incidence of decay as this encouraged moisture retention in the packaging and on the pods thus providing a good environment for microbial growth. At the end of 21 days the non perforated and perforated packaged pods were still marketable unlike the free stored pods.

5.4 Hot water treatment and storage temperature

Hot water treatment when used at low temperature storage slightly reduced chilling injury in the okra pods. This was very conspicuous in the 50°C hot water dipping and storage at 8.5°C compared to storage at 4°C, which experienced chilling injury. Hot water treatment was more effective at higher temperatures and less effective at lower temperatures. A wide range of research findings has shown that hot water treatments alleviate chilling injury in several fruits (Nair R., *et al,* 2001). This could be attributed to

reduced respiration and ethylene production that result in increasing storage duration.

Another school of thought could be due to the fact that heat treatment induced heat shock protein in okra. On storage, heat shock proteins induced by hot water treatment are reinduced by the cold temperatures and hence conferred resistance to chilling injury according to a study by Vlachonasios K. E., *et al.*, (2001) on tomatoes.

Hot water treatment and low temperature storage helped reduce decay incidence in the okra pods. Lowest disease incidence in okra pods was at 4°C and also in hot water treatment at 50°C, thus reducing disease caused decay in the higher storage temperatures. This also applied to bell peppers and tomatoes treated to 50-53°C hot water treatment for 2-3 minutes and then stored at low temperature. Hot water inhibited, weakened or prevented the germination of *Alternaria alternata*, *Botrytis cinerea* and also controlled chilling injury (Lurie *et al*, 1996). Even at higher temperatures hot water treatment prevented decay in okra pods. Microorganisms infection was low in okra treated with hot water and stored at ambient temperatures. Okra that was hot water treated and stored under low temperature had diminished fungal decay as seen in okra stored at 4°C.

Pods at 50°C hot water treatment had less decay, off odour and electrolyte leakage and hence were of high quality after day 21. At low temperature storage of 4°C there was no decay and therefore no off odour but chilling injury increased electrolyte leakage and damaged the pods. This is mainly because okra is a tropical fruit and is susceptible to chilling injury at low temperature storage. The best okra storage treatment was at room storage and hot water treatment at 50°C for one minute.

Hot water treatment and low temperature storage increased fruit firmness due to reduced water loss of okra and delayed senescence. Similar studies show that ripening was inhibited in strawberries dipped in hot water and stored at low temperatures (Civello *et al.*, 1997 and also in bananas treated in hot water and stored at high temperatures of 26-32°C (Acedo *et al.*, 2001). In okra, visual appearance was optimum with pods dipped in hot water and kept at room temperature making the pods more marketable thus concurring with the above results. This could probably mean that hot water treatment at high temperatures delayed senescence of okra pods and prevented yellowing of the pods.

5.5 Hot water treatment and packaging

Hot water treatment helped to reduce decay caused by microorganisms and consequently packaging prevented further reinfection that would cause decay on produce. This was evident where an interaction of hot water dipping at 50°C and perforated packaging considerably reduced decay. Consequently reduced decay also means reduced off odour on the okra pods. Packaging and hot water treatment greatly prevented loss in weight and visual appearance hence improving the quality and, therefore, marketability of okra pods. Hot water treatment and packaging also alleviated electrolyte leakage and chilling injury in okra pods. The best treatment combination was that of hot water treatment at 50°C and packaging in perforated packaging.

5.6 Storage temperature and packaging

Storage temperature and packaging greatly reduced weight loss in okra pods. Storage at 4°C in non perforated packaging had negligible weight loss compared to the other storage temperatures and free pod packaging. This could be due to increased humidity by packaging and reduced metabolism and respiration at low temperature storage. This would in turn provide increased shelf life, fresh appearance, and sufficient internal fluid to maintain turgor and hence reduce weight loss and shrivelling in the pods. This may also explain why okra pods under free packaging and stored at all temperatures were not marketable by day 21. Pods stored at 4°C had least weight loss but chilling injury damaged the pods. In a similar study, storing apples at 0°C in modified atmosphere storage increased firmness, maintained quality and decreased weight loss due to low temperatures and high humidity (Brackman and Bortoluzzi, 2001), thus supporting the findings and observations in the okra study.

Pods stored at high temperatures of 13°C and room storage temperatures had no chilling injury. Low temperature storage caused chilling injury in okra pods. Packaging however reduced chilling injury in perforated and non perforated packaging methods.

Pod blackening was inhibited in perforated packaging kept under room storage giving the best visual appearance of okra pods. This could be explained by the fact that shelf life was severely curtailed by pod darkening but this was controlled by atmosphere modification, which increased shelf life and inhibited discolouration of pods.

In some fruits, packaging at low temperatures gives the best quality of produce after storage while in others packaging at higher temperatures gives the best results. For example, storage of mangoes at low temperature and various packaging delayed ripening, decreased weight loss and increased shelf life. It did not affect changes in soluble solutes and acidity (Jeronimo and Kanesiro, 2000). Peppers stored at 11 ± 1°C in plastic films had shelf life extended by 14 days after evaluation of microbial and quality parameters (Nuin and Perez- Villareal, 2000). These comparative experiences agree with findings that hot water treatment and packaging in okra storage gave optimal quality at room storage and in perforated packaging providing pods with good visual appearance, least off odour, low decay, low electrolyte leakage, no chilling injury and reasonable weight loss. The pods stored under these conditions were of high quality and optimal marketability.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

•The best postharvest treatment combination for okra was hot water dipping at 50°C for one minute, packaging in perforated polyfilm bags and storing at room temperature of 15-19°C.

•It reduced weight loss, electrolyte leakage, off odour, decay, enhanced visual appearance and had no chilling injury.

•The treatment combination suppressed pod quality deterioration and improved shelf life for 21 days.

6.2 Recommendations

- Pods should be hot water dipped at 50°C for one minute.
- Use perforated polythene bags.
- Store pods at 15-19° C room temperature.
- Observe strict hygiene to reduce decay as one infected pod quickly spoils the other pods.

6.3 Further research

Further research needs to be carried out on:

•Improvisation of local cold rooms for farmers using charcoal walls that are regularly watered.

• Research on various hot water dipping temperatures, as 50°C was the maximum temperature investigated as well as time duration for various temperatures to give optimal quality of okra pods.

•Trying this technology on other horticultural produce.

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APPENDIX

Table 2: Experimental layout in storage temperatures

REFRRIDGERATOR 1 (4°C)

NP4	FP3	P3	P4	P1	NP2	NP3	NP1	FP2	FP4	FP1	P2
NP2	FP3	FP1	P3	FP4	P1	NP1	FP2	P2	NP4	P4	NP3
P3	FP4	P1	NP2	NP4	NP3	P4	FP1	FP2	FP3	P2	NP1
P2	FP4	NP3	P1	NP4	FP3	FP1	NP2	NP1	FP2	P3	P4
NP4	FP3	P2	NP3	FP2	P3	NP2	FP3	P2	NP1	FP4	P1
NP1	P3	NP3	FP1	FP2	FP3	NP2	FP4	P2	P4	NP4	P1

REFRRIDGERATOR 2 (8.5°C)

NP4	FP3	P3	P4	P1	NP2	NP3	NP1	FP2	FP4	FP1	P2
NP2	FP3	FP1	P3	FP4	P1	NP1	FP2	P2	NP4	P4	NP3
P3	FP4	P1	NP2	NP4	NP3	P4	FP1	FP2	FP3	P2	NP1
P2	FP4	NP3	P1	NP4	FP3	FP1	NP2	NP1	FP2	P3	P4
NP4	FP3	P2	NP3	FP2	P3	NP2	FP3	P2	NP1	FP4	P1
NP1	P3	NP3	FP1	FP2	FP3	NP2	FP4	P2	P4	NP4	P1

REFRRIDGERATOR 3 (13°C)

NP4	FP3	P3	P4	P1	NP2	NP3	NP1	FP2	FP4	FP1	P2
NP2	FP3	FP1	P3	FP4	P1	NP1	FP2	P2	NP4	P4	NP3
P3	FP4	P1	NP2	NP4	NP3	P4	FP1	FP2	FP3	P2	NP1
P2	FP4	NP3	P1	NP4	FP3	FP1	NP2	NP1	FP2	P3	P4
NP4	FP3	P2	NP3	FP2	P3	NP2	FP3	P2	NP1	FP4	P1
NP1	P3	NP3	FP1	FP2	FP3	NP2	FP4	P2	P4	NP4	P1

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ROOM TEMPERATURE STORAGE (15-20°C)

NP4	FP3	P3	P4	P1	NP2	NP3	NP1	FP2	FP4	FP1	P2
NP2	FP3	FP1	P3	FP4	P1	NP1	FP2	P2	NP4	P4	NP3
P3	FP4	P1	NP2	NP4	NP3	P4	FP1	FP2	FP3	P2	NP1
P2	FP4	NP3	P1	NP4	FP3	FP1	NP2	NP1	FP2	P3	P4
NP4	FP3	P2	NP3	FP2	P3	NP2	FP3	P2	NP1	FP4	P1
NP1	P3	NP3	FP1	FP2	FP3	NP2	FP4	P2	P4	NP4	P1

Key

NP- Non-perforated polythene bag package

P – Perforated polythene bag package

FP- Free pods (Not packaged)

1 - No water dipping

2 - Room temperature water dipping

3 - 40°C hot water dipping

4 - 50°C hot water dipping

ANOVA TABLE

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	v.r	F pr
Replicates	5				
Hot water treatment	3				
Residual	15				
Storage temperature treatment	3				
Hot water & storage temperature	9				
Residual	60				
Package treatment	2				
Hot water & package treatment	6				
Storage temperature & package	6				
Hotwater, storage temperature & package	18				
Residual	160				
Total	287				