



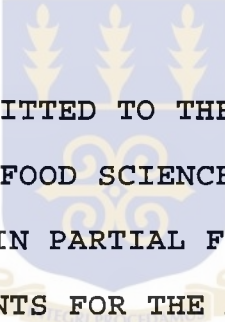
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A STUDY OF BETA-CAROTENE STABILITY IN
PROCESSED VITAMIN A-RICH FOODS

BY

MICHAEL DONYINAH ADJEI

The logo of the University of Ghana is a shield-shaped emblem. It features three golden stalks of grain (likely rice or wheat) arranged vertically in the center. The shield is blue with golden borders and decorative elements. Below the shield is a banner with text in both English and Ghanaian languages.

A THESIS SUBMITTED TO THE DEPARTMENT OF
NUTRITION AND FOOD SCIENCE, UNIVERSITY OF
GHANA, LEGON, IN PARTIAL FULFILMENT OF THE
REQUIREMENTS FOR THE AWARD OF AN
M. Phil. DEGREE IN FOOD SCIENCE

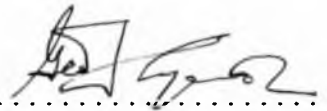
DECEMBER, 1995

DECLARATION

I certify that this work was done by me, under supervision, in the Department of Nutrition and Food Science, University of Ghana, Legon.



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DEDICATION

To the glory of God



ABSTRACT

Vitamin A deficiency (VAD) is a public health problem in Ghana, leading to blindness. Year-round access to Vitamin A-rich foods will curb its incidence. This study sought to identify appropriate processing, preservation and fortification methods to enhance β -carotene retention in foods towards VAD alleviation.

Carrots were steamed, blanched in water, NaHSO_3 , NaCl or alkali rocksalt (Kanwa) solutions. *Amaranthus* and *Xanthosoma* leaves were blanched in a range of kanwa solutions (0-0.1%) at varied temperatures (85-100°C) and time (4-10 min). The effect of the treatment and storage time (0-90 days) of the samples was studied by determining the β -carotene using HPLC. β -carotene degradation in palm oil was evaluated at 100-200°C for 0-240 min. Carrots and palm oil were incorporated into *gari* at 0-20% by co-fermenting or fermenting before addition. β -carotene stability was predicted with mathematical models during processing and storage.

Highest β -carotene retention occurred in oven-dried NaCl , NaHSO_3 and kanwa treated carrots (22.9-65.6%) after storage. Kanwa blanching improved carotene retention during dehydration and storage of *Amaranthus* and *Xanthosoma*. Solar dried products had longer β -carotene half-lives ($T_{1/2}$) than oven dried. High heating temperatures caused complete loss of β -carotene and colour. Thermal degradation rates of $3.9-99.7 \times 10^{-3} \text{ min}^{-1}$ and an activation energy (E_a) of 4.8 Kcal/mole in palm oil were calculated. *Gari* products fortified with carrots and palm oil had 13-28 and 11-20 mg/100g β -carotene respectively. β -carotene losses occurred during fermentation (5-57%) and roasting (30-60%). The rate of β -carotene loss was slower in co-fermented products during storage.

NaCl and kanwa could be used in the preservation of carotene in carrots. Carrot and palm oil fortification of *gari* improved its vitamin A and organoleptic properties. The use of palm oil in deep-fat frying is not recommended. Degradation kinetics and response surface plots generated from predictive models could establish the relationships between processing factors and β -carotene retention.

ACKNOWLEDGEMENT

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I am sincerely grateful to all those who in diverse ways contributed to the successful completion of this work but could not be mentioned.

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1.0 INTRODUCTION

1.1 INCREASING FOOD AND NUTRIENT AVAILABILITY - THE NEED FOR APPROPRIATE PROCESSING AND PRESERVATION METHODS.

The goal of eliminating hunger and malnutrition world wide has necessitated the need for better food processing and preservation methods to ensure nutrient stability and prolong shelf-life of foods. Studies into the effects of processing and preservation variables on essential nutrients in foods is necessary towards the monitoring and control of nutrient and shelf stability of food products. Such studies provide scientific knowledge for the application of appropriate food processing and preservation methods to increase food and nutrient availability.

The need for such investigations becomes more important in view of the accumulating knowledge of the relationship between food (dietary) intake and human diseases.

1.2 VITAMIN A DEFICIENCY (VAD) AND β -CAROTENE

An important micronutrient derived from dietary food intake is vitamin A. Vitamin A deficiency (VAD) occurs when body stores of the vitamin, especially the liver, are exhausted and supplies fail to meet requirements due to insufficient dietary intake (McLaren, 1980). VAD leading to nightblindness (Xerophthalmia) and in many cases death (Sommer et al., 1983) is a public health problem in developing

countries (Bailey, 1992). It is estimated that about 190 million children are at risk of VAD and nearly 250,000 are annually afflicted world wide (Smitasiri et al., 1993).

In Ghana, dietary surveys have reported low intakes of vitamin A. These support available evidence that VAD is widespread (Orraca-Tetteh and Watson, 1976; Lartey and Orraca-Tetteh, 1991; Ghana VAST, 1993). The effects of VAD are wide range. Apart from Xerophthalmia, VAD causes retardation of growth and development, and reduction in immuno competence in children (Sommer, 1989). These conditions are precipitated by malabsorption and infectious diseases. Vitamin A, the essential nutrient needed for the prevention of VAD is found in several foods. It exists as retinol (preformed vitamin A) in foods and products of animal origin such as liver, eggs and milk, and as provitamin A (Carotenoid) in plant foods such as dark-green leafy vegetables (GLVs) orange and yellow vegetables, yellow (non-citrus) fruits and palm oil.

Carotenoids in foods provide most of the vitamin A to a large proportion of the world's population (McLaren, 1980). β -carotene which is the predominant carotenoid with the highest vitamin A activity in foods (Sweeney and Marsh, 1971) plays a major role in the provision of vitamin A in the diet. Carotenoids of dietary origin have recently been the subject of research because of epidemiological evidence indicating an inverse relationship between intake of β -carotene-rich foods and the risk of nutritional diseases. A causal role of this

fat-soluble pigment in preventing nutritional diseases has been related to its well-known provitamin A function (Olson, 1989a).

1.3 FOOD-BASED APPROACH TO THE ALLEVIATION OF VAD

Activities to alleviate VAD have been implemented in some developing countries. At present the major direct control activity is the distribution of capsules of vitamin A and β -carotene in large doses to preschool children in endemic communities (Kavishe, 1992; Ghana VAST, 1993; Bulux *et al.*, 1994). The price of the capsule itself is relatively low, however, the programme is considered expensive and ineffective in covering high risk children (Kuhnlein, 1992).

In view of the importance of VAD, the international community has called for the use of long-term food-based intervention approaches (ICN, 1992; ACC/SCN, 1994).

Promoting the production and/or consumption of inexpensive local sources of carotene-rich foods is considered an appropriate long term approach to eliminating VAD (Ghana VAST, 1993; Wadhwa *et al.*, 1994). This approach focuses on household gardening and nutrition education to help change dietary behaviours. Nutrition education involves creating awareness of the public health implications of VAD, how to avoid and reduce it through the consumption of inexpensive locally available carotene-rich foods. Encouraging household gardening is usually integrated into nutrition education programmes. Nutrition and agricultural extension officers encourage local

communities and schools to cultivate and produce local and under exploited carotene-rich fruits and vegetables for food sufficiency.

Dietary modification approach remains one of the most sustainable means of controlling VAD as is evident in its successful application in Thailand (Smitasiri *et al.*, 1993). However, the goal of alleviating vitamin A deficiency (VAD) through dietary modification should not stop at the "garden gate". It must be extended to include specific efforts leading to improved processing and preservation, and food fortification techniques likely to result in increased food and nutrient availability. Increased availability of β -carotene and other such vital nutrients should be the goal of such improved processing methods.

Vitamin A fortification of foods is a long-term approach to controlling VAD. It is considered as a cost-effective and sustainable method (Solon *et al.*, 1979; Burger, 1993). Vitamin A (retinyl palmitate) has been successfully added to several foods and products including milk, margarine, cereal products and recently monosodium glutamate (MSG). Food fortification with β -carotene rich foods using appropriate traditional processing and preservation methods can ensure a continuous availability of vitamin A towards the alleviation of VAD.

1.4 TRADITIONAL FOOD TECHNOLOGIES

Technologies long associated with a community and employed in food processing and preservation are classified as Traditional (Sefa-Dedeh, 1993). This is because they have deep rooted links with traditions of the locality. Traditional technologies are utilized in the preparation of most processed foods eaten in Ghana. These technologies employ simple equipment and are based on principles similar to those used in modern food industries though they may have efficiency problems. Some of the common unit operations used are dehydration, fermentation, roasting and blanching. These unit operations when combined in a systematic manner can enhance the processing and preservation of foods towards the control of VAD.

1.5 APPLICATION OF TRADITIONAL TECHNOLOGIES IN FOOD FORTIFICATION WITH CAROTENE-RICH FOOD SOURCES.

The elimination of VAD as a public health problem has been given high priority in international nutrition and health (ICN, 1992; ACC/SCN, 1994). Carotenes in food provide most of the vitamin A for a majority of people in the developing countries (McLaren, 1980) including Ghanaians. Year-round availability and adequate consumption of carotene-rich foods will be required to eradicate the deficiency.

Traditional food technologies can be employed effectively in vitamin A food fortification in Ghana. In the fortification

of a popular food product with the vitamin source, however it is important to ensure that the functional and quality characteristics of the product are not compromised.

Gari, a convenient ready-to-eat and shelf-stable product, is widely consumed in Ghana and other West African Countries (Sefa-Dedeh, 1984). This fermented and roasted product processed from cassava, is a high carbohydrate food. It is low in moisture and has high swelling and water absorption capacities. It is grossly deficient in most nutrients including Vitamin A.

Yellow gari, a palm-oil coloured product, is of high premium and enjoys wide patronage. The yellowing improves the nutritional (vitamin A) quality of the product and makes it more attractive to consumers. The use of other carotene-rich food sources such as carrots (a yellow-orange root and tuber crop) to fortify gari will improve the nutritional value of gari (Ayernor and Collison, 1993), widen the choices and increase the availability of carotene-rich foods. This will go a long way to promote the production and consumption of local carotene-rich foods. Such fortified products can be utilized by vulnerable groups in hospitals or rehabilitation centers and for disaster or emergency situations.

The processing of gari is done in the informal small-scale level and involves the use of simple and low cost equipment.

1.6 AIM AND OBJECTIVES

1.6.1 Aim

This study sought to identify appropriate traditional food processing, preservation and fortification techniques that can enhance the stability of β -carotene in vitamin A-rich foods and products as means of contributing towards the control of VAD.

1.6.2 Objectives

The specific objectives of this study were:

1. To optimize processes that will lead to maximum retention and stability of β -carotene in carotene-rich local foods and products.
2. To study the effects of periods of heating and high temperature as pertains in deep-fat frying on β -carotene in palm oil.
3. To study the appropriateness and performance of two carotene-rich food sources (Carrot and palm-oil) in the fortification of gari with respect to:
 - i. β -carotene stability in processed food
 - ii. storage stability of β -carotene
 - iii. To predict the stability of the β -carotene in the processed foods and products during processing and storage using a mathematical model.

4. To study some quality indices of the Vitamin A fortified food.
 - i. Physico-chemical properties of the food
 - ii. Functional properties of the fortified food
 - iii. Organoleptic qualities of the fortified food.

2.0 LITERATURE REVIEW

2.1 β -CAROTENE - A UNIQUE CAROTENOID

2.1.1 Structure

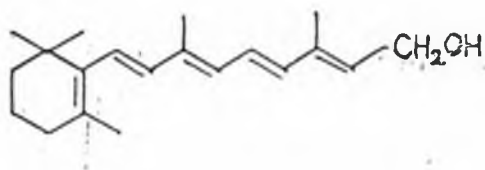
Carotenoids are a group of highly pigmented compounds with different structural characteristics and biological activities found in nature (Olson, 1989b). The basic feature of carotenoids is the C_{40} tetraprenoid structure (Burton and Godwin, 1971). This may be modified by desaturation, cyclization and the introduction of oxygen functions, to give several groups of carotenoids. Some of these include the acyclic pigments eg. lycopene, and those in which the carbon atoms C-1 to C-6 form a cyclohexane ring. The cyclohexanes may have a C-4,5 double bond α -ionone or a C-5,6 double bond β -ionone (Figure 2.1). One sub-group of carotenoids are the carotenes, the hydrocarbons, whilst the xanthophylls constitute the hydroxylated sub-group (Park, 1987).

2.1.2 Functions

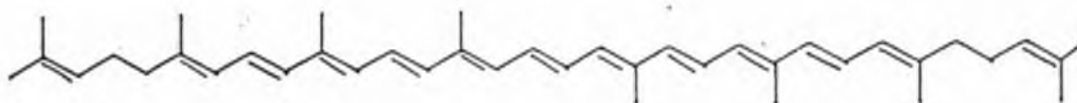
2.1.2.1 Nutritional activity

Biopotency in relation to retinol (vitamin A) activity is conferred on carotenoids by the presence of the β -ionone ring (Rodriguez-Amaya, 1990; Booth *et al.*, 1992). All carotenoid pigments with this characteristic structure are designated as provitamin A. β -carotene (Figure 2.1) having two such rings is considered 100% vitamin A active (Table 2.1) (Bauernfeind,

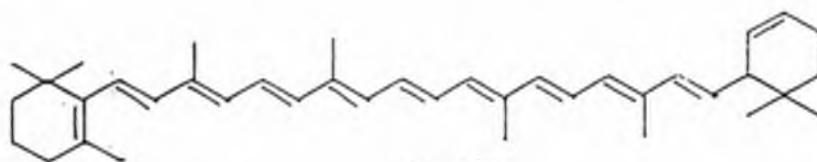
Figure 2.1 Structures of some carotenoids showing the various types and sub-groups in relationship with the β -ionone ring in Retinol (Vitamin A)



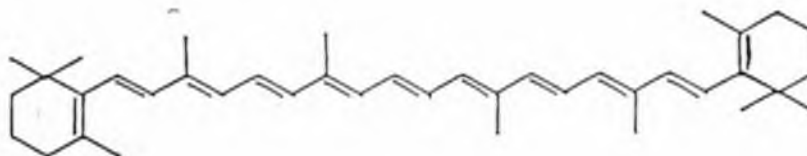
i. Retinol



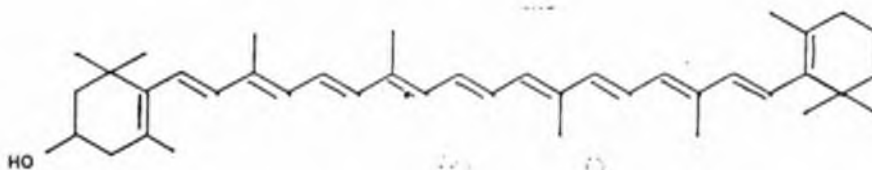
II. Lycopene



III. α -Carotene



IV. B-Carotene



V. B-Cryptoxanthin

Source: (1) Carvalho and Carvalho, 1992.

(2) Rodriguez-Amaya, 1990.

1972) and together with other β -ionone derivatives are converted *in vivo* to vitamin A (Olson, 1989b). Nutritionally, β -carotene plays a vital role in the prevention of vitamin A deficiency (Devadas and Saroja; Wadhwa et al., 1994).

Table 2.1. Vitamin A activity of some provitamin A carotenoids and their occurrence

Carotenoid	Activity (%)	Food
β -carotene	100	Palm oil, Carrot
α -carotene	50 - 54	Carrot, GLV
β -cryptoxanthin	50 60	Papaya, green peppers
γ -carotene	42 50	Sweet potatoes, Tomato
β -zeacarotene	20 40	Corn, Tomatoes
β -apo-8-carotenal	36 72	Citrus fruits
Lycopene	inactive	Tomatoes

Source: Bauernfeind, 1972.

2.1.2.2 Colouring agent

β -carotene, a carotenoid pigment, is a major precursor of vitamin A in plant foodstuffs which have a pleasant yellow-orange colour (Sweeney and Marsh, 1971; Bao and Chang, 1994). Extracts from such foodstuffs (fresh) identified to be β -carotene absorb light maximally between 480-450nm, corresponding to the wavelength range as that of the yellow-orange band in the light spectrum (Purcell et al., 1969). Mir and Nath (1993) attributed the loss of colour in fortified

mango bars during storage to the loss of β -carotene. Colour loss in highly pigmented food products results in the loss of their appeal to customers.

β -carotene has been used as a natural food colourant in formulated foods (Gordon et al., 1985). Several synthetic forms of β -carotene, both oil and water dispersible, are commercially available for use in foods.

2.1.2.3 Antioxidant

During autooxidation of food products and biological systems containing polyunsaturated fats the oxidative products (free radicals) formed cause development of off-flavours in food systems. In biological systems these products can be dangerous to living cells and tissues (Burton, 1989). β -carotene reacts with these active free radicals formed during the chain-reaction mechanism of lipid oxidation to form stable inactive products (Burton, 1989). This prevents the oxidative reaction from the production of off-flavours in foods and the potential damage of living cells in biological systems. This antioxidant role play by β -carotene is independent of its Vitamin A activity and is more efficient at low oxygen partial pressures (Burton, 1989).

2.2 FOOD SOURCES OF β -CAROTENE

2.2.1 Traditional sources

Many foods especially those of plant origin have high concentration of carotenoids. Animal foods and products are exclusive sources of preformed vitamin A, while the carotenoids (provitamins) are primarily found in plants (Bauernfeind, 1972).

Eggs, fish (Cod) and animal organs such as liver serve as rich sources of vitamin A while dairy products provide a lesser amount. In Ghana certain cultural practices such as the use of poultry and livestock as dowries lead to under utilization of such products (Armar-klemesu et al., 1992). In most cases the evisceration of these products during processing, renders them virtually free of vitamin A (Dei, 1991). This situation is aggravated by the general high price of animal products beyond the reach of the rural poor who consequently become the most afflicted with vitamin A deficiency (VAD).

Plant foods (eg. fruits and vegetables) which are readily available and cheaper provide the majority of Ghanaians with dietary β -carotene. Green leafy vegetables (GLV) such as Alefi (*Amaranthus* spp), cowpea (*Vigna unguiculata*), Borkorborkor (*Talanium triangulare*), Kontomire (*Xanthosoma* sp.) and cassava (*Manihot esculenta*) are traditionally consumed in Ghana as freshly boiled and/or fried products. These GLVs contain high amounts of carotenes (Table 2.2 and 2.3). Kontomire and Alefi are the most widely used leaves. These are eaten as sauces with cereal and starchy root and tuber staples which have

little or no carotene (Ayernor and Collison, 1993). In most cases indigenous vegetables may have higher carotene content than most exotic vegetables. However, some exotic vegetables such as carrot is one of the richest sources of carotene (Table 2.2) and it is widely accepted among Ghanaian vegetable growers and consumers. Elsewhere it has assumed a centre stage in vitamin A nutriture (Devadas and Saroja, 1987; Wadhwa *et al.*, 1994).

Table 2.2. Vitamin A^{*} content of selected animal and plant foods.

Food	Vitamin A	
	RE	
Animal		
Liver (Beef) ^a	840	
Eggs (Chicken) ^a	200	
Milk (Cow) ^a	29 - 38	
Plant		
Palm oil ^a	2,035	24,647
Carrot ^a	648	3500
Amaranthus ^a	380	
Mango ^a	118	400
Papaya ^a	50	417
Green bean ^b	15	
Maize ^a	20	
Cassava ^a	1	6
Sweet potato ^c	43	1650

^{*}R.E.: Retinol equivalent in $\mu\text{g}/100\text{g}$ edible portion, raw.

A retinol equivalent is defined as $2\mu\text{g}$ retinol, which is equal to $6\mu\text{g}$ β -carotene or $12\mu\text{g}$ mixed provitamin A carotenoids.

Source: ^aBooths, *et al.*, 1992. ^bAddo, 1994. ^cDignos, *et al.*, 1992.

Palm oil derived from the mesocarp of the oil palm (*Elaeis guineensis*) is considered the richest natural source of provitamin A (Table 2.2). It is a very popular vegetable oil in Ghana and some West African countries where it is used in deep-fat frying of starchy fruits like plantain or added to vegetable sauces. It serves a dual role as a provitamin A source and fulfills energy and lipid requirements of most Ghanaians.

Fruits such as Mangoes and Pawpaw (Papaya) are also rich sources of carotene (Table 2.3). Traditionally these fruits do not feature regularly in the Ghanaian diet but contribute appreciably to dietary vitamin A intake when they are in season.

2.2.2 Secondary sources

The addition of nutrients to foods to enhance nutritional value or to correct a dietary deficiency is common in the developed countries. Vitamins and minerals have been added to food products (Burger, 1993). Foods and other products such as Monosodium glutamate (MSG), margarine and edible oils have been fortified with vitamin A towards the alleviation of VAD. These foods serve as secondary sources of vitamin A.

Table 2.3. Distribution of vitamin A activity in selected green leafy vegetables (fresh) consumed in Ghana.

Leaf	β -carotene ($\mu\text{g}/100\text{g}$)	Vitamin A*
Amaranthus ^a	63384.62	10564.10
Cowpea ^a	63194.63	10532.44
Borkorborkor ^b	67605.63	11267.61
Cassava ^a	36311.57	6051.93
Kontomire ^b	22792.79	3798.80
Lettuce ^a	403.16	67.19
Ayoyo ^a	58333.53	9722.22
Cabbage ^b	238.09	39.68

*Retinol equivalent in $\mu\text{g}/100\text{g}$ edible portion, raw. A retinol equivalent is defined as $2\mu\text{g}$ retinol, which is equal to $6\mu\text{g}$ β -carotene.

Source: ^aTakyi et al., (1992) ^bGomez, (1981)

The addition of β -carotene rich food sources to other dishes/foods as sometimes practiced in Ghana is not primarily aimed at improving nutritional value. Sefa-Dedeh (1984) stated the following as reasons for practicing staple food mixing in Ghana:

- i. To achieve acceptable product characteristic
- ii. To provide good nutrition
- iii. As a customary or cultural practice.

Traditionally, palm oil, a very rich source of β -carotene, is used in the preparation of the following food products or

dishes:

- a. *Adibi* A spiced maize dumpling popular in the Ashanti and Brong-Ahafo regions of Ghana.
- b. *Apapransa* A spiced thick cooked paste of roasted maize and cowpea.
- c. *Palm oil-gari* A fermented, roasted and granulated cassava pulp, with added palm oil.

The colour produced by the palm oil is considered beneficial as it provides an essential nutrient, β -carotene. These products do not serve as primary or natural sources of β -carotene. The increasing importance of natural β -carotene in fighting VAD and cancer has given special importance to palm oil and other β -carotene rich foods in food fortifications. Traditional methods may be improved through research for the incorporation of β -carotene rich food sources into vitamin A deficient foods. Research may help provide useful information on the nutrient's stability and organoleptic changes as affected by processing and storage towards the provision of a shelf-stable and consumer acceptable product.

2.3 TRADITIONAL FOOD PROCESSING AND PRESERVATION OF VITAMIN A-RICH FOODS.

Fruits, vegetables and Palm oil constitute a large proportion of vitamin A-rich foods eaten in Ghana. The technologies used in the processing and preservation of these commodities are deep rooted in traditions (Sefa-Dedeh, 1990).

Techniques commonly utilised are boiling or cooking, blanching, frying and dehydration. These unit operations may either be employed singly or combined and the choice of technique may depend on the:

- i. type of commodity
- ii. availability of material ie. whether commodity is in season or scarce.
- iii. desired characteristics of the final product.

Leafy vegetables which form the bulk of β -carotene rich foods may be utilised in the following ways:

- a. boiled or blanched, mashed and/or fried in oil (for immediate consumption)
- b. blanched, dried in the sun or in traditional ovens used for bread baking (Pace et al., 1989).

The fresh appearance, texture and taste of fruits are preferred by majority of consumers and any change is unacceptable. Fruits are generally seasonal and are consumed fresh as they come in season. They are therefore not traditionally processed and preserved for off-season.

2.4 FACTORS INFLUENCING β -CAROTENE STABILITY IN FOODS

β -carotene, a naturally occurring nutrient, is affected by processing and preservation methods that generally influence the stability of food nutrients. Some traditional food technologies have severe effects on β -carotene (Gomez, 1981; Lyimo et al., 1991). Processing and preservation methods

responsible for affecting the retention of β -carotene in foods involve factors such as:

1. Enzyme activity
2. Oxygen/oxidation
3. Time and temperature
4. pH

Oxidation of β -carotene may occur at high temperatures and during long heat processing and preservation times in the presence of light (Pesek and Warthesen, 1987), oxygen (Saguy et al., 1985) and variations of pH. β -carotene can also be decolourised by enzyme systems (Blain, 1970). Usually the degree of stability of β -carotene in processed food products depends largely on the methods of processing or technology used.

2.5 EFFECT OF PROCESSING AND PRESERVATION

2.5.1 Thermal Processing

Thermal processing plays a prominent role in traditional food systems. A large proportion of foods consumed in Ghana, are heat treated. Heat treatment provides a means of:

- i. Rendering foods safe and palatable for consumption
eg. roasting of cassava pulp causes the breakdown of toxic hydrocyanic glucosides (Ihenkoronye and Ngoddy, 1985).
- ii. Improving the digestibility of foods eg. cooking of legumes.

Regardless of the method of heating, the effect of thermal processing on β -carotene depends on the following factors:

- . Time and temperature of heating
- . Amount of oxygen present during heating
- . pH of the system

Heat processing may result in oxidative loss of carotenoids in fruits and vegetables. Edwards and Lee (1986) reported that heating induces the transformation of all trans β -carotene to its *cis* isomers. The quantity of *cis* isomers formed is related to the intensity and length of heating (Chandler and Schwartz, 1988), and the availability of oxygen (Saguy et al., 1985). The vitamin A value of the food is affected because the *cis* isomers formed have lower provitamin A activity (Table 2.1)

2.5.1.1 Blanching

This involves the immersion of food in hot water or steam to inactivate enzymes that would lead to deterioration in colour. This may precede freezing, drying and sometimes canning and storage.

Traditionally, vegetable blanching is practiced on large scale on red hot peppers (Pace et al. 1989). These are pre-cooked for a few minutes in hot water before drying to preserve the colour during dehydration and storage. In rural and peri urban homes, leafy vegetables are either blanched in boiling water or steamed on half cooked staples such as yam, cassava or plantain before mashing to prepare sauce or soup.

The type of blanching used during food processing has

varying influence on the retention of β -carotene. Chandler and Schwartz (1988) reported an increased retention of 104-112% β -carotene in sweet potatoes blanched in boiling water for 2-10 mins. In contrast, steam blanching resulted in 92% retention. Steam blanching has been reported to enhance total β -carotene retention by 117.5% in carrots (Portocarrero *et al.*, 1992) whilst a reduction of 15.7% was observed using water blanching (Bao and Chang, 1994). Lyimo *et al.* (1991) reported a general decline in carotene content during traditional water blanching of cassava and pumpkin leaves.

Conflicting reports of blanching effects on β -carotene have been documented. However, evidence indicate that blanching, like cooking, reduces the potency of carotenes in foods due to prolonged exposure to temperatures (Baloch *et al.*, 1977a). Blanching and cooking result in the loss of soluble solids and the apparent increase in carotene content has been attributed to this phenomenon (Baloch *et al.*, 1977a; Imungi and Potter, 1983).

Various blanching methods utilizing different concentrations of salts (alkali and acid) have been investigated in their ability to reduce leaching of soluble solids and improve other product qualities such as colour, texture and aroma (Onayemi and Badifu, 1987). Nutting *et al.* (1970) reported that alkali and sulphite blanching considerably enhance β -carotene retention in fruits and vegetables. Traditionally alkali cooking of cowpea is

practiced in Ghana using *Kanwa*, an alkaline rocksalt (Orraca-Tetteh, 1989a) but its effect on β -carotene in foods has not been investigated.

2.5.1.2 Cooking

Cooking is meant to improve texture, flavour and palatability. Changes in carotenes resulting from traditional methods of cooking carotene-rich vegetables have been reported. Studies by Lyimo et al. (1991) indicated that cassava, pumpkin and Mwage (*Sesbania* spp) leaves lost 22, 29 and 24% of their original carotene content respectively after boiling for 90 minutes (Cassava) and 50 minutes (Pumpkin and Mwage). Cooking losses of 20% have been observed in *Amaranthus* leaves (Devadas and Saroja, 1987).

Carotenes in carrots are considered stable to cooking procedures. Devadas and Saroja (1987) and Portocarrero et al. (1992), working on carrots reported complete retention of or an increase in β -carotene when boiled for 5-45 minutes. Dignos et al. (1992) analysed 3 varieties of sweet potatoes for β -carotene and found mean losses of 10-23% for boiled (25-30 minutes) samples as compared to the fresh samples.

2.5.1.3 Dehydration

The application of heat in the removal of water from food products is practiced in the tropics for food preservation. Sun drying is a common traditional method of food preservation

employed in Ghana. The removal of water in foods by sundrying prevents the growth of spoilage microorganisms, and also reduces enzymatic and biochemical activities to very low levels. Open-air sundrying is disadvantageous by its exposure to environmental contaminants. Solar drying (controlled sundrying) provides a better alternative to sundrying. It improves drying rates by providing higher air temperatures and continuous air flow (Mandhyan *et al.*, 1988). This results in a higher quality product.

Drying may considerably affect β -carotene depending on the commodity and such conditions as the duration of drying, temperature and exposure to light. Losses of 53, 53.6 and 63% of β -carotene during sundrying have been reported for cassava, Pumpkin and Mwage leaves respectively (Lyimo *et al.*, 1991). Losses of carotene in vegetables can be severe during drying but blanching provides a protective effect (Gomez, 1981). Mugula *et al.* (1994) observed that the effects of conventional oven drying on β -carotene retention in banana beverage powder did not differ significantly from sundrying.

2.5.1.4 Roasting

Roasting, another form of dry heating, is utilized in the processing of several food commodities. Roasted foods such as:

- i. Groundnuts are eaten as a snack
- ii. Roots and tubers, and starchy crops like cocoyam, yam and plantain (ripe and unripe) may be eaten

with roasted groundnuts as a meal.

- iii. Cereals and legumes are utilized in the preparation of weaning foods (Orraca-Tetteh, 1989b) and local dishes like Apapransa.

As a technique applied in food processing and preservation, roasting combines dehydration and cooking simultaneously (Sefa-Dedeh, 1984; Nout, 1991a). This results in moisture reduction and partial gelatinization of starch and flavour development as observed in gari processing. Like all heating processes, roasting affects β -carotene levels in foods to which they are applied. Lawal (1986) reported that β -carotene decreased by 25% when seeds of African breadfruit (*Treculia africana*) were subjected to roasting. Though roasting is widely used in the processing of a wide range of food crops in Ghana, little or no information is available on its effect on β -carotene in foods.

2.6 FERMENTATION

Fermented foods form a large proportion of food products consumed in Ghana (Sefa-Dedeh, 1989). Fermentation is a biological method of food processing and preservation. Traditional food fermentations are usually spontaneous, involving various types of microbes (Akinrele, 1970). Fermenting systems therefore act as bioreactors where biochemical reactions occur with the aid of microorganisms and enzymes.

The general desirable qualities of fermented foods are caused by these biochemical reactions (Nout, 1991b). Microbial enzymes break down food components such as starch and proteins to form organic acids and alcohols (Banigo and Muller, 1970). The organic acids produced lower pH and together (with low pH) inhibit the growth of spoilage and pathogenic bacteria (Mensah et al., 1991). On the other hand, the acidic conditions created during fermentations may be detrimental to carotenoids. Carotenoids are unstable in acidic environments and may undergo oxidative decomposition (Burtton and Godwin, 1971).

Carotene oxidizing factors with peroxidase activity in plant tissue extracts have been reported by Blain (1970) and Kanner et al. (1977). Baloch et al. (1977a), working with carrots observed that incubating unblanched carrot at 25°C for 60 minutes in the dark resulted in about 7% loss in carotenoid content.

2.7 STORAGE

Food storage remains an essential operation in national food delivery systems. Both fresh and processed food products are stored under varied conditions for different time durations as a means of ensuring food security. The duration and conditions of storage may lead to the reduction of β -carotene thus decreasing the nutritional value of the food. In general, β -carotene losses in foods progress with time of storage (Baloch et al., 1977b; Eusebio et al., 1991; Mugula et al.,

1994). Lyimo *et al.* (1991) observed that the use of earthenware pots in traditional storage do not enhance β -carotene stability in dehydrated vegetables and suggested the use of moisture-proof containers for storage. Moisture-proof containers do not provide adequate protection against carotenoid oxidation because they undergo photodegradation when exposed to light (Pesek and Warthesen, 1987). Lovric *et al.* (1970) reported that foods stored in darkness retained more carotenoids than those exposed to day light.

Pretreating vegetables (blanching and sulphiting) before storage enhances the retention of carotenes in dehydrated foods (Gomez, 1981). However temperature of storage has a significant effect on the reduction of β -carotene in carotene-rich foods (Mir and Nath, 1993).

During storage several undesirable changes occur in food products including colour. Loss of colour in stored food products has been attributed to loss of carotenoids, the pigments responsible for the yellow and orange colour in food commodities (Lovric *et al.*, 1970; Pesek and Warthesen, 1987). This colour loss is more pronounced in stored spray-dried products than flaked products (Seshadri *et al.*, 1991).

2.8 DEGRADATION PRODUCTS FROM β -CAROTENE

β -carotene, like most lipids with long chain unsaturated fatty acids are susceptible to oxidation resulting in the formation of organoleptically undesirable by-products

(Dugan, 1976). Basically, β -carotene undergoes 2 types of degradation; thermal isomerization and oxidative decomposition (Cole and Kapur, 1957a). Breakdown products of carotenoid origin could be used in determining the type of changes occurring in the molecule.

2.8.1 *Cis-trans isomerization*

β -carotene, naturally exists in the all *trans* form. Some fresh green vegetables have been found to contain the *cis*- and *trans*-isomers of β -carotene whilst the yellow-red pigmented vegetables contain little or none (Sweeney and Marsh, 1970; Chandler and Schwartz, 1987). O'Neil and Schwartz (1995) reported that photo-isomerization of all-*trans* β -carotene occurs in the presence of chlorophyll.

Thermal food processes such as canning and extrusion cooking cause the conversion of the *trans*- β -carotene and other carotenes (α -carotene) to their *cis*-stereoisomers (Ogunlesi and Lee, 1979; Marty and Berset, 1988). Neo- β -carotene U and neo- β -carotene B are the commonly encountered stereoisomers of β -carotene in foods. These isomers having lower provitamin A activity lead to a reduction in the nutritional value of thermally processed foods (Sweeney and Marsh, 1971). The neo- β -carotene B and neo- β -carotene U have recently been renamed 13- and 9-mono *cis*- β -carotene respectively (Chandler and Schwartz, 1987). Thermal processing of vegetables seem to favour the conversion of all-*trans* β -carotene to its

stereoisomers (*cis*-isomers) particularly the 13-mono *cis*-isomer (Sweeney and Marsh, 1971; Ogunlesi and Lee, 1979). However freeze drying, though it caused a reduction in carotene content, did not result in stereoisomer formation (Sweeney and Marsh, 1971).

Several analytical methods have been used to detect and quantify *cis-trans* stereoisomers of β -carotene (Sweeney and Marsh, 1971; Ogunlesi and Lee, 1979; Rodriguez-Amaya, 1990). High performance liquid chromatography (HPLC) is commonly used because of its reproducibility. The isomers are resolved on a column of adsorbents (Ca(OH)_2 , Al_2O_3 , MgO) either singly packed or combined in different ratios and eluted with different solvents. The separated pigments or isomers are later quantified using spectrophotometry.

2.8.2 Oxidative decomposition

Dehydrated stored products containing carotenoids give off- flavours described as hay- or grass-like odour (Lovric et al., 1970; Baloch et al., 1977b). These off-flavours have been attributed to the breakdown of β -carotene and other carotenoids (Walter et al., 1970). Cole and Kapur (1957b) and Walter et al. (1970) detected the production of both volatile and non-volatile products during thermal processing of serum-free tomato juice and dehydrated stored tomatoes. These were characterized as carbonyl fragments from the decomposing carotenoids but were not quantified. The general decomposition

of the carotenoid molecule occurs at the sites of C-C double bonds which give rise to products like aldehydes and ketones (Cole and Kapur, 1957a). Lovric *et al.* (1970) detected *cis*-isomers of carotenoids in freshly dehydrated tomato (foam-mat dried) but these less stable isomers disappeared after 150-200 days of storage. This suggests that oxidative decomposition may consume both *cis*- and *trans*- isomers of carotenoids to produce non-carotene compounds.

The presence of carbonyl products eg. malonaldehyde can be quantified as lipid oxidation products (Baloch *et al.* 1977b) by the use of the 2-Thiobarbituric acid-malonaldehyde test of Tarladgis *et al.* (1964).

3.0 MATERIALS AND METHODS

3.1 MATERIALS

3.1.1 Effect of processing variables on β -carotene retention in vegetables

3.1.1.1 Carrots

Freshly harvested carrots (*Daucus carota*) were obtained from a local farmer and stored at 4°C overnight. The carrots were trimmed, peeled and washed in clean water. The samples were sliced using a vegetable slicer (Quanlhiem Inc., USA) set at 2cm. The sliced samples were divided into four 400g batches. One batch was not treated any further and analysed as fresh untreated. The second batch was dehydrated without blanching and analysed as dehydrated unblanched. The third batch was steamed blanched, while the fourth was blanched in boiling water. Figure 3.1 is a flow diagram of the process.

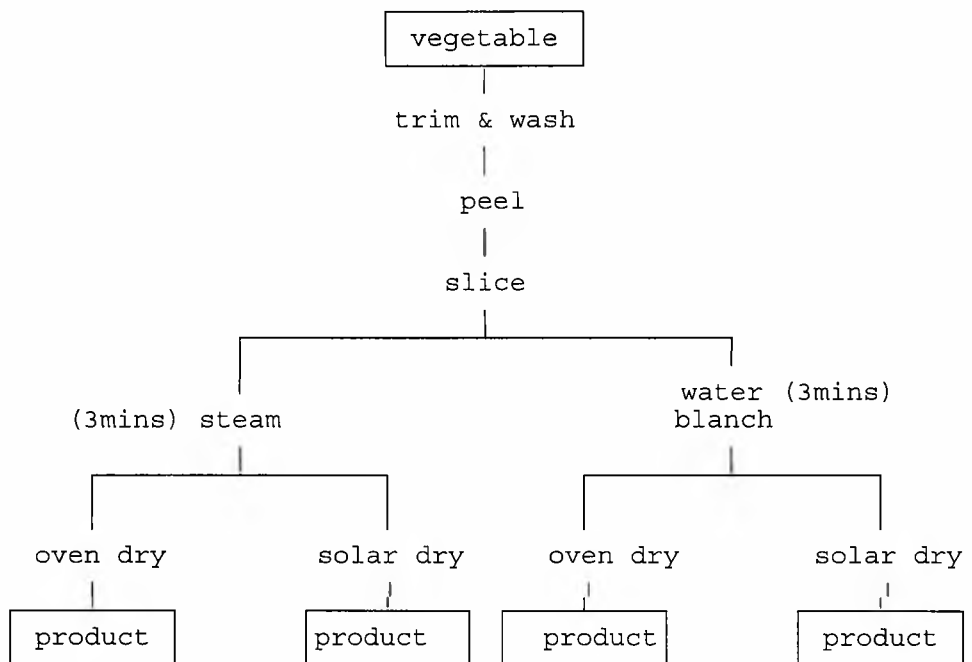
Experimental design for analysis of carrots

The experiment was designed on a 6 x 2 x 4 factorial pattern. The factors investigated were:

- i. blanching treatment (fresh unblanched, steamed blanched, blanching in hot water, NaHSO₃, NaCl and Kanwa (alkaline rocksalt) solutions)
- ii. dehydration method (oven and solar drying)
- iii. storage intervals (0, 30, 60 and 90 days)

Dependent variables measured were moisture, β -carotene content, water insoluble solids.

Figure 3.1 Processing scheme for carrot into dehydrated products.



3.1.1.2 Green leafy vegetables (glv)

Fresh leaves of *Alefi* (*Amaranthus* spp.) and *Kontomire* (*Xanthosoma* spp.) were purchased from a local farmer and processed on the day of purchase. The leaf stalk and other inedible parts were separated from the edible parts and washed under tap water. After draining off excess water, the leaves were chopped with a vegetable slicer (Qualhiem Inc., USA) set at 2cm. Two batches of the chopped vegetables were kept unblanched, one to serve as fresh and the other as control unblanched dehydrated samples. The remaining samples were blanched in alkali solution of *kanwa* (rock salt) (Figure 3.2).

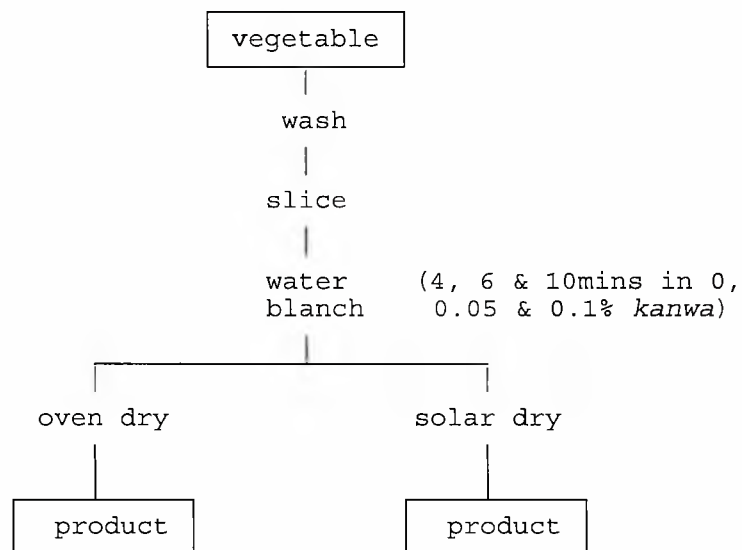
Experimental design for analysis of green leafy vegetables

A 3 x 3 x 3 x 2 x 4 factorial design was used, with the following as independent variables:

- i. blanching liquor concentration (0, 0.05 and 0.1% *kanwa*)
- ii. time of blanching (4, 6 and 10 minutes)
- iii. temperature of blanching (85, 95 and 100°C)
- iv. dehydration method (oven and solar drying)
- v. storage interval (0, 30, 60 and 90 days)

The samples were evaluated for moisture, pH, water insoluble solids and β -carotene.

Figure 3.2 Processing of carotene-rich green leafy vegetables into dehydrated products.



3.1.1.3 Blanching procedures

3.1.1.3.1 Carrots

Sliced fresh carrots were placed in a stainless steel tray and steamed for 3 minutes at atmospheric pressure.

Various blanching solutions (NaCl, NaHSO₃, and *Kanwa*) were made to 1% concentration and heated to 100°C in a steam jacket kettle. Samples were submerged for 3 minutes in the boiling solutions; NaCl, NaHSO₃, and *kanwa* respectively. One batch of samples was blanched in boiling water. The ratio of carrots to the blanching water/solution was 1:2 w/v. The blanched samples were cooled in cold water and divided into two batches. One batch was analysed as blanched undehydrated and the other was dehydrated (Oven at 70°C or Solar) before analysis.

3.1.1.3.2 Leafy vegetables

Three hundred grammes (300g) of shredded vegetables were blanched in 600 mL of the *Kanwa* blanching solutions contained in a one litre beaker. The ratio of vegetables to blanching solution was 1:3 w/v. Samples were immediately cooled in cold water (20°C) after blanching. The blanched vegetables were divided into two (2) batches. One batch was not further treated and kept for analysis as blanched undehydrated vegetables and the second batch was dehydrated before analysis.

3.1.1.4 Dehydration

The blanched and unblanched samples were each divided into two batches and spread thinly on stainless steel trays. One batch was dried in a cabinet oven (Baird & Tatlock London Ltd., England) and the other in a solar dryer (Figure 3.2 and 3.3). The dehydrated products were sealed in polyethylene bags and stored at ambient temperature (28°C). Samples were withdrawn every 30 days for analysis.

3.1.2 Effect of heating on β -carotene content of palm oil

Freshly processed palm oil obtained from a local processor at Madina, was divided into 4 batches. One batch was set aside to serve as fresh untreated (control) and the other 3 batches were heated at 100, 170 and 200 $\pm$ 10°C respectively in an air oven (Baird & Tatlock London Ltd., England). Aliquots of samples were taken at time intervals of 5, 10, 20, 30, 60 and 240 minutes, cooled immediately and analysed for moisture, β -carotene.

3.1.3 Fortification of gari with carrot and palm oil

Palm oil was obtained fresh after preparation from a processor. Fresh carrots and cassava (*Manihot esculenta*) were obtained from a local farmer. The traditional method of gari processing was followed in the fortification procedure. The cassava and carrot were trimmed, hand peeled and washed. The cassava was grated and divided into 3 batches. To one batch,

grated carrot was added and co-fermented. Grated carrot and palm oil were respectively added to the other two batches of cassava pulp after fermentation (72 hours). The fortified samples (cassava pulp) were sieved and roasted in a shallow aluminum pan. The products were sealed in polyethylene bags and stored at ambient temperature (28°C), and were withdrawn at 30 days intervals for analysis. The flow diagram for the process is at figure 3.3.

**Experimental design for carrot/palm-oil fortification
of cassava products**

A factorial design of 5 x 2 x 4 was used with the following treatments as independent variables:

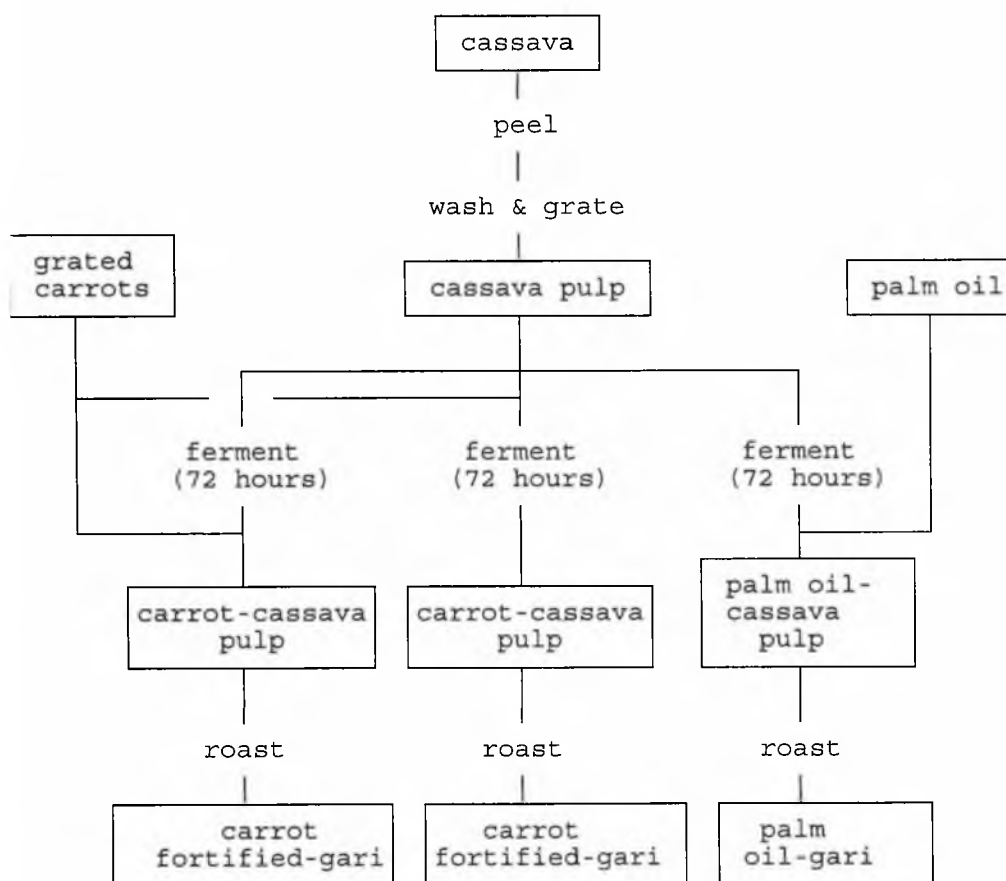
- i. fortification level (0, 5, 10, 15 and 20%)
- ii. method of fortification (before and after fermentation)
- iii. storage period (0, 30, 60 and 90 days)

The dependent variables, evaluated to determine the effect of the treatments were:

- a) moisture
- b) β -carotene
- c) swelling capacity
- d) water absorption capacity
- e) organoleptic evaluation

Fermentation and roasting as unit operations in the processing of gari were also studied to determine their effects on β -carotene retention. For this study, a 4 x 4 x 2 factorial

Figure 3.3 Flow diagram for β -carotene fortification of gari using carrot and palm oil.



design representing fortification level (5, 10, 15 and 20% carrot), fermentation time (0, 24, 48 and 72 hours) and roasting (before and after) was employed. pH, acidity and β -carotene were determined on the samples as responses to the treatments.

3.2 METHODS

3.2.1 ANALYSIS OF PRODUCTS

3.2.1.1 Moisture content

Moisture content was determined on 2g of ground sample in a vacuum oven (Towson & Mercer Ltd., England), heated at 70°C for 6 hours. The samples were removed, cooled over a desiccant for 15 minutes, weighed and the loss in weight of sample on drying calculated as percent moisture.

3.2.1.2 pH and Acidity

A slurry of 10g sample in freshly boiled and cooled distilled water was made up to 100mL and shaken for 30 minutes on a rotary shaker. The pH of the slurry was measured with a pH meter (TOA Electronics, Japan).

The slurry was filtered (Whatman no.4 paper) and 10mL aliquots were pipetted into conical flasks containing 100mL of distilled water (previously boiled and cooled). The aliquots were titrated against 0.1N NaOH with 1% phenolphthalein solution as indicator. The acidity was calculated as percent lactic acid.

3.2.1.3 Water insoluble solids

Water insoluble solids were estimated by the method of the AOAC (1975) procedure no. 20.020.

3.2.1.4 β -CAROTENE ANALYSIS

The concentration of β -carotene was determined by modifications of the procedure used by Bureau and Bushway (1986) as below:

3.2.1.4.1 Calibration of HPLC

An all *trans*- β -carotene (Sigma Chem. Co., USA) was dissolved in hexane to obtain a standard stock solution of 50 μ g/mL. This was diluted to give 1 μ g/mL to serve as a working standard solution. To obtain the retention time for β -carotene, 20 μ L of the working standard solution was injected into the column and eluted. An average of 4 runs established a retention time of 1.10 $\pm$ 0.04 minutes. To establish an HPLC concentration factor upon which β -carotene concentrations of processed samples would be used in calculations, 20 μ L of the working standard solution of β -carotene representing 0.02 μ g/20 μ L was injected and eluted. After 3 runs, the recorder calculated the factor (1.21498×10^{-7}) corresponding to 0.02 μ g β -carotene per 20 μ L of solution. This factor was used to programme the HPLC recorder in computing concentrations of subsequent injections of samples with unknown β -carotene

content.

3.2.1.4.2 Extraction of β -carotene from vegetables (low fat samples)

One gramme of anhydrous MgCO_3 (to neutralise any acid liberated) and 0.5g pyrogallol (to reduce oxidation) were added to 2g sample in a mortar and extracted with the aid of a pestle with 4mL of acetone-hexane (1:1 v/v). The acetone-hexane extract was pipetted with a micropipette. The procedure was repeated four times until the residue was colourless. The extracts were combined and washed with 4mL distilled water. The water layer formed was pipetted and 1.0g anhydrous NaSO_4 added and stirred using a mixer to remove all traces of water from the extract. 2mL of the extract was pipetted into a 10mL brown test tube and evaporated to dryness under a stream of N_2 gas. This was redissolved in 10mL of hexane and flushed with N_2 gas for HPLC analysis.

3.2.1.4.3 Extraction of β -carotene from palm oil and palm oil-products (high fat samples)

Three millilitres (3mL) of methanolic KOH (60%) and 0.3g of pyrogallol were added to 0.5g of sample in a 25mL brown test tube. The mixture was refluxed in a water bath at 80°C for 20 minutes. After refluxing, 2mL of distilled water was used to wash the sides of the condenser into the mixture and allowed to cool to room temperature. The saponified mixture was twice

extracted with 4mL of hexane into another 25mL brown test tube. The extracts were combined, washed with 2mL distilled water to remove any residual alkali, and dried over anhydrous Na_2SO_4 . 4mL of the anhydrous hexane extract was pipetted into a 10mL brown test tube and brought to dryness under a stream of N_2 gas. This was redissolved in 10mL of hexane and flushed with N_2 gas for HPLC analysis.

3.2.1.4.4 HPLC quantitation of β -carotene in food samples

Twenty microlitres of the hexane extract was manually injected into a stainless steel column of 25cm x 4.6mm (i.d.) packed with Hichrosorb C18 reverse-phase material and eluted isocratically with hexane at a flow rate of 2mL per minute using a Shimadzu (model LC-6A) single pump solvent delivery system. The samples were quantified from their absorbances at 450nm using a flow-through spectrophotometer (SPD 6AU detector) and an integrated programmable recorder/printer (model C-R6A, Shimadzu, Japan).

β -carotene content of samples were calculated using the following formula:

$$\beta\text{-carotene } (\mu\text{g} / 100\text{g}) = \text{HPLC (factor)} \times \frac{\text{vol. of hexane (ext.)}}{\text{vol. of hexane (evap.)}} \times \frac{\text{final vol. (ext.)}}{\text{vol. injected}} \times \frac{100\text{g}}{\text{sample wt. (g)}}$$

3.2.1.5 FUNCTIONAL PROPERTIES OF FORTIFIED GARI

3.2.1.5.1 Swelling capacity

The method described by Fleming *et al.* (1974) was used. 10g of the gari sample was placed in a 10mL graduated measuring cylinder and the volume noted. The measuring cylinder was made to the 100mL mark with distilled water and quickly stirred. The mixture was stood for 1 hour and the settled volume of sample in the measuring cylinder was noted as it swelled at the following time intervals: 0, 1, 5, 10, 15, 20, 30, 45 and 60 minutes.

3.2.1.5.2 Water absorption capacity

Five grammes of sample was mixed with 30mL of water and allowed to stand for a period of 30 minutes. The supernatant was centrifuged at 3000rpm for 20 minutes. The amount of water absorbed was measured as the increase in weight of the sample after all the supernatant had been carefully decanted. Results were reported on dry matter basis.

3.2.1.6 SENSORY EVALUATION

Gari (both fortified and unfortified) samples were presented to 14 randomly selected regular consumers as panelists for quality evaluation. Samples were randomly presented in identical containers coded with random 3 digit numbers. Panelists were asked to evaluate and rank products

according to their degree of preference for overall acceptance, flavour, colour and taste. The most preferred sample was ranked 1 and the least preferred 10. The panelists evaluated and ranked samples for colour and flavour in order of increasing intensity given 1 as most intense and 10 as least intense.

The panelists were required to indicate whether they would buy products ranked as highly acceptable if found in the market but at a slightly higher cost. The questionnaire administered is attached at appendix 1.

3.2.2 DATA ANALYSIS

3.2.2.1 Reaction rate constants (K) and activation energies (E_a) of β -carotene degradation

The results of β -carotene losses for all processed and stored products were analysed by the first-order rate function (Labuza and Riboh, 1982):

$$- d[C]/dt = K [C]^n \quad (1)$$

where C = quantitative value of β -carotene

t = time

K = first order rate constant

and n = order of the reaction.

The integral form of a first-order reaction is obtained by integrating the equation (1) for n = 1 and can be written as the following expression:

$$\ln ([C]_0/[C]_t) = Kt \quad (2)$$

where C is the value of β -carotene at time 0 and $[C]_t$ is the value after reaction time t .

Activation energies were determined by the Arrhenius equations given by:

$$K = A_0 \exp (-E_a/RT) \quad (3)$$

where K = rate constant

A_0 = Arrhenius energy

T = absolute temperature ($^{\circ}\text{K}$)

E_a = activation energy

and R = gas constant (1.987 cal/ $^{\circ}\text{K}$ mole).

Rate constants (K) and activation energies (E_a) for degradation of β -carotene were calculated by linear regression.

3.2.2.2 Statistical analysis

The data obtained were analysed using ANOVA procedures and multiple range tests (i.e. LSD), on the computer software STATGRAPHICS version 4.2 (Statistical Graphics Corp., STSC Inc., USA).

4.0 RESULTS AND DISCUSSION

4.1 PROCESS OPTIMIZATION FOR THE MAXIMUM RETENTION OF β-CAROTENE IN DEHYDRATED VEGETABLES

4.1.1 Effect of blanching treatment on β-carotene content of carrots

Pre-treatments such as acid, alkali and steam treatments have been used to reduce discoloration of minimally processed carrots (Howard et al., 1994; Bolin and Huxsoll, 1991).

Blanching had an effect on β-carotene content in the carrots. The effects are reflected in the percentage difference between the β-carotene contents of treated carrot and the fresh untreated samples (Table 4.1). β-carotene content of carrot varied significantly ($p \leq 0.05$) among the five blanching treatments. Samples from the steam blanched, and sulphite and kanwa blanching solutions showed high retention values (52.51, 51.49 and 50.31 mg/100g β-carotene respectively) and did not differ from each other at $p \leq 0.05$. Carrot samples blanched using NaCl solution retained 63.23% of the initial β-carotene (43.0 mg/100g). This is lower than those from steamed, sulphite and kanwa blanched samples but higher than that of hot water blanched carrot (36.98 mg/100g).

When carotene content was calculated on dry matter basis (DMB), kanwa-treated carrots had the highest β-carotene (31.29 mg/100g) after Fresh untreated (32.39 mg/100g). This was followed in decreasing order by NaHSO₃, hot water, steamed and

NaCl treatments with 28.73, 28.66, 26.95 and 22.41 mg/100g respectively.

Table 4.1 Effect of blanching method on β -carotene^{*} and soluble solids retention for processed carrots.

Blanching treatment	β -carotene (mg/100g)			Soluble solids loss (%)
	DMB	WIS		
Fresh (unblanched)	32.39	67.9	(100) ^a	
Steamed	26.95	52.51	(77.5) ^b	4.26
Hot water	28.66	36.98	(54.5) ^d	29.79
NaHSO ₃	28.73	51.49	(75.83) ^b	8.1
NaCl	22.41	43.0	(63.32) ^c	4.41
Kanwa	31.92	50.31	(74.09) ^b	15.75

^aValues in parenthesis are % retention of Fresh unblanched carrot.

^cValues with different superscripts within columns are significantly different ($p < 0.05$)

DMB = Dry matter basis WIS = water insoluble matter basis.

This observation is contrary to results reported by other workers. Devas and Saroja (1987) and Portocarrero *et al.*, (1992) reported an increase in β -carotene content of carrots after blanching or cooking when carotene concentration was calculated on dry matter basis. This has been attributed to the leaching of soluble solids (Baloch *et al.*, 1977a; Imungi and Potter, 1983). The results here indicate that the addition of salts (NaHSO₃, NaCl and kanwa) to the blanching water reduces the loss of soluble solids (Table 4.1). The loss of carotene

was caused by thermal breakdown or isomerization (Marty and Berset, 1988; Ogunlesi and Lee, 1979) since no β -carotene was detected in the blanching solution after processing. The data obtained (Table 4.1) suggests that kanwa has similar protective effects on β -carotene retention in carrots as sulphite during blanching.

4.1.2 Dehydration of blanched carrots

Dehydration (oven and solar) significantly lowered β -carotene levels in the carrots either as unblanched or blanched (Table 4.2) ($p \leq 0.05$).

There was a variation in the degree of β -carotene reduction in the treated carrots. The sulphited carrots retained the highest level of 44.0 and 36.68 mg/100g, representing 65.9 and 54.29% of the fresh untreated carrots for oven and solar dehydration respectively. The samples blanched in water (plain) retained lower carotene than the kanwa and steamed treated carrots (Figure 4.1). Blanching together with dehydration caused between 34.0-59.1% and 45.7-66.72 % loss of β -carotene in oven and solar dehydrated samples respectively. This suggests that dehydration together with blanching can cause considerable reduction of β -carotene in carrots.

Table 4.2 Effect of dehydration method on beta-carotene of blanched carrots.

Blanching treatment	β -carotene content (mg/100g)		
	before dehydration	after dehydration	
		oven	solar
Fresh (unblanched)	67.90	34.85	27.44
Steamed	52.51	32.36	24.86
Hot water	36.98	27.77	22.60
NaHSO ₃	51.49	44.78	36.86
NaCl	43.0	36.3	27.48
Kanwa	50.31	38.19	35.73

Solar dried carrots had significantly lower levels of carotene than the oven dried samples ($p \leq 0.05$) (Figure 4.1). A decrease of 13-48.7% was observed during oven drying with the sulphite and fresh unblanched carrots recording the lowest and highest respectively. Solar dehydration of carrots resulted in a loss of 28.4-59.6% of carotene. Similarly sulphite and fresh dehydrated carrots had the lowest and highest loss respectively. Dignos et al. (1992) reported an average loss of 38% β -carotene due to sun-drying of sweet potatoes, almost double the value for oven dried samples. The direct exposure of carotene-rich foods to light and temperature

Fig. 4.1 Retention of β -carotene in carrots as affected by blanching treatments and dehydration methods.

Treatments:

F = Fresh

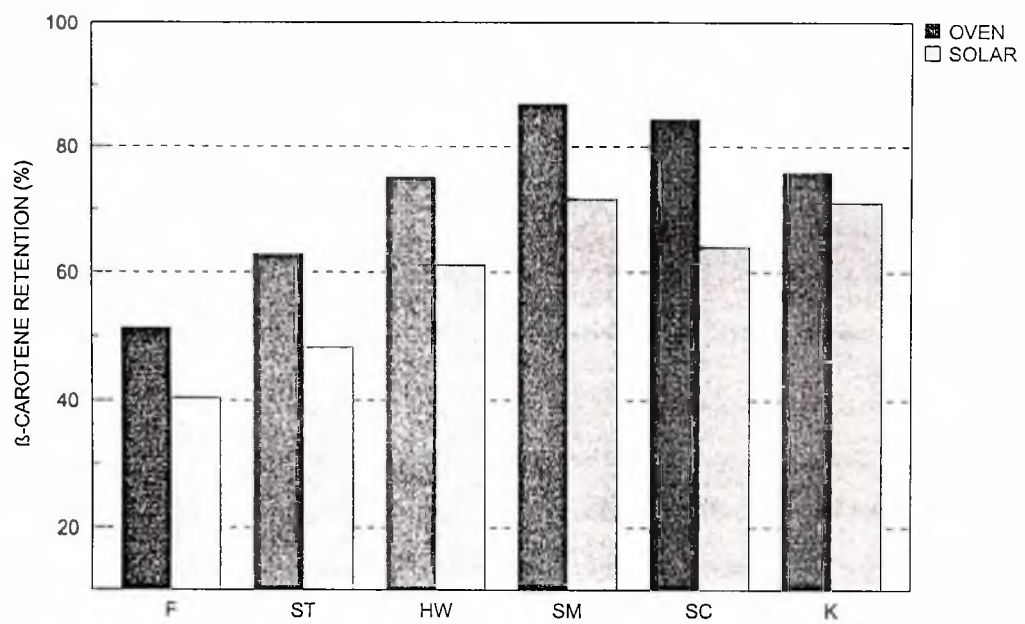
ST = Steam treated

HW = Hot water blanched

SM = Sulphite treated

SC = Sodium Chloride treated

K = Kanwa treated



for long periods caused the high loss of provitamin A loss in the solar dried products (Maeda and Salunkhe, 1981; Gomez, 1981).

4.1.3 Changes in β -carotene content of dehydrated carrots during storage

The effect of blanching treatment and dehydration methods were compared for β -carotene of dehydrated carrots during storage (Table 4.3). The content of carotene decreased in dehydrated carrots stored in transparent polyethylene bags as the storage period extended.

Statistical analysis (ANOVA) indicated that the storage period caused significant loss of carotene ($p \leq 0.05$). Exposure of β -carotene to oxygen and changes in moisture in packaging atmosphere have been reported to result in carotene loss during storage (Saguy et al., 1985). The packaging material used in this study was permeable to oxygen and was not light-proof.

The various blanching treatments had significant effect on carotene retention in the carrots during storage. At the end of three months of storage, NaHSO₃ and NaCl treated samples retained the highest carotene followed by steamed and kanwa treated carrots (Table 4.3). The lowest retention (25.2%) was observed in the fresh untreated carrots. A similar pattern was observed among the solar dried products. For these products, kanwa treated products had the highest retention

followed by NaCl, sulphite and steamed products in decreasing order (Table 4.3).

Table 4.3 Changes in beta-carotene content of dehydrated carrots after 90 days of storage.

Product	β-carotene content (mg/100g)			
	0 day		after 90 days	
	oven	solar	oven	solar
Fresh (unblanched)	34.85	27.44	8.8	6.45
Steamed	32.36	24.86	20.32	13.65
Hot water	27.77	22.6	7.71	5.87
NaHSO ₃	44.78	36.86	20.96	14.49
NaCl	36.3	27.48	23.8	14.81
Kanwa	38.19	35.73	18.5	15.45

A highly significant ($p \leq 0.05$) interaction was observed between blanching treatment and dehydration method. A similar interaction occurred between blanching treatment and storage, indicating that blanching treatment either steamed, hot water or in salt solutions (sulphite and kanwa) coupled with oven drying lead to high retention of β-carotene in carrots during storage at room temperature. This suggests that blanching probably deactivates carotene-bleaching enzymes (Blain, 1970) and thus enhanced the retention of carotene.

Kinetic models were used to predict the rate of β-carotene

degradation and the shelf-life of the dehydrated carrots. The degradation of β -carotene during storage followed a first-order reaction kinetics as indicated by the linear relationship ($r = 0.92-0.99$) of the logarithm plot of β -carotene retention (%) with storage time for all samples (Figure 4.2A & B). The reaction rate constants and half-lives calculated from the slope of the logarithm plots are shown in Table 4.4.

Table 4.4 **Beta-carotene degradation rate constants (K) and half-life ($T_{1/2}$) of dehydrated carrots during 90-day storage.**

Product	Drying method	Rate (K) $\times 10^{-3} \text{ day}^{-1}$	Half-life ($T_{1/2} \times \text{days}$)
Fresh (unblanched)	oven	16.08 (0.987)*	43.1
	solar	17.07 (0.987)	40.6
Steamed	oven	4.93 (0.921)	140.6
	solar	6.56 (0.993)	105.6
Hot water	oven	15.12 (0.979)	45.8
	solar	15.79 (0.986)	43.9
NaHSO ₄	oven	4.64 (0.984)	149.3
	solar	6.50 (0.983)	106.6
NaCl	oven	4.52 (0.992)	153.3
	solar	6.91 (0.997)	100.3
Kanwa	oven	7.82 (0.971)	88.6
	solar	9.36 (0.978)	74.0

* Values in parenthesis are correlation coefficients of slopes from which rates were calculated.

Fig. 4.2 Changes in β -carotene retention in oven (A) and solar (B) dehydrated carrots variously treated and stored at room temperature.

Treatments:

F = Fresh

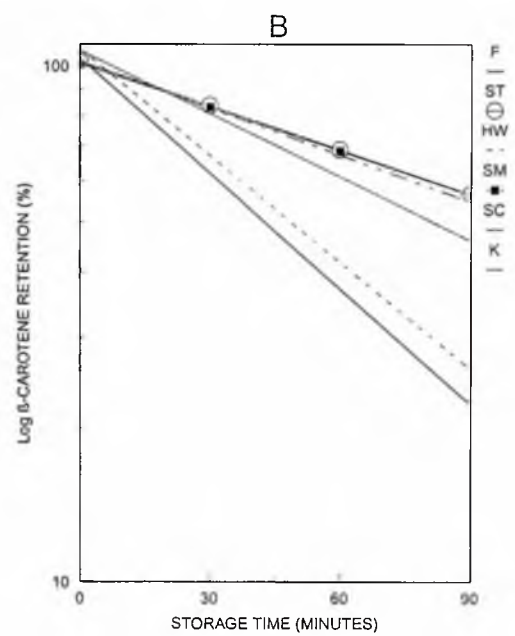
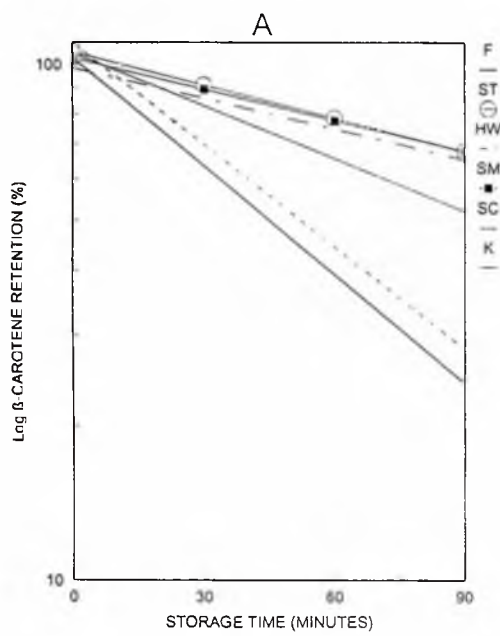
ST = Steam treated

HW = Hot water blanched

SM = Sulphite treated

SC = Sodium Chloride treated

K = Kanwa treated



Blanching treatments and dehydration methods significantly reduced/affected the rate of carotene degradation. The reaction rate constants calculated for the products in this study were lower than those calculated by Baloch et al. (1977c) for sulphited carrots. This may be due to the elevated storage temperature used in their study. Blanching leads to about two- to four-fold increase in the half-life of the dehydrated products. The highest half-life (ie the time required for half the initial concentration of β -carotene to be degraded) was observed for NaCl, sulphite and steamed products (153, 149 and 149 days, respectively). Kanwa had a $T_{1/2}$ of 88 days almost twice that of water blanched (45 days) and fresh untreated (43 days) carrots. A similar trend was observed for the solar dehydrated products.

NaCl and kanwa are locally available salts and could be used as substitutes for sulphite in the preservation of carrots.

4.1.4 Effect of alkali blanching on β -carotene content of green leafy vegetables

4.1.4.1 *Amaranthus incurvatus*

Alkali blanching as a pre-treatment to the dehydration of green leafy vegetables has been shown to improve colour and texture, and to enhance the retention of carotene (Nutting et al., 1970; Onayemi and Badifu, 1987).

To obtain data for optimum β -carotene retention in

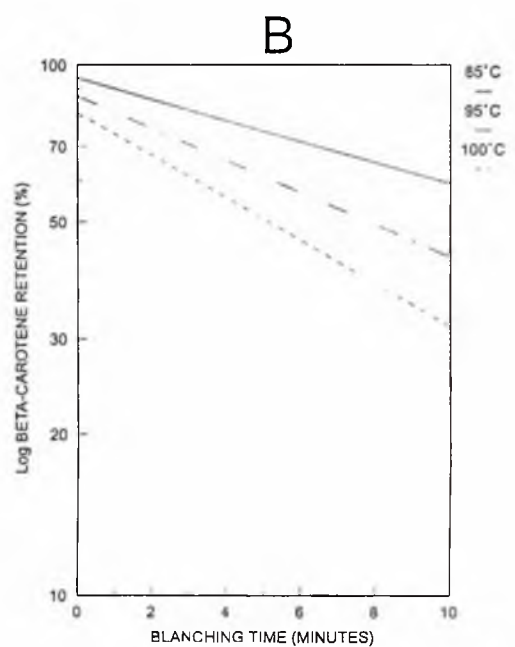
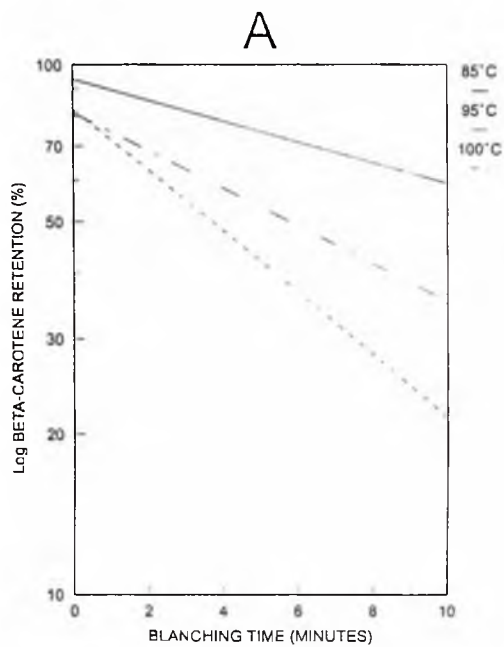
dehydrated leafy vegetables (*Amaranthus* and *Xanthosoma* sp.), the temperature dependence of the enhancing effect of alkali (Kanwa) blanching was tested in the concentration range of 0-0.1% and blanching time of 4-6 minutes.

Figure 4.3 (A, B & C) shows the comparative results of the enhancing activity of kanwa on β -carotene retention at the various temperatures and blanching times studied. Higher temperatures and longer times of blanching promoted higher β -carotene degradation ($p \leq 0.05$). The logarithm plot of percent β -carotene remaining against time of blanching gave good straight lines with correlation coefficients (r) of 0.89-0.99 which indicate an apparent first order kinetics. This is supported by Baloch et al. (1977b) who reported a first-order kinetic degradation for β -carotene in carrots, contrary to the the second order kinetics for β -carotene reported by Chen and Gutmanis (1968).

The rate constants calculated for β -carotene degradation from the retention curves (Figure 4.3A, B & C) are presented in Table 4.5. Examination of the data shows a general increase in the rate of β -carotene loss with increasing temperature at all kanwa concentrations ($p \leq 0.05$). This was expected considering the instability of β -carotene at high temperatures in the presence of oxygen (Saguy et al., 1985; Edwards and Lee, 1986).

Kanwa concentration enhanced retention of carotene and appeared to affect the rate of degradation (Table 4.5). This was however not significant ($p \leq 0.05$). The extent of carotene

Fig. 4.3 β -carotene degradation as a function of blanching time for *Amaranthus incurvatus* leaves in kanwa solutions at 0% (A), 0.05% (B) and 0.1% (C)



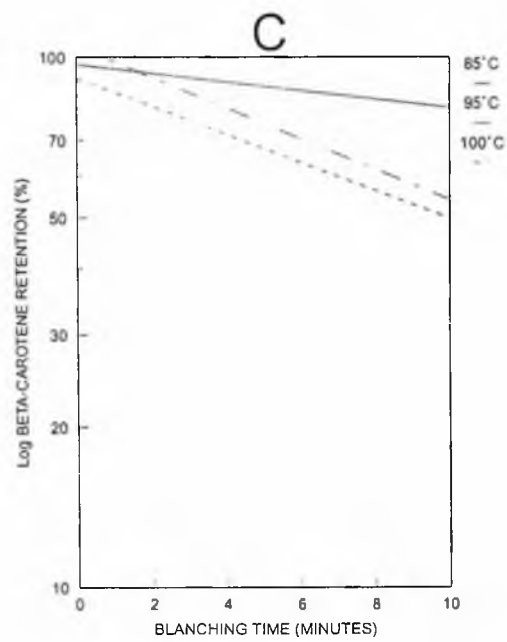


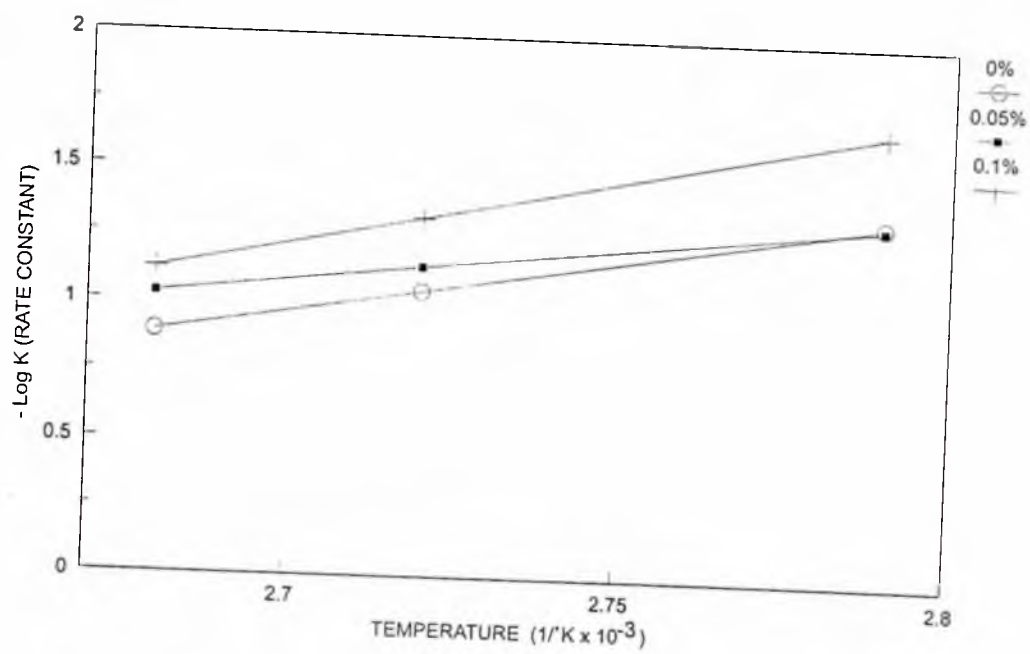
Table 4.5 Effect of blanching temperature and kanwa concentration on the reaction rate constants (K), activation energies (E_a) and half-lives ($T_{1/2}$) of β -carotene in *Amaranthus incurvatus* during blanching.

kanwa concentration (%)	Temperature (°C)	Rate (K) $\times 10^{-3} \text{ min}^{-1}$	E_a (Kcal/mol)	$T_{1/2}$ (min)
0	85	43.17	18.44	15.0
	95	83.58		8.3
	100	134.79		5.1
0.05	85	46.67	12.27	14.8
	95	71.23		9.7
	100	94.47		7.3
0.1	85	18.48	22.85	37.5
	95	66.0		10.5
	100	60.42		11.5

degradation decreased with increased concentration of kanwa (Figure 4.3A, B & C). NaHCO_3 and Na_2CO_3 have been identified as the major components in kanwa (Uzogara et al., 1991). Onayemi and Badifu (1987) reported that NaHCO_3 and NaCO_3 together effectively enhanced carotene retention and other quality attributes (colour and texture) of blanched and dehydrated leafy vegetables. A combination of sulphite and NaHCO_3 has also been reported to have a similar effect with regards to carotene retention in parsley (Nutting et al., 1970).

As the loss of β -carotene followed first-order kinetics in this study, the temperature dependence of the calculated rate constants (K) was modelled after the Arrhenius equation (Eq. 2, section 3). The Arrhenius plot is shown in Figure 4.4. Activation energies (E_a) for β -carotene degradation in

Fig. 4.4 Arrhenius plots of the first-order reaction constants for β -carotene changes in *Amaranthus incurvatus* blanched in kanwa solutions (0, 0.05 and 0.1%)



Amaranthus as determined by the Arrhenius equation at different concentrations were slightly different (Table 4.5). They were higher at higher concentrations. However, blanching in 0.05% kanwa had a lower E_a than 0% kanwa. A higher activation energy (E_a) implies that a smaller temperature change is required to degrade a specific amount of carotene. Therefore β -carotene in kanwa concentration of 0% with a E_a of 18 kcal/mole is more susceptible to thermal degradation than those at 0.1%.

A mathematical model was developed to predict β -carotene content of *Amaranthus incurvatus* leaves during blanching (Eq. 4):

$$Z = 97.368 + 4.273X_1X_2 - 7.91X_1X_3 \quad (4)$$

where X_1 = temperature of blanching

X_2 = kanwa concentration

X_3 = blanching time

The coefficients of the model were estimated using stepwise multiple regression. The model developed was significant ($p \leq 0.05$) and could explain 75.4% ($R^2 = 0.7538$) of the variations in the response variable (β -carotene). The interaction between temperature and time accounted for 99.9% of the changes in β -carotene of the *Amaranthus* during blanching and was the most important factor. It suggests that the change in carotene at any temperature depends on blanching time.

Response surfaces were generated from the models (Eq. 4) and is shown at Figure 4.5. The figure shows that β -carotene

Fig. 4.5 Response surface plot for β -carotene content of *Amaranthus incurvatus* blanched for 4 minutes under various conditions specified below.

Model:

$$Z = 97.368 + 4.273X_1X_2 - 7.91X_1X_3$$

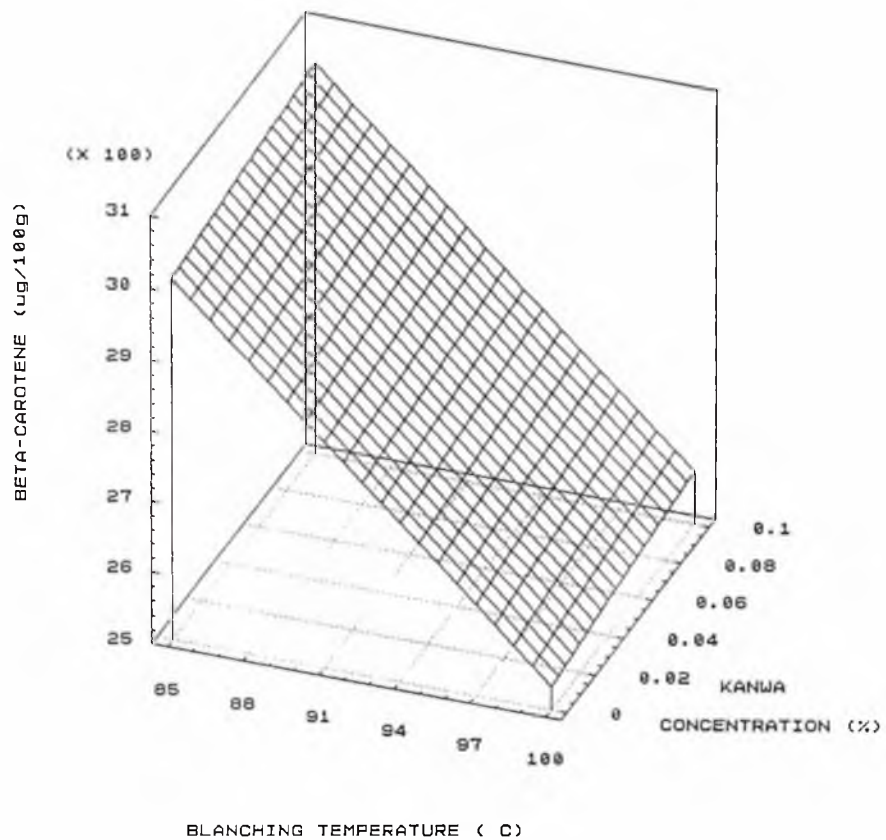
where Z = β -carotene content

X_1 = temperature of blanching

X_2 = kanwa concentration

X_3 = blanching time

$$R^2 = 0.7538$$



content decreased linearly as temperature decreased at all levels of *kanwa* concentration while β -carotene retention seemed to improve with increasing *kanwa* concentration and temperature of blanching.

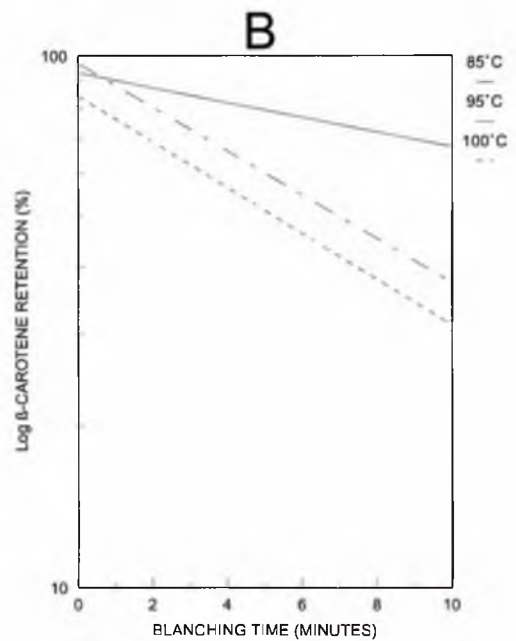
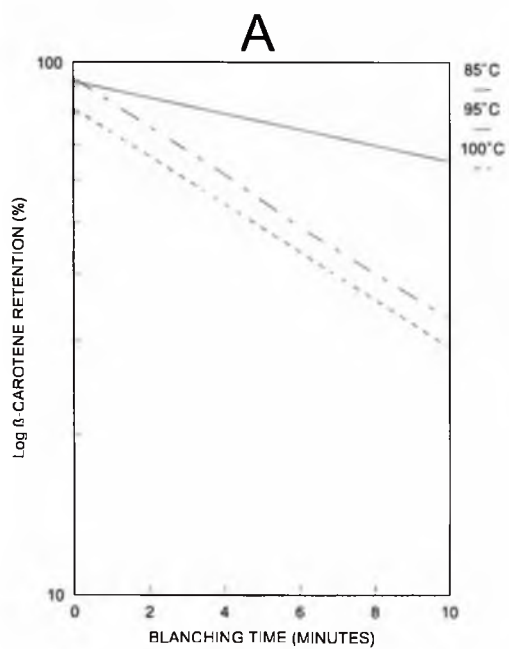
β -carotene, as well as other carotenoids degradation is reported to be pH dependent (Kearsley and Rodriguez, 1981; Tsimidou and Tsatsaroni, 1993). Because of the known effect of pH on the stability of carotenoids, the pH values of the blanching solutions were measured. They were 6.85, 10.53 and 10.55 for 0, 0.05 and 0.1% concentrations, respectively. There was a significant difference between the pH values for the *kanwa* blanching solutions and the plain water. However, the 0.05 and 0.1% solutions showed a difference of about 0.02 pH units.

4.1.4.2 *Xanthosoma maffafa*

Similar results were obtained for *Xanthosoma* as for *Amaranthus*. β -carotene in 0.1% *kanwa* blanched vegetables were significantly higher than in the 0 and 0.05% blanched samples at all temperatures (Figure 4.6A, B & C).

The loss of β -carotene in *Xanthosoma* in this study was temperature dependent and conformed to the Arrhenius model (Figure 4.7). The activation energies (E_a s) for 85-100 °C are comparable to those obtained for *Amaranthus* (Table 4.6). However, activation energies (E_a) decreased with increasing concentration of *kanwa* in contrast with that of the

Fig. 4.6 Retention of β -carotene as related to blanching time for *Xanthosoma maffafa* in 0% (A), 0.05% (B) and 0.1% (C) kanwa solutions



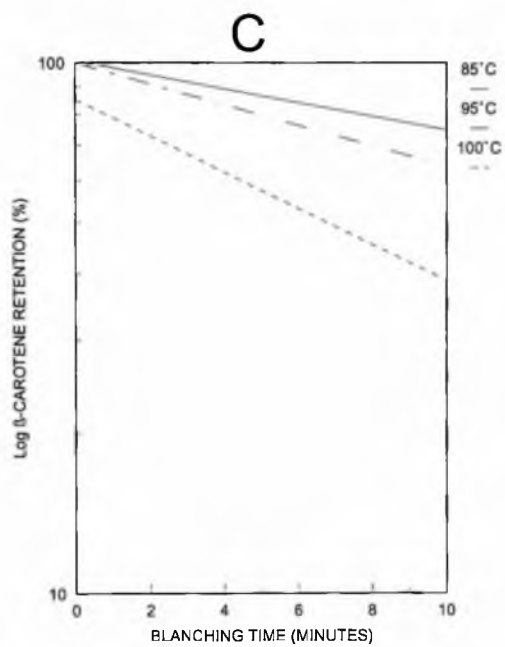


Fig. 4.7 Arrhenius plots for the first-order reaction rate constants for β -carotene changes in *Xanthosoma maffafa* blanched in kanwa solutions (0, 0.05 and 0.1%).

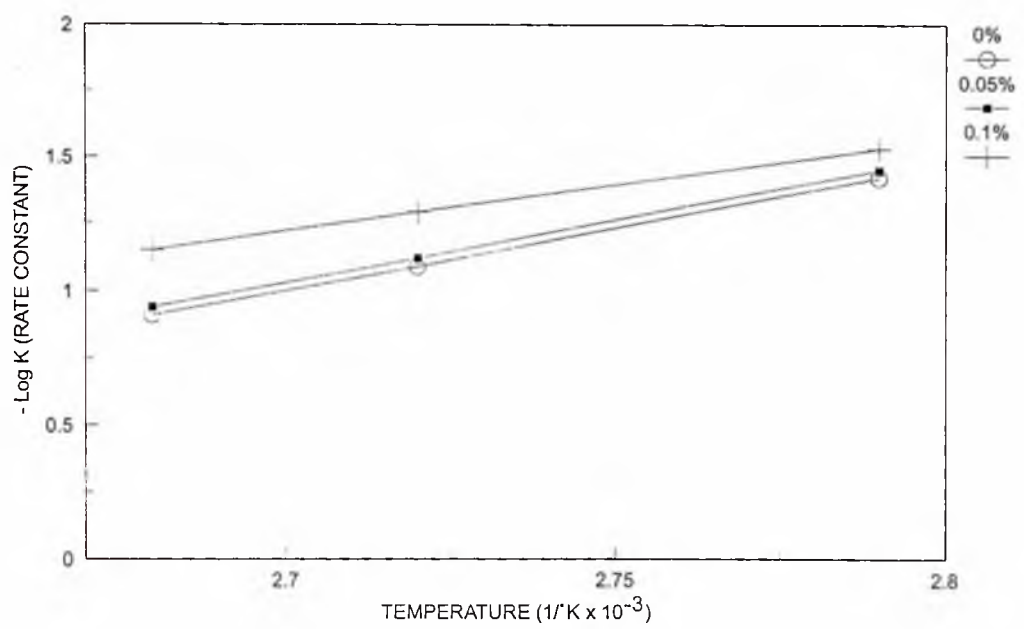


Table 4.6 Effect of blanching temperature and kanwa concentration on the reaction rate constants (K), activation energies (E_a) and half-lives ($T_{1/2}$) of β -carotene in *Xanthosoma maffafa* during blanching.

kanwa concentration (%)	Temperature (°C)	Rate (K) $\times 10^{-3} \text{ min}^{-1}$	E_a (Kcal/mol)	$T_{1/2}$ (min)
0	85	34.64	20.82	20.0
	95	104.2		6.6
	100	103.59		6.7
0.05	85	32.12	21.26	21.6
	95	95.04		7.3
	100	99.32		6.0
0.1	85	29.94	16.04	23.1
	95	44.81		15.5
	100	78.37		8.8

Amaranthus. This could be due to species difference.

Equation 5 shows the predictive model that was established for the stability of β -carotene in *Xanthosoma maffafa* leaves during blanching.

$$Z = 72.354 + 2.008X_1X_2 - 5.457X_1X_3 \quad (5)$$

X_1 = temperature of blanching

X_2 = kanwa concentration

X_3 = blanching time

The model could explain 76.9% of the observed variations in β -carotene content of the leaves during blanching. Interaction between temperature and time contributed 74.6% to the changes in β -carotene observed. Concentration and temperature interaction was not significant and could explain only 0.23% of the variations.

Figure 4.8 shows the response surface plot for the model (Eq. 5). It indicates that increasing temperature during blanching reduces β -carotene retention irrespective of the kanwa concentration.

4.1.5 Effect of dehydration on blanched green leafy vegetables

4.1.5.1 Moisture

The two dehydration methods (oven and solar drying) reduced drastically the moisture content of the blanched vegetables from 93.29-90.51 to 4.08-10.07 and 93.29-90.51 to 12.18-14.3 for the oven and solar dried samples respectively. The solar dried products contained the highest moisture even after the prolonged drying period (16 hours). The high-moisture highly-perishable vegetables were converted to low moisture products.

Similar results were observed for *Xanthosoma*, where moisture decreased from 93.04-90.03 to 4.1-9.45 and 6.92-10.27 for oven and solar respectively.

Fig. 4.8 Response surface plot for β -carotene content of *Xanthosoma maffafa* blanched for 4 minutes under various conditions specified below

Model:

$$Z = 72.354 + 2.008X_1X_2 - 5.457X_1X_3$$

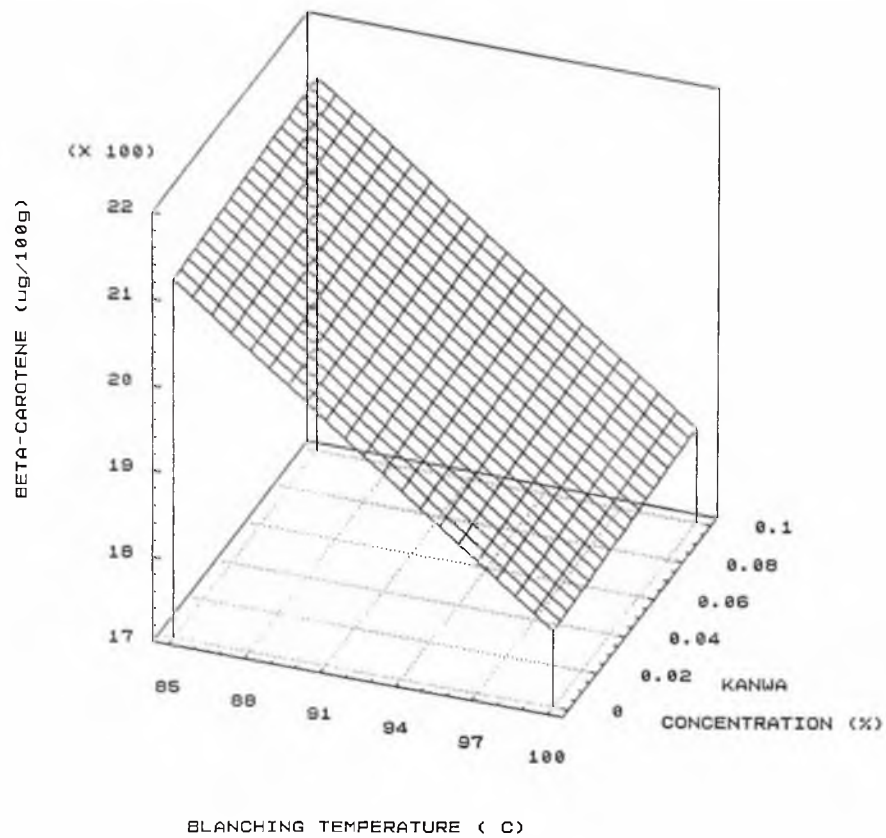
where Z = β -carotene content

X_1 = temperature of blanching

X_2 = kanwa concentration

X_3 = blanching time

$$R^2 = 0.7693$$



4.1.5.2 β -carotene content

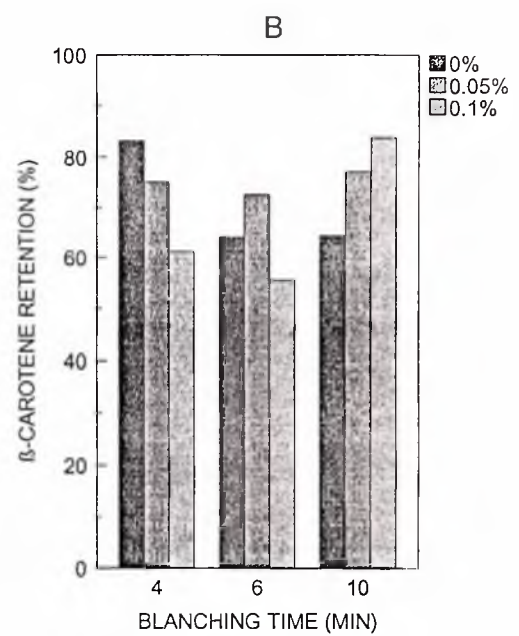
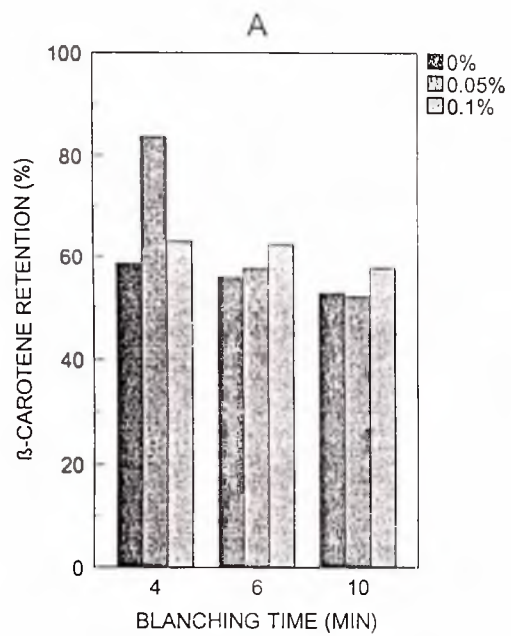
4.1.5.2.1 *Amaranthus*

β -carotene content of the blanched dehydrated vegetables was influenced by the drying process (Figures 4.9 & 4.10). Dehydration caused a loss of between 5.5 to 84.1% of β -carotene in the products. The highest carotene losses (56.6-84.1%) occurred during solar drying while oven drying resulted in 5.5-48% losses. This may be explained by the long exposure of the vegetables to light during solar drying (16 hours) compared to the enclosed and short drying time (8 hours) of the oven dryer. Maeda and Salunkhe (1981) reported that drying under shade promotes carotene retention in vegetables.

The retention of carotene in blanched vegetables was a function of the three treatments studied as shown in figures 4.9 and 4.10 (A, B & C). The three treatments of blanching concentration of kanwa, temperature and time showed varied effects on β -carotene retention during dehydration. In general, high temperature of blanching seemed to promote stability of β -carotene during drying in both oven and solar dried products. Blanching at 100°C gave the highest β -carotene stability at all blanching times and concentration (Figure 4.9C & 4.10C). Alkali concentration at the levels of 0, 0.05 and 0.1% did not show consistent effect on the retention of β -carotene during drying. The retention appeared to vary with temperature and time of blanching. Samples blanched with 0.05% alkali appeared to exhibit high carotene retention during drying.

Fig.4.9 Stability of β -carotene in *kanwa* (0, 0.05, 0.1%)
blanched *Amaranthus incurvatus* during oven
dehydration.

A = blanched at 85°C
B = blanched at 95°C
C = blanched at 100°C



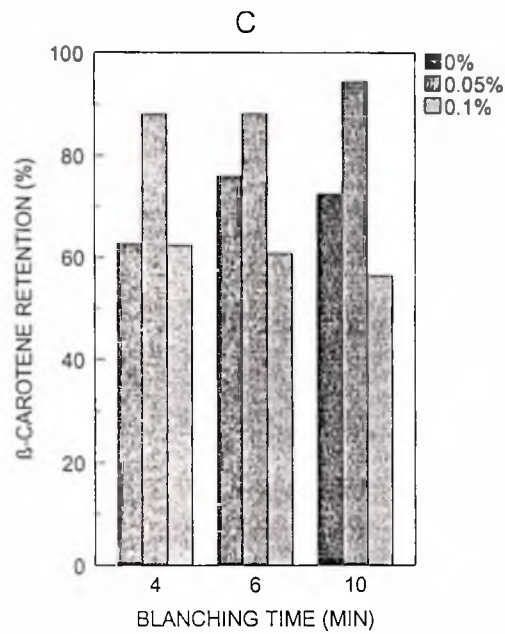
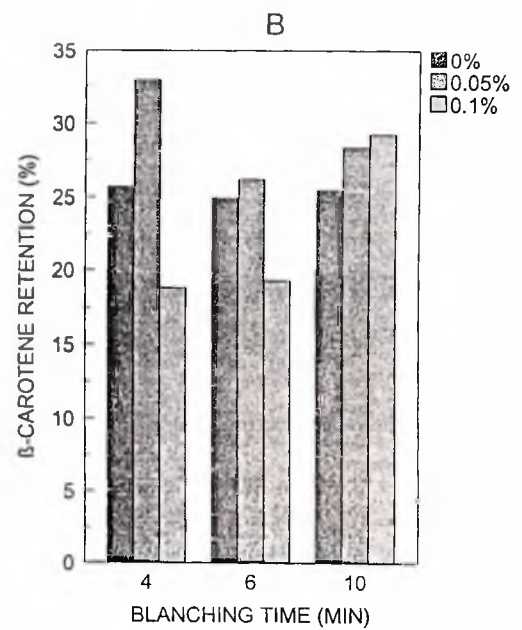
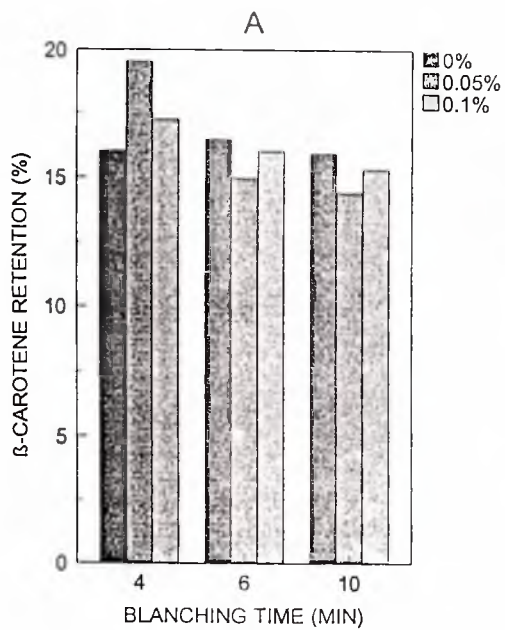
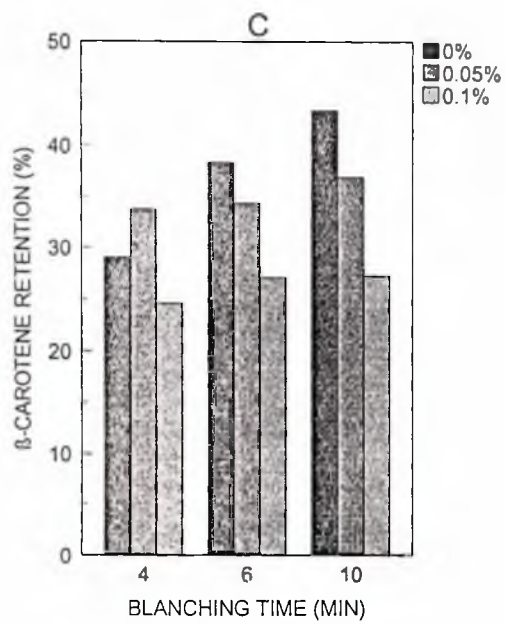


Fig.4.10 Stability of β -carotene in kanwa (0, 0.05, 0.1%)
blanched *Amaranthus incurvatus* during solar
dehydration
A = blanched at 85°C
B = blanched at 95°C
C = blanched at 100°C





4.1.5.2.2 *Xanthosoma*

Temperature of blanching was found to have significant effect ($p \leq 0.05$) on carotene retention in *Xanthosoma* during dehydration. Similar to *Amaranthus*, blanching at 100°C enhanced the highest retention followed by the 95°C, with 85°C samples having the lowest retention at all process variables (Figures 4.11 & 4.12). In contrast with the result obtained for the *Amaranthus* samples (Figures 4.9 & 4.10), alkali treated vegetables at 0.05 and 0.1% kanwa had the highest retention of carotene (Figures 4.11 & 4.12). This observation was pronounced in the samples blanched at 85 and 100 °C (Figures 4.11A, C, 4.12A & C).

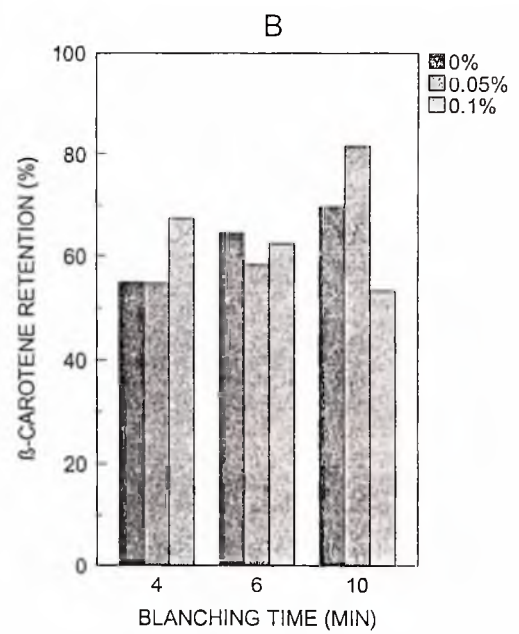
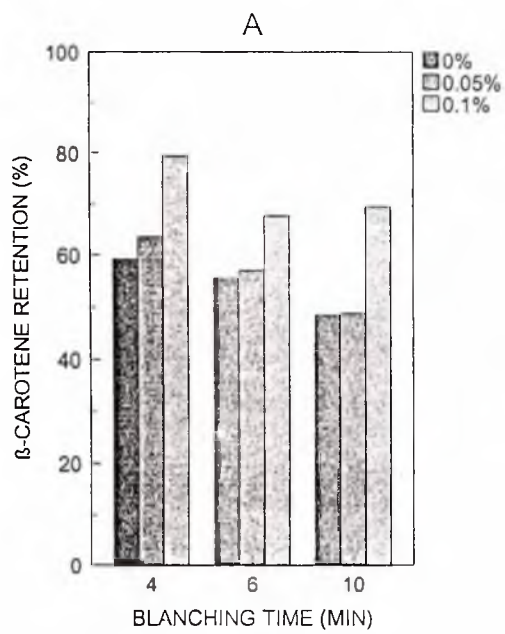
In general, the *Xanthosoma* samples retained higher carotene levels than *Amaranthus* for both oven and solar drying.

4.1.6 Storage stability of blanched dehydrated vegetables

4.1.6.1 Moisture

Moisture content of the stored products ranged from 4.0-10.7 to 6.39-14.91 for the oven dried products, and 10.1-11.6 to 6.9-9.4 for the solar dried products at the end of the storage period. There was a general increase in moisture content for all the products as storage progressed.

Fig. 4.11 Retention of β -carotene during oven dehydration of
kanwa (0, 0.05, 0.1%) blanched *Xanthosoma maffafa*
A = blanched at 85°C
B = blanched at 95°C
C = blanched at 100°C



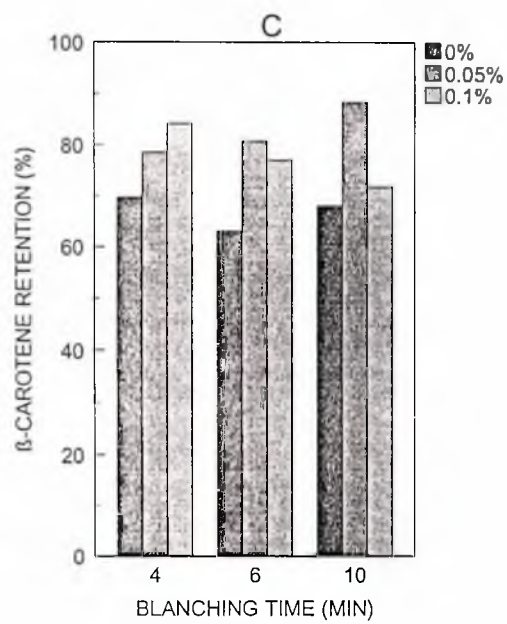
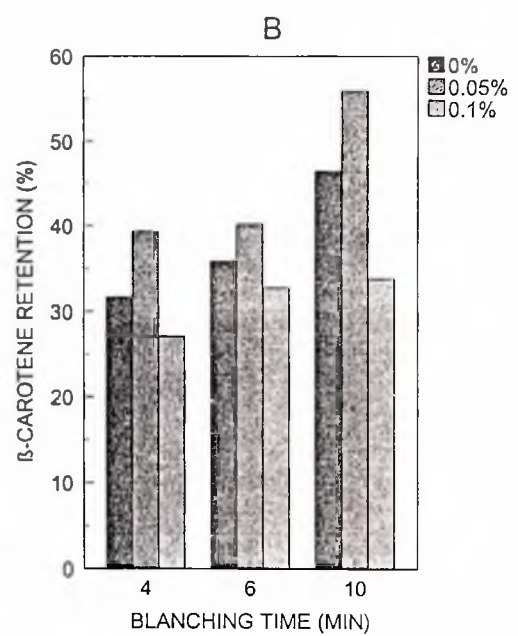
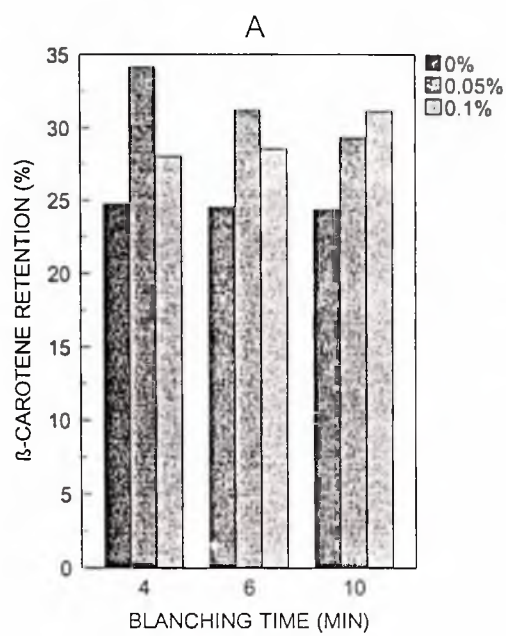
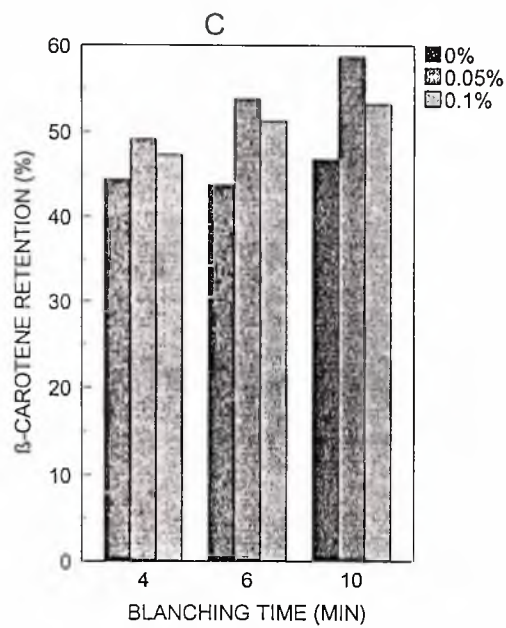


Fig. 4.12 Retention of β -carotene during solar dehydration of
kanwa (0, 0.05, 0.1%) blanched *Xanthosoma maffafa*
A = blanched at 85°C
B = blanched at 95°C
C = blanched at 100°C





4.1.6.2 *Amaranthus*

The storage resulted in a decrease in initial carotene content of all the samples. The initial variation in carotene levels before storage was due to the kind of treatment each product received (Appendix 3). At the end of three months of storage, β -carotene retention appeared to be higher in the oven dried products as compared to solar dried. This was not statistically significant ($p \leq 0.05$). Mugula et al. (1994) observed no significant difference between the loss of carotene in oven and sun dried banana powder over 12 weeks of storage.

To predict the retention of blanched dehydrated *Amaranthus* products during storage at room temperature, regression models were developed for each month's storage. Table 4.7 shows the coefficients of the processing variables at the end of each storage month.

Figures 4.13A & B show three dimensional response surface plots for oven and solar dehydrated products respectively. At low blanching temperatures, increasing kanwa concentration enhanced carotene retention at the end of 30 day storage. The retention is further enhanced at higher temperatures of blanching for solar dehydrated products.

Table 4.7 Regression models for β -carotene in dehydrated *Amaranthus incurvatus* leaves

Oven

1. Initial storage

$$Z = 50.2667 + 20.4X_2 + 11.9944X_1 - 9.9889X_3 + 3.1444X_2^2 + 2.4083X_1X_3$$

2. 1 month storage

$$Z = 15.8133 + 11.3X_1 + 3.3258X_2 + 3.3056X_1^2 + 2.708X_2X_3$$

3. 2 month storage

$$Z = 16.2103 + 0.5578X_1X_2 + 1.0196X_1X_3$$

4. 3 month storage

$$Z = 6.9296 + 10.9667X_2 + 3.15X_1 - 2.4167X_3 + 2.0111X_2^2 + 0.6389X_1^2$$

Solar

1. Initial storage

$$Z = 8.5778 + 7.6278X_2 + 2.477X_3 + 0.3333X_3^2 - 1.35X_2^2 + 0.194X_1X_3$$

2. 1 month storage

$$Z = 2.1 + 2.2182X_1 + 5.0778X_2 + 0.35X_2^2 + 0.2452X_1X_3 + 0.3917X_1X_2$$

3. 2 month storage

$$Z = 3.5717 + 4.0422X_2 + 0.4783X_1^2 + 0.3401X_1X_2 - 0.3559X_2X_3$$

4. 3 month storage

$$Z = 1.6612 + 5.1667X_2 - 0.2111X_1X_2 + 0.3468X_1X_3 - 0.5X_2^2 + 0.5389X_1^2$$

X_1 = Temperature of Blanching

X_2 = Kanwa Concentration

X_3 = Blanching Time

Fig. 4.13 Response surfaces for β -carotene content of solar (A) and oven (B) dried *Amaranthus incurvatus* at initial and 60 day of storage respectively under various conditions specified below:

Model:

$$(A) \quad Z = 16.2103 + 0.5578X_1X_2 - 1.0196X_1X_3$$

$$R^2 = 0.6478$$

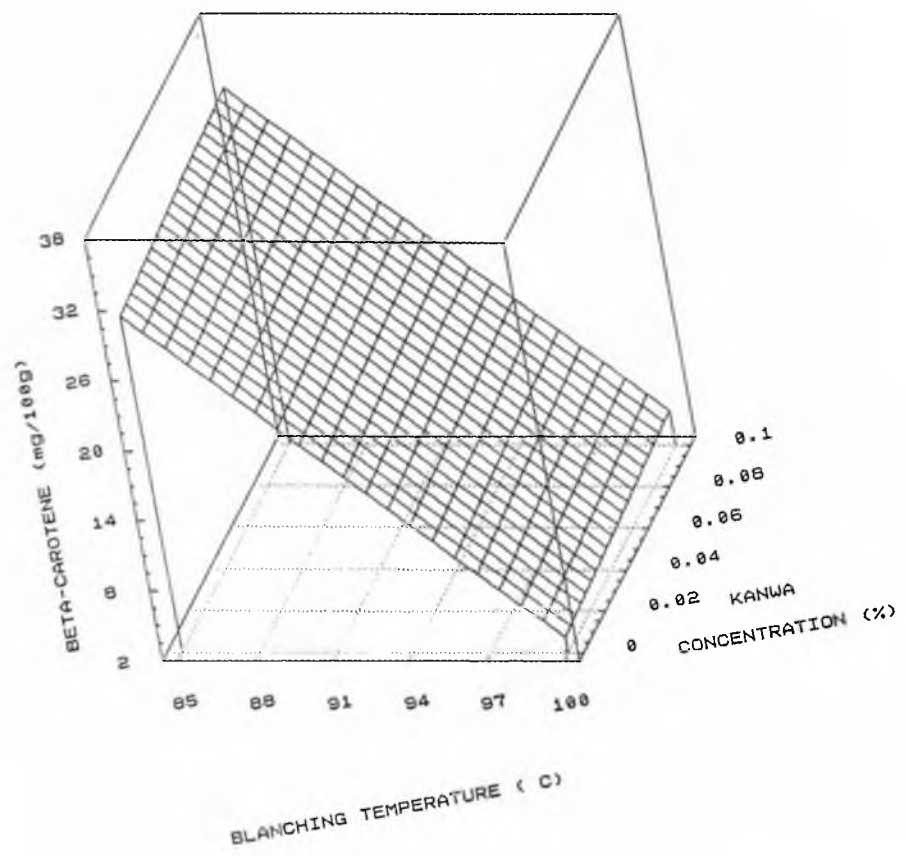
$$(B) \quad Z = 8.5778 + 7.6278X_2 - 2.477X_3 - 0.3333X_1^2 - 1.35X_2^2 + 0.194X_1X_3$$

$$R^2 = 0.8633$$

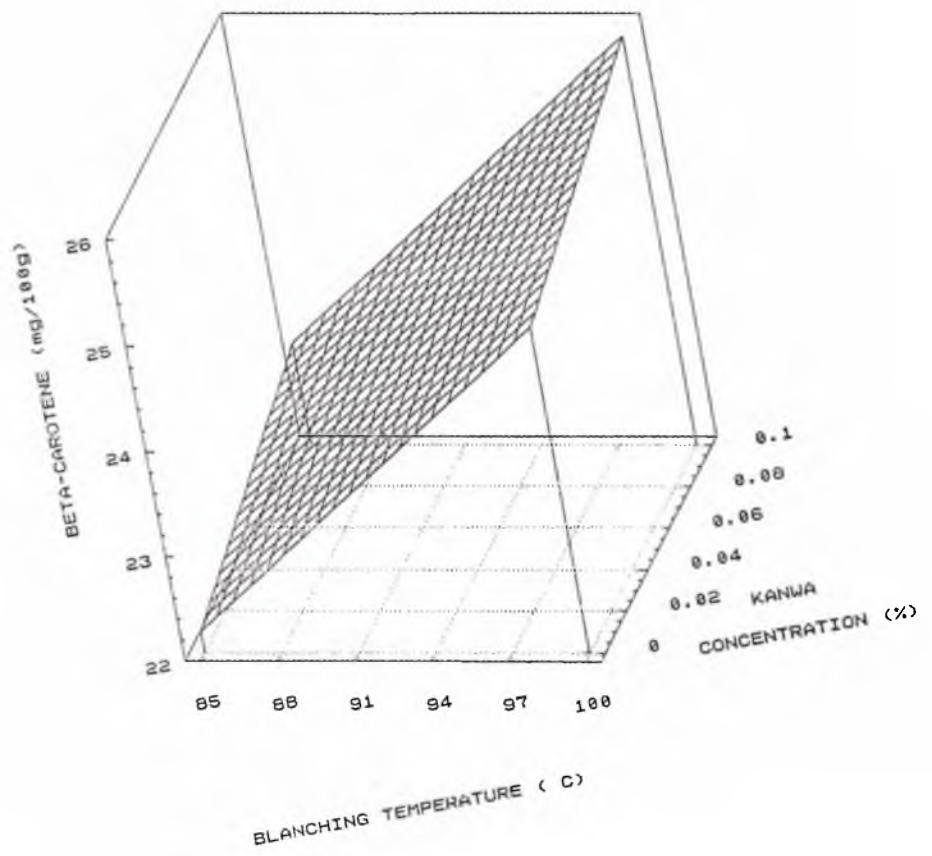
where

Z = β -carotene content
 X_1 = Temperature of Blanching
 X_2 = Kanwa Concentration
 X_3 = Blanching Time

A



B



All samples blanched at low temperatures had higher carotene content than their counterparts that were blanched at high temperature at each level of kanwa concentration (fig. 4.13B). More carotene was retained in the samples blanched in higher concentrations of kanwa. As blanching concentration decreased less carotene was retained with increasing temperature.

The rate of carotene degradation in the dehydrated products during storage was calculated and modelled after first-order kinetics. First-order rate constants for carotene degradation and the corresponding half-lives are presented in Table 4.8. For the oven dried products, degradation rate constants did not show any definite pattern. Concentration, temperature and time of blanching had no significant effect on the rate of carotene degradation. However, degradation rates for the solar dried vegetables showed a different trend. Blanching in 0.1% kanwa showed significantly slower rates of β -carotene degradation compared to 0.05 and 0% kanwa treated samples. In samples that received oven drying, β -carotene degradation occurred at a faster rate ($p \leq 0.05$) compared to the solar dried (Table 4.8). This led to a half-life of 37.6-296 days in solar dried samples compared to the 35.1-66.6 days for oven dried vegetables, about four-fold increase in carotene stability. The difference could be due to the lower initial concentration of carotene in the solar dehydrated products leading to the slower rate of destruction (Park, 1987).

Table 4.8 Rate constants (K) and ($T_{1/2}$) half-lives of beta-carotene in *Amaranthus incurvatus* stored for 90 days

Kanwa Conc (%)	Temperature (°C)	Time (min)	K x 10 ⁻³ day ⁻¹		T _{1/2} days	
			oven	solar	oven	solar
0	85	4	19.71	6.71	35.2	103.3
		6	17.19	7.60	40.3	91.2
		10	19.72	10.63	35.1	65.2
	95	4	12.48	5.14	55.5	87.1
		6	15.00	5.65	46.1	122.7
		10	19.31	6.08	35.9	113.9
	100	4	12.17	4.66	57.0	117.0
		6	14.92	4.00	46.5	173.1
		10	14.68	5.46	47.2	126.8
0.05	85	4	16.08	5.08	43.1	136.4
		6	12.38	4.67	56.0	148.2
		10	11.77	4.19	58.9	165.5
	95	4	14.56	7.95	47.9	87.1
		6	14.90	6.12	46.5	113.2
		10	14.79	5.88	46.9	117.8
	100	4	13.23	18.43	52.4	37.6
		6	14.64	3.14	47.3	220.7
		10	13.93	4.01	49.7	172.9
0.1	85	4	15.65	3.56	44.3	194.6
		6	16.39	3.34	42.3	207.3
		10	17.66	4.32	39.2	160.3
	95	4	16.63	2.77	41.7	250.5
		6	17.53	3.48	39.5	199.2
		10	18.62	3.55	37.2	195.0
	100	4	10.40	2.34	66.6	296.1
		6	12.71	2.52	54.5	274.4
		10	14.46	14.45	47.9	47.9

Blanching at a temperature of 100°C for 4 minutes in 0.1% alkali solution resulted in the highest half-life of 66 and 296 days for oven and solar dehydrated *Amaranthus*, respectively.

4.1.6.3 *Xanthosoma maffafa*

Similar results were observed for the *Xanthosoma* products. The predictive models for carotene in dehydrated *Xanthosoma* at the various stages of storage are shown in Table 4.9.

Table 4.9 Models for β -carotene in dehydrated *Xanthosoma maffafa* leaves

Oven

1. Initial storage

$$Z = 29.7615 + 3.9215X_2^2 - 2.6129X_1X_2 - 2.0332X_2X_3$$
2. 1 month storage

$$Z = 18.8718 + 2.5111X_2 + 0.7596X_1X_3$$
3. 2 month storage

$$Z = 13.6762 + 2.5944X_2 + 0.7046X_1X_3$$
4. 3 month storage

$$Z = 5.6333 + 11.2705X_2 - 3.6461X_3 - 1.3833X_2^2 + 1.6269X_1X_3 + 1.2897X_1X_3$$

Solar

1. Initial storage

$$Z = 7.6222 + 8.7778X_2 + 0.7667X_3 + 1.5667X_2^2$$
 2. 1 month storage

$$Z = 5.7333 + 8.9024X_2 + 1.6833X_2^2 - 0.255X_1X_2 + 0.1512X_2X_3$$
 3. 2 month storage

$$Z = 4.6778 + 7.7222X_2 - 0.55X_3 - 1.5333X_2^2$$
 4. 3 month storage

$$Z = 4.0333 + 7.2167X_2 - 0.4889X_3 + 1.5833X_2^2$$
-

X_1 = Temperature of Blanching

X_2 = Kanwa Concentration

X_3 = Blanching Time

At the end of the third month of storage of the blanched leaves, β -carotene level in the solar dried products decreased with increasing of kanwa concentration (Figure 4.14). The effect of blanching temperature on carotene level was dependent on the concentration of the blanching kanwa solution. At low kanwa concentration, blanching temperatures did not seem to have any effects on β -carotene. At high kanwa concentration, however, increased blanching temperature decreased β -carotene levels in the leaves.

The response plot (Fig. 4.15) generated for the oven dehydrated products at the initial storage period showed the same trend as the solar products.

Solar dehydrated samples resulted in about three-fold increase in half-life over the oven dried samples (Table 4.10). The highest half-life of 158 days was observed for the oven dried products blanched at 95°C for 4 minutes in 0.05% kanwa whilst pre-treating the vegetables in 0.05% kanwa for 4 minutes at 100°C led to a half-life of 212.6 days in the solar dried samples.

The rate of carotene degradation decreased significantly with increasing blanching temperature ($p \leq 0.05$). This suggests that the blanching at higher temperatures was adequate to reduce the activities of carotene-bleaching enzymes (Blain, 1970).

Fig. 4.14 Response surface plot for β -carotene content of solar dried *Xanthosoma maffafa* at 30 days of storage under various conditions specified below:

Model:

$$Z = 5.7333 + 8.9024X_1 - 1.6833X_1^2 - 0.255X_1X_2 - 0.1512X_2X_3$$

where Z = β -carotene content

X_1 = Temperature of Blanching

X_2 = Kanwa Concentration

X_3 = Blanching Time

$$R^2 = 0.9455$$

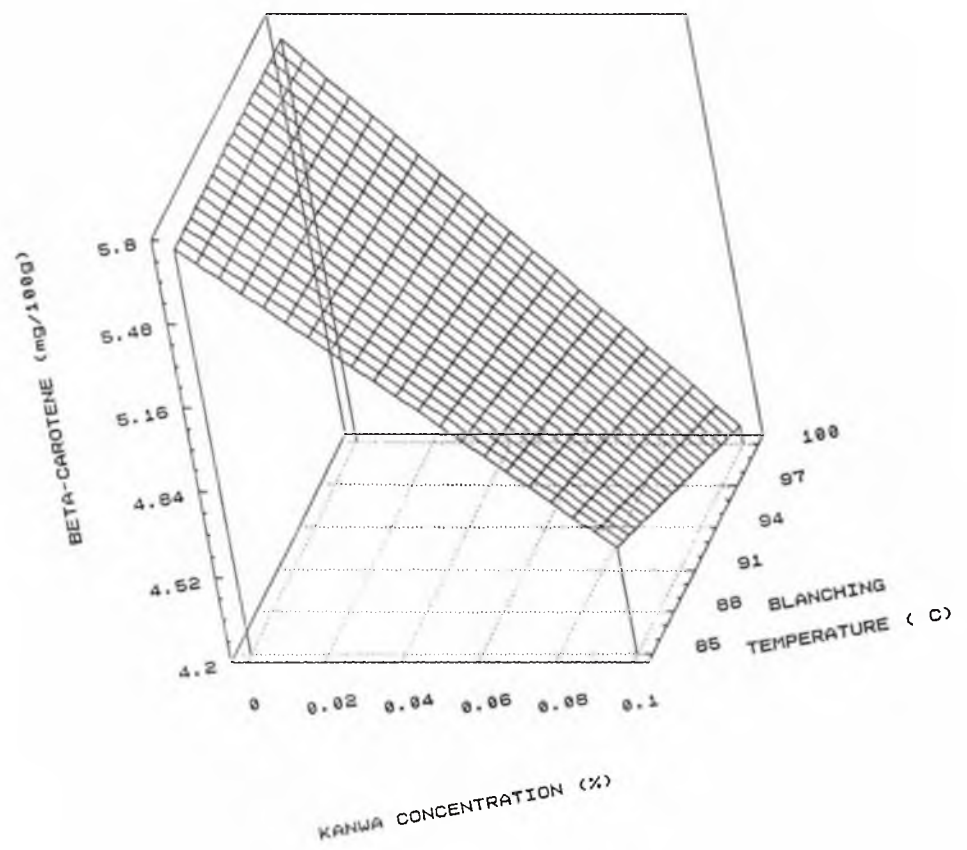


Fig. 4.15 Response surface plot for β -carotene content of oven dehydrated *Xanthosoma maffafa* at initial storage under various conditions specified below:

Model:

$$Z = 29.7615 + 3.9215X_1^2 - 2.6129X_1X_2 - 2.0332X_1X_3$$

where Z = β -carotene content

X_1 = Temperature of Blanching

X_2 = Kanwa Concentration

X_3 = Blanching Time

$R^2 = 0.8714$

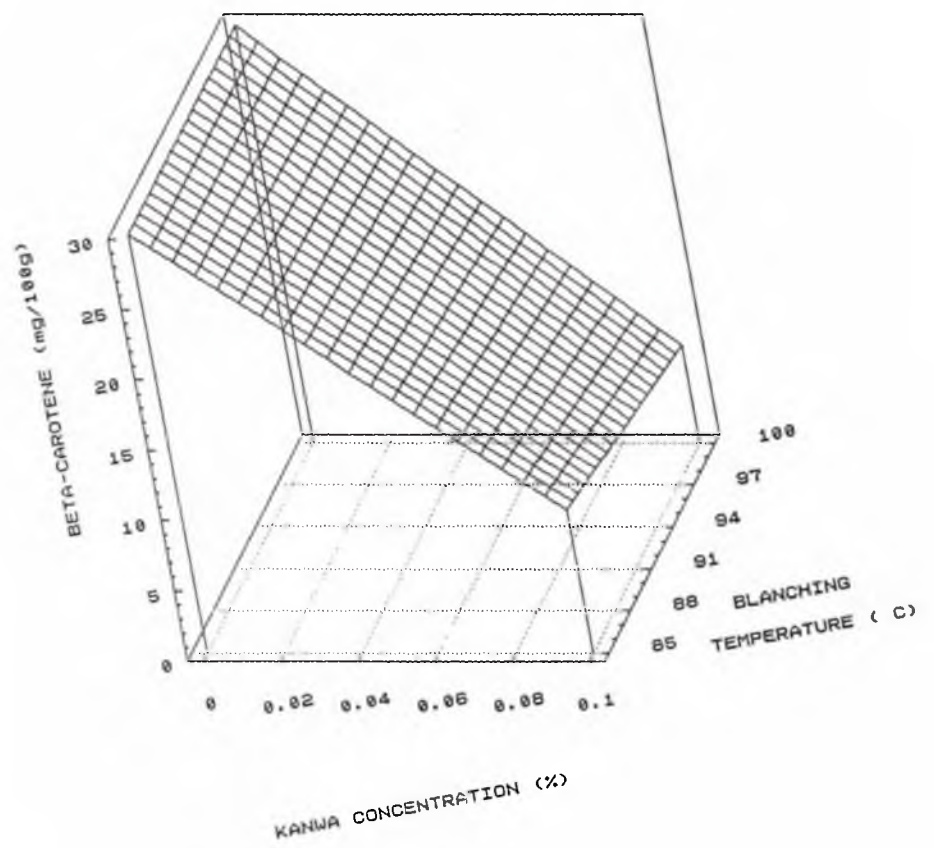


Table 4.10 Rate constants (K) and (T_{1/2}) half-lives of beta-carotene in *Xanthosoma maffafa* stored for 90 days

Kanwa Conc (%)	Temperature (°C)	Time (min)	K x 10 ⁻³ day ⁻¹		T _{1/2} days	
			oven	solar	oven	solar
0	85	4	8.48	5.34	81.7	129.7
		6	15.06	5.25	46.0	132.0
		10	13.11	5.18	52.8	133.8
	95	4	11.48	5.30	60.3	130.8
		6	10.58	5.11	65.5	135.6
		10	9.25	4.82	74.9	143.8
	100	4	8.70	4.66	79.7	148.8
		6	6.23	5.01	111.2	138.4
		10	6.05	4.30	114.5	161.0
0.05	85	4	8.02	5.31	86.4	130.5
		6	10.50	9.24	66.0	75.0
		10	8.30	5.40	83.2	128.4
	95	4	4.37	5.43	158.6	127.6
		6	5.89	5.16	117.7	134.4
		10	9.24	5.47	75.0	126.7
	100	4	8.15	3.26	85.0	212.7
		6	8.09	3.87	85.7	197.0
		10	8.07	5.97	85.9	116.1
0.1	85	4	11.13	5.75	62.4	120.5
		6	9.09	6.30	76.2	110.1
		10	9.06	6.50	76.5	106.6
	95	4	12.03	5.40	57.6	128.3
		6	9.64	6.04	71.8	114.7
		10	9.38	5.79	73.9	119.6
	100	4	8.70	7.66	79.6	91.0
		6	7.93	5.90	87.3	117.4
		10	7.04	5.81	98.4	119.3

The study suggests that solar drying coupled with alkali blanching could be employed to enhance the shelf stability of carotene in green leafy vegetables. Solar drying is a cheap and affordable method of dehydration and preservation of foods common to the tropics (Maeda and Salunkhe, 1981) whilst kanwa is locally available and is already utilized in vegetable cooking (Uzogara *et al.*, 1991; Orraca-Tetteh, 1989).

4.2 β - CAROTENE STABILITY IN PALM OIL

The concentration of β -carotene in freshly prepared palm oil from a local processor was determined by HPLC analysis to be 111.14 mg/100g sample. This value is lower than those reported by Rao (1994) and Rukmini (1994).

ANOVA showed that heating time and temperature were equally significant ($p \leq 0.01$) in the degradation of β -carotene (Table 4.11). In addition, the data indicates that temperature and time of heating do not act independently of each other. Similar findings were reported by Crandall *et al* (1983).

Table 4.11 Summary of F-values for β -Carotene content of palm oil.

Source of variation	β -carotene
Heating temperature	1000.0**
Heating time	1000.0**
Temperature x Time	486.5**

**Significant at $p \leq 0.01$.

Data for β -carotene retention during the heating of palm oil at 100, 170 and 200°C are presented in Figure 4.16. The lines were determined to fit a first order kinetics model. β -carotene degradation was better described by using logarithmic relationship. The correlation coefficients (r) at 100, 170 and 200°C were 0.953, 0.979 and 0.983, respectively. First order kinetics, or pseudo-first order kinetic behaviour has been reported for β -carotene degradation due to oxidation and heat (Chou and Greene, 1972; Haralampu and Karel, 1983). However, Crandall et al. (1983), reported second-order kinetics for β -carotene in orange oil stored for 12 months.

At the end of 30 minutes of heating, samples heated at 200°C had completely lost the yellow colour and no β -carotene was detectable. It took over 60 minutes for the complete degradation of β -carotene at 170°C, while the sample heated at 100°C maintained about 33% of its initial β -carotene at the end of 240 minutes of heating. Cottrell (1991) reported that the β -carotene content in palm oil becomes negligible after heating to 200°C for 30 minutes.

Fig. 4.16 Plots of the logarithm of percent β -carotene retention in palm oil versus heating time at various temperatures.

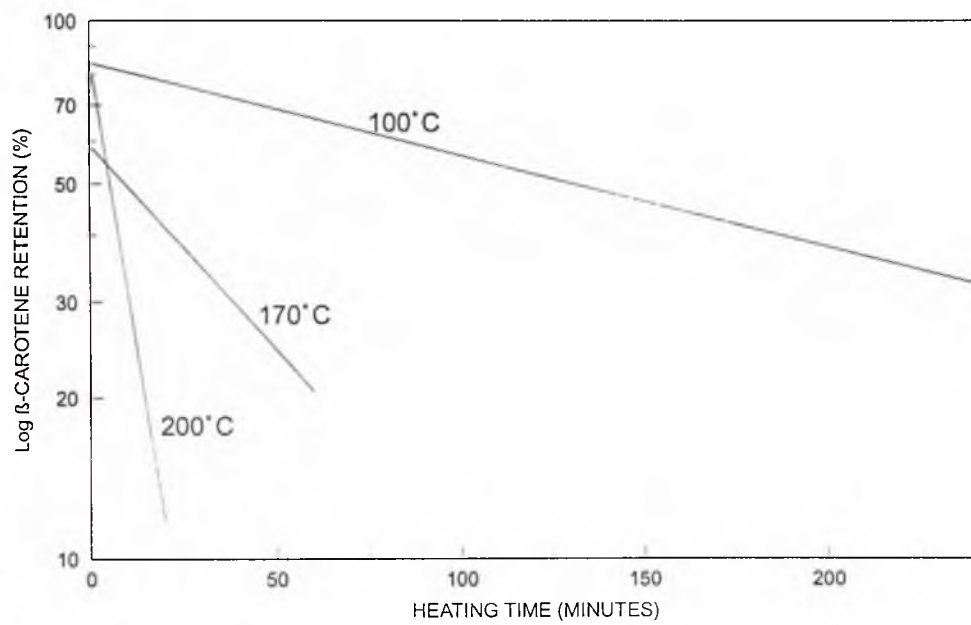


Table 4.12 shows the rate constants and half-lives of β -carotene at various temperatures of heating. The temperature dependence of rate constants as determined is shown in Figure 4.17. The data indicate that rate constant for β -carotene degradation varies linearly with temperature. Rate constants varied from $3.96 \times 10^{-3} \text{ min}^{-1}$ at 100°C to $99.72 \times 10^{-3} \text{ min}^{-1}$ at 200°C . This corresponds to half-lives ranging from 175-6.95 minutes. An approximately twenty-five fold decrease in stability was observed when temperature is increased from 100 - 200°C .

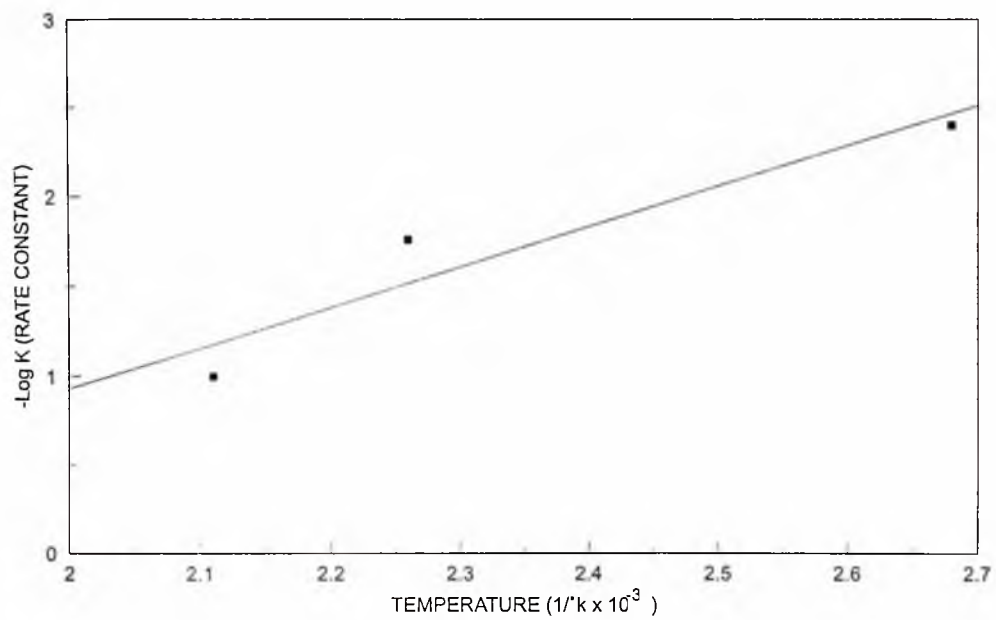
Table 4.12 Rate constants (k) and half-lives ($T_{1/2}$) of β -carotene degradation in palm oil.

Temperature ($^\circ\text{C}$)	Rate constant ($\text{K} \times 10^{-3} \text{ min}^{-1}$)	Half-life ($T_{1/2} \text{ min}$)	r^2
100	3.96	175	90.85
170	17.55	39.49	95.83
200	99.72	6.95	96.65

*Values based on points obtained from regression

The activation energy (E_a) calculated from the slope of the Arrhenius plot (Figure 4.17) was 4.48 kcal/mole ($r^2 = 90.3$). The E_a calculated was lower than the 10.3 and 12.8 kcal/mole reported by Baloch et al (1977c). The difference might have occurred because the E_a was determined for β -carotene in dehydrated model systems at lower temperatures of storage (37 - 50°C) as compared to the high heating temperatures in this study.

Fig. 4.17 Temperature dependence of the rate constant of the thermal degradation of β -carotene in palm oil



4.3 SUITABILITY AND PERFORMANCE OF CARROT AND PALM OIL IN THE FORTIFICATION OF GARI

4.3.1 Fermentation studies

4.3.1.1 pH and Acidity.

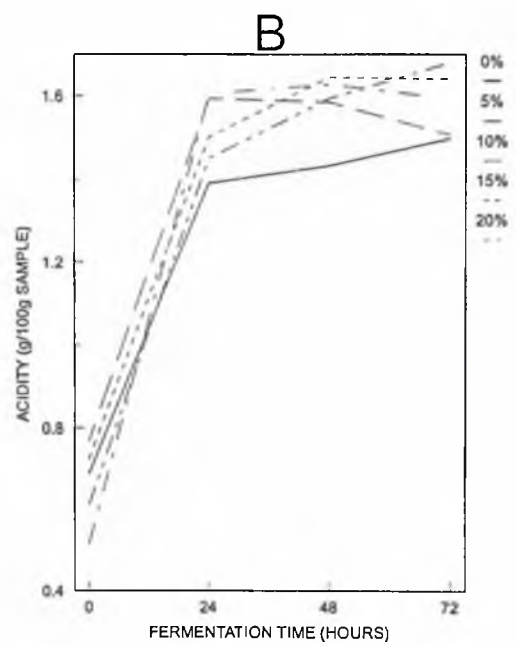
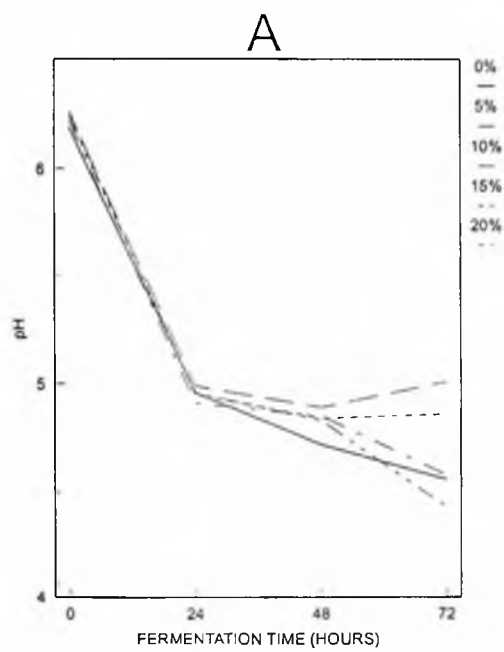
Cassava pulp and the co-fermented samples showed similar changes in pH during fermentation. Fermentation of the cassava pulp and those co-fermented with carrots led to a decline in pH. The first 24 hours of fermentation produced a sharp decline in pH from 6.19-6.26 to 4.91-4.96 in all the samples fermented (Figure 4.18A). However, the last 36 hours of fermentation showed a gradual drop in pH.

As the fermentation progressed the acidity of cassava and co-fermented samples increased (Figure 4.18B). The addition of carrots caused an increase in acidity of the cassava pulp. This was more noticeable after 24 hours of fermentation. Carrot is a rich source of fermentable sugars such as fructose, glucose and sucrose (De Castro *et al.*, 1995; Fleming *et al.*, 1983). These might have contributed to this observation.

Carrot and cassava are starchy crops and they undergo lactic acid fermentation to produce mainly lactic acid and other organic acids which contribute to flavour development (Nout, 1991; Fleming *et al.*, 1983), a desirable product quality in gari. Cassava fermentation also leads to cyanide detoxification (Sefa-Dedeh, 1993) and for the carrot-cassava co-fermenting system to show similar pH and acidity profiles adds another value, increased carotene

Fig. 4.18 Changes in pH (A) and titratable acidity (B) during co-fermentation of carrot-cassava pulp in Vitamin A fortification process.

0% = unfortified cassava
5% = 5% carrot in cassava
10% = 10% carrot in cassava
15% = 15% carrot in cassava
20% = 20% carrot in cassava



content, apart from the and flavour-souring development.

4.3.1.2 Effects of fermentation on carotene

The fortification of cassava pulp at the levels of 5, 10, 15 and 20% before fermentation resulted in high levels of carotene in the pulps. There was no detectable carotene in the raw cassava pulp at the sensitivity of the HPLC method used (Table 4.13). This remained so throughout the fermentation period (72 hours). Fermentation resulted in a general decrease in carotene content of all the fortified samples.

Statistical analysis (ANOVA) indicated fermentation time to be a significant factor ($p \leq 0.05$) affecting carotene disappearance in the fermenting systems.

Carotene bleaching enzymes have been reported in plant extracts (Blain, 1970). Baloch et al. (1977a) attributed the loss of carotenoid in incubated carrot homogenate to carotenoid-destroying enzymes. Carrot and cassava fermentation involves a complex biochemical system of microflora and enzymes (De Castro et al., 1995; Nout, 1991b; Fleming et al., 1983). The disappearance of carotene could be due to the activities of these microbes. Lactic acid fermentation of carrots has been shown to reduce the levels of beta-carotene and phytofluene (Minquez-Monquera et al., 1989).

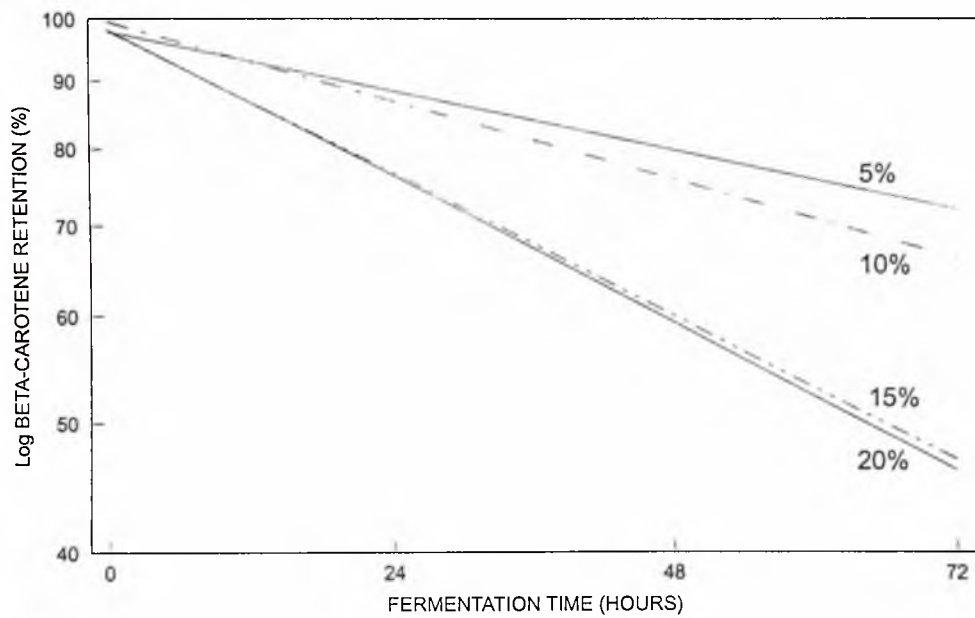
Table 4.13 Initial β -carotene content of carrot-fortified cassava pulp, degradation rate constants (K) and half-lives ($T_{1/2}$) during 72 Hour fermentation.

Carrot concentration	β -carotene content (mg/100g)	Rate (K) ($\times 10^{-3}$ H)	Half-life ($T_{1/2} \times H$)
0			
5	26.34	4.27 (0.984)	162.3
10	46.22	5.65 (0.999)	122.65
15	59.9	10.23 (0.994)	67.74
20	82.10	10.51 (0.995)	65.94

Values in brackets are correlation coefficient values.

To measure the rate of loss of carotene during fermentation, rate kinetics was applied to the disappearance of carotene in the fermenting system. Figure 4.19 shows the semi-logarithm plots for carotene disappearance during fermentation. The reaction rate constants calculated from the slopes in Figure 4.19 are given in Table 4.13. Higher fortification appeared to promote higher rates of carotene degradation. The 15 and 20% fortified samples had about the same rate (10.23 and $10.51 \times 10^{-3} \text{ H}^{-1}$ respectively). This was about twice the rate observed for the 5 and 10% samples (Table 4.13).

Fig. 4.19 First-order regression lines for the degradation of β -carotene with respect to fortification level (5, 10, 15 and 20%) in carrot-cassava pulp fermenting system at room temperature.



4.3.2 Effects of roasting on β -carotene in fortified gari

Roasting is an important unit operation in the processing of gari. During roasting dry heat is applied to the de-watered fermented cassava pulp. This brings about temperature dependent reactions including browning leading to colour and flavour development, desirable quality characteristics of gari (Nout, 1991a; Sefa-Dedeh, 1984). The reaction of the heat labile β -carotene with the acids produced during fermentation may possibly lead to oxidation or isomerization in the presence of oxygen.

β -carotene concentrations were drastically affected by the heating process during the roasting of the gari irrespective of level of fortification and method of fortification (Figure 4.20A, B & C). This was significant at $p \leq 0.05$. β -carotene retention of 50 - 70% and 35 - 67% were observed for the co-fermented and the single component fermentation systems respectively.

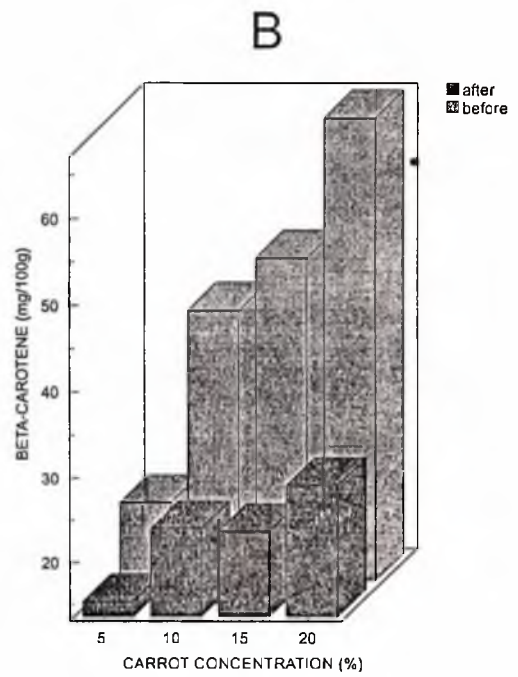
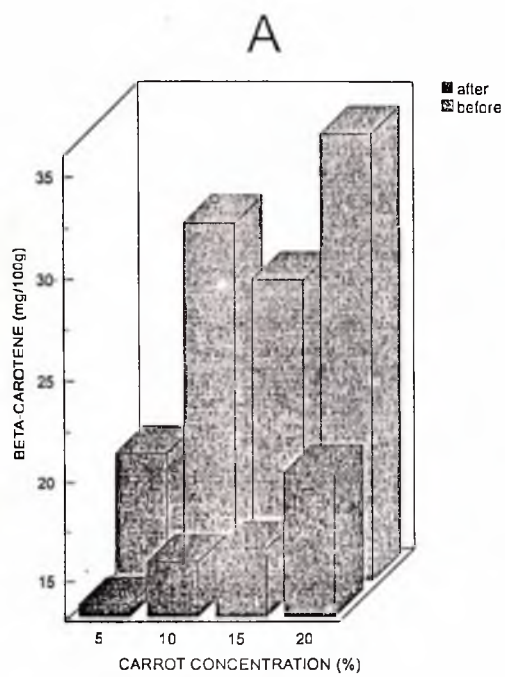
This suggests that co-fermenting carrot and cassava played an important role in β -carotene stability during the roasting. The retention of β -carotene decreased with increasing level of carrot fortification. Among the single component fermented gari samples, the 5% fortified product retained the highest carotene (70%) during roasting ($p \leq 0.05$). The loss of β -carotene in the 10, 15 and 20% fortification levels were 47.1, 57.2 and 57.1% respectively.

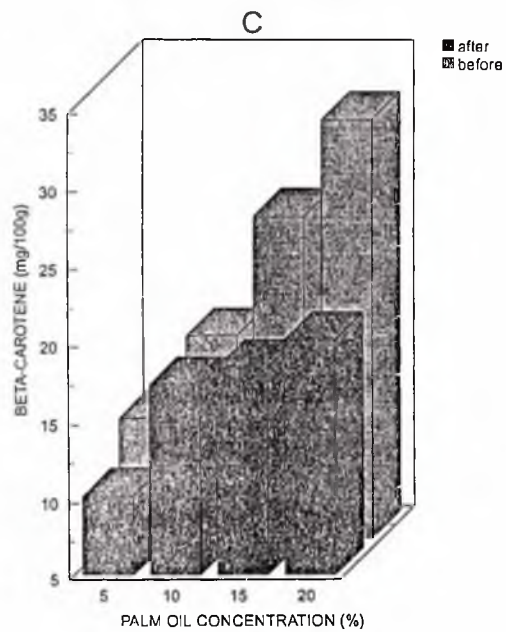
Fig. 4.20 Retention of β -carotene during roasting of carrot-fortified gari: a = after roasting and b = before roasting of gari.

A = carrot-fortified gari (co-fermented)

B = carrot-fortified gari (added after fermentation)

C = palm oil-fortified gari (added after fermentation)





A similar trend was observed in the co-fermented carrots and the palm oil fortified gari products, except that in the co-fermented carrot-fortified products, the 10% product retained the lowest whilst the opposite was true for the palm oil fortified products.

Park (1987) observed that the initial concentration of β -carotene affects its degradation in dehydrated vegetables. This he explained may be due to a "dilution effect" whereby a dilute solution is more stable than a more concentrated one.

Sudhakar and Maini (1994) also attributed the relative stability of carotenoids in Mango pulp to the presence of lower fructose and sucrose concentrations as compared to higher concentrations. Carrots are rich sources of fructose and sucrose (De Castro *et al.*, 1995; Fleming *et al.*, 1983). Increasing the levels of carrots during the fortification may increase the levels of these sugars and lead to low stability of β -carotene as observed in this study.

Comparative β -carotene retention of the carrot fortified- (single fermented systems) and the palm oil fortified-gari products showed that, in general, the palm oil products had higher retention of β -carotene (Figure 4.20B & C). The palm oil may require a longer time to raise the temperature to levels that will lead to drastic carotene degradation compared to the carrot-cassava systems.

Statistical analysis (ANOVA) of the data indicated that processing parameters such as fortification and method of

fortification (co-fermented and single fermented systems) significantly affected the β -carotene retention of the gari products ($p \leq 0.05$). However these variables acted independently of each other.

4.3.3 Storage stability of β -carotene in carrot- and palm oil-fortified gari

The moisture content of the freshly prepared gari (unfortified) was 5.1%. This increased to 5.9% at the end of the three months storage period. Similarly the fortified gari products with an initial moisture content of 3.2-5.6%, 5.3-6.0% and 4.4-5.9% increased to 3.2-6.95, 5.3-6.7% and 5.1-8.2% for the carrot fortified (single fermented), carrot co-fermented and palm oil fortified products, respectively. Gari is a low moisture product, and this quality characteristic makes it convenient. Low moisture is generally known as a requirement for long storage stability.

Table 4.14 shows the beta-carotene content and vitamin A equivalent of the fortified gari products. The freshly prepared gari samples showed a marked decrease in β -carotene during the storage period (Table 4.14). The highest loss of 80% occurred in the 15% palm oil fortified gari. The remaining β -carotene after three months of storage was about the same as the recommended daily requirements of vitamin A in an adult male (FAO, 1988). After three months of storage the decrease in β -carotene varied between 43.8 to 57.1% and 51.8 to 67.5%

for carrot fortified (single fermented) and the co-fermented products respectively. During the same period, the decrease was 50.5 - 80.4% in the palm oil fortified products (Table 4.14).

Table 4.14 Effect of storage on β -carotene and vitamin A* content of fortified-gari products.

Product	Initial		After 3 months	
	β -carotene mg/100g	Vitamin A RE	β -carotene mg/100g	Vitamin A RE
5A	14.84	2,474	4.82	804
10A	23.56	3,926	8.20	1,366
15A	23.20	3,866	11.19	1,866
20A	28.65	4,775	13.77	2,295
5B	13.64	2,273	7.6	1,274
10B	15.79	2,631	7.58	1,263
15B	16.48	2,746	7.07	1,178
20B	20.28	3,380	11.42	1,903
5PO	11.76	1,960	4.4	745
10PO	17.29	2,881	8.56	1,426
15PO	18.40	3,067	3.6	599
20PO	20.22	3,310	9.31	1,551

*Vitamin A is reported in retinol equivalents (RE)

RE = 1 μ g retinol equivalent 6 μ g β -carotene.

A = carrot-fortified gari (single fermented cassava pulp).

B = Carrot-fortified gari (co-fermented carrot-cassava).

PO = Palm oil fortified gari.

5, 10, 15 and 20 level (%) of carrot or palm oil

Statistical analysis (ANOVA) indicated that storage time, level of carrot fortification and method of fortification significantly affected the level of β -carotene in all the stored products. Similarly when palm oil and carrot fortified samples (single fermented) were compared, the data showed significant effects during storage ($p \leq 0.05$). Method of fortification showed significant interaction with the level of fortification and storage time. Source of carotene for the fortification and level of fortification did not act independently of each other.

The breakdown of β -carotene followed a first-order kinetics as can be seen by the high coefficients of variation ($r^2 = 86.36-99.95$) obtained for the degradations (Table 4.15).

The first-order kinetics was employed to calculate the rate constants and half-lives of β -carotene in the gari products (Table 4.15). The Rate of breakdown of carotene in the co-fermented carrot fortified products were slower ($6.32-8.19 \times 10^{-3} \text{ day}^{-1}$) compared to the other products. Carrot fortified samples (single fermented) seem to have about the same rates of degradation as the palm oil products.

The data seem to suggest that co-fermentation of carrot with cassava pulp lowers the rate of β -carotene loss during storage. This is confirmed by the longer half-lives calculated for the co-fermented products in relation to the other products (Table 4.15).

Table 4.15 Degradation rate constants (*K*) and Half-lives of fortified gari products during 90 days of storage.

Product	Rate (<i>K</i>) $\times 10^{-3} \text{ day}^{-1}$	Half-life $T_{1/2} \text{ day}^{-1}$	r^2
5A	12.81	54.1	99.19
10A	11.81	56.7	99.95
15A	7.92	87.5	98.96
20A	7.05	98.3	99.67
5B	6.32	109.6	99.68
10B	8.19	84.6	99.94
15B	8.06	86.0	99.12
20B	6.35	109.4	99.98
5PO	10.42	66.5	97.47
10PO	8.5	81.5	93.5
15PO	12.26	56.5	86.36
20PO	8.92	77.7	94.06

A carrot fortified gari (carrot added after fermentation of cassava)

B = carrot fortified gari (co-fermented with cassava).

PO Palm oil fortified gari.

5, 10, 15 and 20 = level (%) of carrot or palm oil

Analysis of variance (ANOVA) of the rates data indicated that method of fortification significantly influenced the rate of loss of β -carotene. Level of fortification and the source of carotene fortification had no influence ($p \leq 0.05$). Similarly method of fortification was significant with respect to half-life of β -carotene in the products. However, effects of fortification level and source of carotene were not

statistically significant.

4.3.4 Functional properties of fortified gari products

4.3.4.1 Swelling capacities

Swelling is a quality characteristic of gari as it is usually eaten either soaked in excess water with sugar or in adequate amount of water to allow maximum swelling to enable easy moulding and swallowing. A high swelling quality is therefore an advantage in gari products. Swelling profiles for the various gari products (control and the fortified) are shown in Figure 4.21A. The volume of gari products (swelled volume) increased with time of soaking for all products irrespective of the treatment. Within the first 10 minutes of soaking, the unfortified product showed a sharp rise in volume (37.0 cm) resulting in a near linear relationship between swelled volume and time of soaking. After 10 minutes of soaking a near steady state was observed/attained (Figure 4.21). A similar trend was observed for all the fortified products.

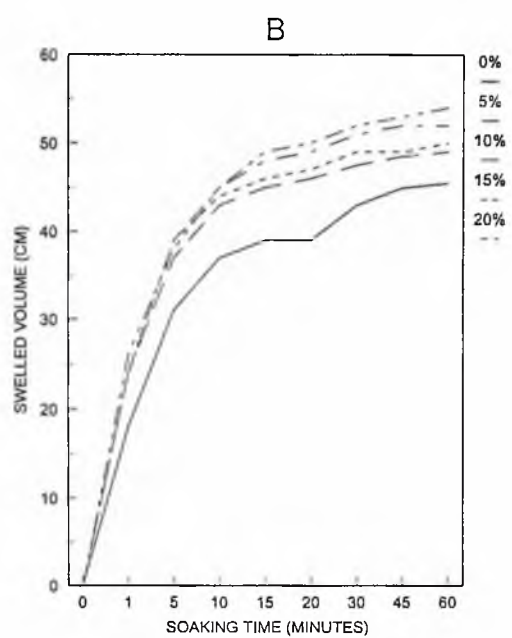
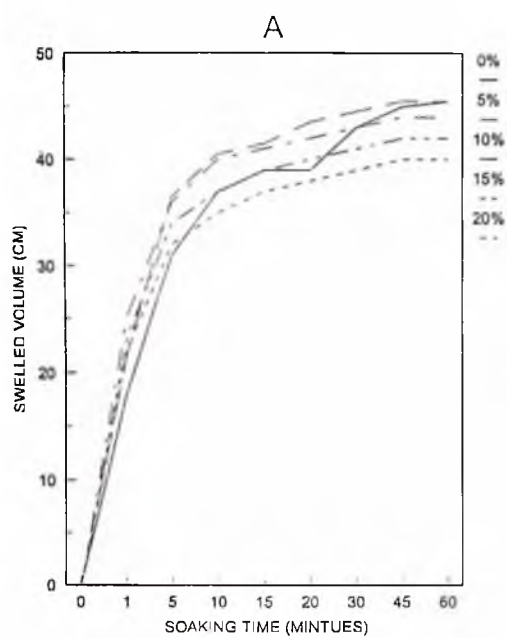
Figure 4.21 (A & B) show the effect of addition of carrots on swelled volume and the rate of swelling of gari samples. All the carrots fortified samples showed higher rate of swelling compared to the unfortified products (control). Among the carrot fortified products, co-fermented products had slightly higher rates than the single fermented systems. This observation could be due to the co-fermentation of the carrot and cassava.

Fig. 4.21 Swelling profiles of gari fortified with various concentrations of carrot and palm oil.

A = carrot fortified (co-fermented)

B = carrot fortified (added after fermentation)

C = palm oil fortified (added after fermentation)



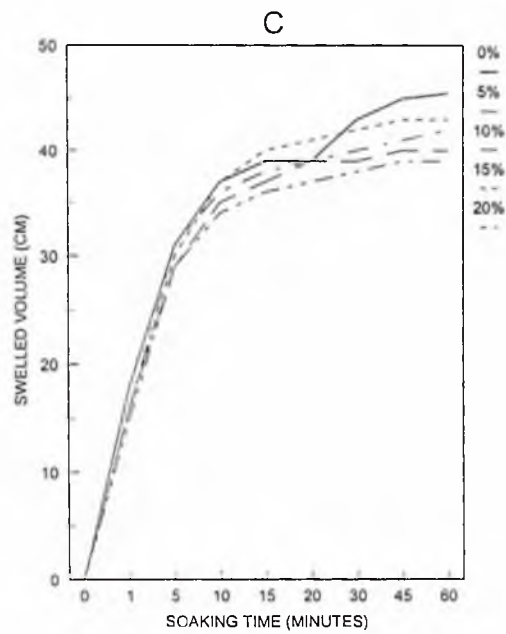


Figure 4.21C shows the influence of palm oil fortification on the rate of swelling in gari products. The palm oil-fortified gari swelled at a slower rate in relation to the control. The oil might have formed a water proof barrier around the starch thereby reducing the imbibition of water.

4.3.4.2 Water absorption

Water absorption capacity of gari products at room temperature (28°C) are presented in Table 4.16. The results indicated that the products absorbed about three to four times their unit weight of water. The unfortified gari products had the highest capacity to absorb water though this was not significantly different ($p \leq 0.05$) from the other products.

The data (Table 4.16) suggests that the co-fermentation of cassava with carrot improved the water absorption capacity of the fortified gari samples as these products absorbed relatively higher amount of water than the other fortified products. As expected the palm oil fortified products showed considerable low water absorption capacities compared to the carrot fortified products probably due to the presence of the water immiscible palm oil.

Statistical analysis (ANOVA) indicated that water absorption capacity was not significantly affected by any of the process treatments namely fortification level, method of fortification and source of carotene fortification.

Table 4.16 Water absorption* capacities of fortified gari products.

Sample	Fortification level (%)				
	0	5	10	15	20
Control (unfortified)	433.2	-	-	-	-
Singly fermented system (carrot)		403.1	407.0	427.0	410.5
Co-fermented system (carrot)	-	433.1	432.6	415.8	428.8
Singly fermented system (palm oil)		420.2	401.0	417.0	376.5

*water absorption values are reported in gramme water absorbed/100g of dry gari.

4.3.5 Sensory evaluation

The result of the sensory scores for carrot- and palm oil-fortified gari are summarized in Table 4.17. The panelists showed consistency in evaluating the products with respect to all quality attributes.

4.3.5.1 Colour

Colour is an important attribute of food products. Data obtained indicated that fortification levels affect the intensity of the products colour (difference test) (Table 4.17). High fortification levels led to high colour intensity. The co-fermented products had, in general, low scores of colour compared to the single-system fermented products (Figure 4.22A & B).

Table 4.17 Mean scores assigned to carrot- and palm oil-fortified gari products.

Product Flavour	PREFERENCE				DIFFERENCE	
	colour	Flavour	Taste	Overall Acceptance	Colour	
control	5.3 ^{bc}	3.9 ^{ab}	3.6 ^a	3.7 ^{ab}	8.1 ^d	3.7 ^{ab}
5A	5.0 ^{abc}	5.1 ^{bc}	4.9 ^{abc}	4.9 ^{abc}	7.7 ^{cd}	5.6 ^{bcd}
10A	6.6 ^{cd}	6.7 ^c	6.4 ^{cd}	6.3 ^{cd}	6.0 ^{bc}	6.6 ^d
15A	8.0 ^d	6.6 ^c	6.4 ^{cd}	7.9 ^d	3.6 ^a	6.1 ^{cd}
5B	7.3 ^d	6.4 ^c	5.6 ^{abcd}	5.6 ^{bc}	5.9 ^{bc}	6.8 ^d
10B	6.7 ^{cd}	6.9 ^c	7.5 ^d	7.9 ^d	4.4 ^{ab}	6.8 ^d
15B	6.6 ^{cd}	6.3 ^c	5.9 ^{bcd}	6.6 ^{cd}	4.6 ^{ab}	5.7 ^{bcd}
5PO	3.4 ^{ab}	6.6 ^c	4.0 ^{ab}	5.6 ^{bc}	4.3 ^{ab}	4.4 ^{abc}
10PO	3.6 ^{ab}	2.9 ^a	5.1 ^{abc}	3.3 ^a	5.7 ^{bc}	3.3 ^a
15PO	3.1 ^a	4.0 ^{ab}	4.4 ^{abc}	3.3 ^a	4.9 ^{ab}	4.9 ^{abcd}

^{a-d} Means with the same letter under the same column are not significantly different ($p \leq 0.05$)

A = carrot fortified gari (carrot added after fermentation of cassava).

B = carrot fortified gari (co-fermented with cassava).

PO = Palm oil fortified gari.

5, 10, 15 and 20 level (%) of carrot of palm oil.

Fig. 4.22 Samples of packaged Vitamin A-fortified gari products.

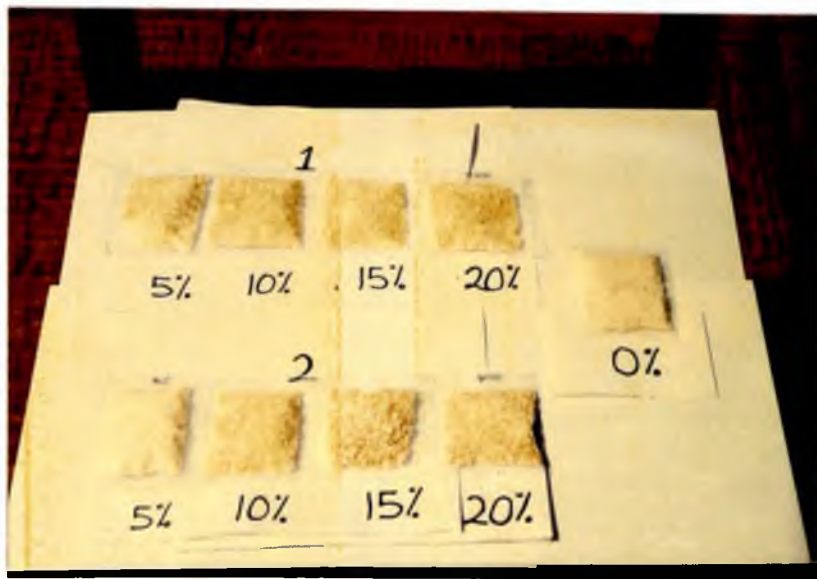
- A. Carrot fortified products at 0, 5, 10, 15 and 20% fortification level
 - 1. co-fermented
 - 2. added after fermentation

- B. Carrot- and palm oil-fortified products at 0, 5, 10, 15 and 20% fortification level
 - 1. carrot fortified
 - 2. palm oil fortified

A



B



Panelists showed high preference for palm oil-gari products in terms of colour over the other products ($p \leq 0.05$). Though unfortified gari was rated high, it was not significantly different from the carrot-fortified products.

The yellow orange colour in palm oil and carrot is mainly due to β -carotene, the predominant carotenoid (Bauernfeind, 1972). This is imparted to the gari through the fortification to give it the appealing yellowish colour consumers prefer. This observation holds promise for attempts at vitamin A nutrification of gari and other foods as the β -carotene enhances the colour and improves the nutritional value of the product.

4.3.5.2 Flavour

Flavour is one of the important sensory characteristics that influences the acceptability of foods. It becomes even more important when new products are developed through fortification with highly flavoured commodities such as carrots. Results indicate that palm oil-fortified gari (especially at 10% fortification level) was the most preferred followed by the control (Table 4.17). Consumers found minor differences in flavour between the co-fermented and the single system fermented products.

4.3.5.3 Taste

In terms of taste, the control (unfortified) sample had significantly better taste ($p \leq 0.05$) than the other products (Table 4.17). The fortified products were not significantly different from one another. The acceptability scores for taste of palm oil-fortified gari were generally lower than the carrot fortified products.

4.3.5.4 Overall acceptance

For a new product to become competitive in the market, it must be accepted by the consumers. The data (Table 4.17) indicated that palm oil gari (at fortification level 10 and 15%) were the most accepted products and suggest that fortification with palm oil resulted in slightly higher overall acceptance scores (Table 4.17). Although the control products (unfortified gari) received a better higher overall mean acceptance score than the carrot fortified products, it was not significantly different from the 5% fortified (both single and co-fermented) products (Table 4.17)

Assessing the potential success of the fortified products in the market by consumer acceptability tests, all the panelists indicated that they were more likely to purchase the products if made available in the market. About 71% of the consumers were willing to pay the same or slightly higher price for the fortified gari than the traditional gari. This suggests that palm oil and carrot fortified gari could find a

fairly wide acceptance and be a potential success in the market.

5.0 CONCLUSIONS

5.1 On optimizing the retention of β -carotene in processed vegetables it can be concluded that:

- (a). blanching treatment was the most important influence on the retention of β -carotene. Among the five blanching treatments, maximum retention was found in NaCl, Sulphite and kanwa treated products after 90 days of storage. Regardless of the blanching pretreatment and drying method used, dehydration significantly affected the loss of β -carotene in carrots. Retention of carotene was higher in oven dried products than solar.

NaCl and kanwa could be used as substitutes for sulphite in the preservation of carotene in carrots.

- (b). Alkali blanching though caused initial blanching losses from heat degradation improved retention appreciably in dehydration and during storage. Carotene was more stable at higher levels of kanwa. β -carotene losses occurred in both oven and solar drying of *Amaranthus* and *Xanthosoma*. Temperature and time of blanching were unimportant in β -carotene retention during storage. Solar drying resulted in better carotene retention and storage stability of products (*Amaranthus* and *Xanthosoma*) than oven drying.

5.2 On effect of heating temperature on β -carotene in palm oil, high temperatures of heating led to complete loss of colour and β -carotene in palm oil. Continuous heating at high temperatures as in deep frying using palm oil lowers the nutritional value in terms of ultimate vitamin A.

5.3 On kinetic studies, it was evident that:

(a). β -carotene degradation rates were satisfactorily described by first-order kinetics and were dependent on temperature and method of fortification.

(b). The kinetic approach can be used to model or predict the effects of processing parameters on the breakdown of β -carotene in vegetables (carrots, *Amaranthus* and *Xanthosoma*) and palm oil during processing and storage. This model can be used to predict the effects of various processing options to minimize β -carotene levels in carotene-rich foods and processed products during processing and storage.

5.4 On the appropriateness and performance of carrots and palm oil in gari fortification, it is conclusive that:

(a). adding carrots to cassava before fermentation initiates similar souring process peculiar to cassava fermentation during the processing of gari.

- (b). fortification with either carrot or palm oil (carotene-rich source) led to an increase in carotene content of the gari products. This was influenced by the level of fortification. The highest fortification level gave the highest carotene content.
- (c). the method of incorporation of carotene-rich source affected the level of carotene in the final product. This was also affected by the various unit operations of the gari process via fermentation and roasting. The addition of carrot or palm oil after the fermentation of cassava pulp resulted in higher carotene contents of gari. However, co-fermenting the cassava with carrot led to low rate of carotene destruction and longer carotene shelf-stability.
- (d). fortifying gari with carrot or palm oil did alter its water absorption capacity and swelling pattern.
- (e). colour intensity of gari increased as a result of carrot and palm oil fortification. This was preferred by the consumers, especially the products from palm oil. Taste did not differ from traditional gari when it is enriched with carotene from carrots and palm oil. However, the flavour was slightly altered by the fortification.

Panelists adjudged palm oil-fortified products as most acceptable and indicated they would purchase it if available in the market.

RECOMMENDATIONS

Further studies are recommended in the following areas:

- (a). The use of efficient solar dryers for faster drying of blanched vegetables to enhance maximum retention of β -carotene during drying.
- (b). The incorporation of blanched dehydrated vegetables into weaning foods to study their bio-availability.
- (c). Further studies be done to include elevated temperatures and exposure to light as prevails in a typical market where these products are likely to be sold to come out with appropriate storage conditions and packaging material for dehydrated carotene-rich foods and fortified products.

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APPENDIX

APPENDIX 1. Questionnaire

NUTRITION AND FOOD SCIENCE DEPARTMENT
UNIVERSITY OF GHANASENSORY EVALUATION OF FORTIFIED GARI

1. You have been provided with coded samples of Gari. Kindly rank the samples provided according to the intensity of the attribute indicated. The most intensified is 1 and the least intensified 10.

SAMPLE	COLOUR	FLAVOUR
-----	-----	-----
-----	-----	-----
-----	-----	-----
-----	-----	-----
-----	-----	-----
-----	-----	-----
-----	-----	-----
-----	-----	-----
-----	-----	-----

2. Please rank the given coded samples with respect to your preference for the following attributes. The most preferred is ranked 1 and the least 10.

SAMPLE	COLOUR	TASTE	FLAVOUR	OVERALL ACCEPTANCE
-----	-----	-----	-----	-----
-----	-----	-----	-----	-----
-----	-----	-----	-----	-----
-----	-----	-----	-----	-----
-----	-----	-----	-----	-----
-----	-----	-----	-----	-----
-----	-----	-----	-----	-----
-----	-----	-----	-----	-----
-----	-----	-----	-----	-----

3. Would you buy such a product if available in the market?
a. Would buy b. Undecided c. Not buy
4. Would you be willing to pay slightly higher the usual price for this product?
a. YES b. NO

Appendix 3 Effect of dehydration method on beta-carotene in *Amaranthus incurvatus* stored for 90 days

Kanwa conc (%)	Temperature (°C)	Time (min)	β-carotene mg/100g			
			0 day		After 90 days	
			oven	solar	oven	solar
0	85	4	46.6	12.7	8.5	6.7
		6	40.6	12.0	8.4	5.9
		10	36.3	11.0	5.8	4.3
	95	4	40.9	12.6	12.4	7.8
		6	30.8	12.0	7.8	7.1
		10	30.0	11.9	5.2	6.8
	100	4	27.6	12.8	9.5	8.7
		6	25.0	12.6	6.7	8.7
		10	20.9	12.5	5.3	7.3
0.05	85	4	67.5	15.8	17.2	10.0
		6	44.0	15.0	15.1	9.9
		10	35.7	14.4	11.8	9.8
	95	4	45.4	19.9	14.1	9.3
		6	43.1	15.5	11.1	9.2
		10	40.8	15.0	10.1	9.0
	100	4	41.4	15.8	13.1	13.5
		6	40.2	15.6	10.5	11.2
		10	39.3	15.3	11.0	10.6
0.1	85	4	59.9	17.3	17.4	12.3
		6	58.7	16.0	14.3	12.0
		10	52.7	15.3	10.7	10.9
	95	4	55.0	16.9	14.5	12.9
		6	47.7	16.6	12.2	12.1
		10	47.1	16.4	10.7	12.0
	100	4	46.0	18.2	18.4	14.8
		6	38.0	16.9	13.0	13.5
		10	34.4	16.6	11.0	12.2

APPENDIX 4 Effect of dehydration method on beta-carotene in
Xanthosoma maffafa stored for 90 days

Kanwa conc (%)	Temperature (°C)	Time (min)	β-carotene mg/100g			
			0 day		After 90 days	
			oven	solar	oven	solar
0	85	4	32.8	13.7	14.8	8.8
		6	30.6	13.5	8.1	8.7
		10	26.1	13.1	8.8	8.5
	95	4	24.0	13.8	8.3	8.7
		6	23.6	13.1	8.9	8.4
		10	18.8	12.5	8.2	8.3
	100	4	22.2	14.2	9.9	9.4
		6	19.4	13.5	10.7	8.7
		10	18.0	12.3	13.5	8.7
0.05	85	4	36.0	19.4	17.8	12.0
		6	32.0	17.5	12.9	10.7
		10	27.0	16.2	12.8	10.0
	95	4	26.3	18.9	17.8	11.5
		6	24.9	17.2	14.5	11.0
		10	23.9	16.4	10.3	10.2
	100	4	28.1	17.6	12.3	13.0
		6	25.1	16.7	12.4	11.9
		10	24.9	16.5	15.2	10.1
0.1	85	4	56.0	19.7	19.1	11.7
		6	43.4	18.2	18.3	10.3
		10	40.0	17.9	16.2	10.0
	95	4	45.3	18.2	15.3	11.1
		6	34.3	18.0	14.5	10.4
		10	26.8	17.0	11.9	10.1
	100	4	33.2	18.6	14.2	9.1
		6	28.4	18.9	13.0	10.8
		10	24.8	18.4	13.4	10.6

APPENDIX 5 Moisture content of fortified gari stored for 90 days

Product	Storage Time (days)			
	0	30	60	90
0	5.10	5.24	5.53	5.89
5A	3.22	3.23	3.62	3.82
10A	4.24	4.56	4.71	4.85
15A	5.65	5.85	6.26	6.87
20A	4.52	5.28	5.40	5.49
5B	6.04	6.91	6.74	6.74
10B	5.73	5.75	5.80	6.07
15B	5.91	6.09	6.15	6.31
20B	5.33	5.26	5.50	5.66
5PO	5.95	6.23	8.19	9.16
10PO	4.63	4.75	4.95	5.14
15PO	4.85	4.78	4.96	6.11
20PO	4.44	4.70	4.83	5.44

A = carrot fortified (added after fermentation of cassava, single fermenting system).

B = carrot fortified (carrot co-fermented with cassava).

PO = palm oil fortified gari (oil added after fermentation)

0, 5, 10, 15 and 20 level (%) of fortification.

LIST OF ABBREVIATIONS

ACC/SCN	Adminstration Comittee on Cordination Sub-Committee on Nutrition
ANOVA	Analysis of Variance
FAO	Food and Agriculture Organization, UN
GLV	Green leafy vegetable
HPLC	High Performance Liquid Chromatography
ICN	International Conference on Nutrition
LSD	Least significant difference
MSG	Monosodium glutamate
VAD	Vitamin A deficiency
VAST	Vitamin A Supplementation Trials