KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY,

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COLLEGE OF SCIENCE

FACULTY OF BIOSCIENCES

DEPARTMENT OF FOOD SCIENCE AND TECHNOLOGY

SHELF LIFE STUDIES OF VACUUM PACKAGED ‘FANTI-KENKEY’

BY

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NOVEMBER, 2018

SHELF LIFE STUDIES OF VACUUM PACKAGED FANTI-KENKEY

A THESIS SUBMITTED TO THE DEPARTMENT OF FOOD SCIENCE AND TECHNOLOGY, KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF

MASTER OF FOOD QUALITY MANAGEMENT IN FOOD SCIENCE AND TECHNOLOGY (MSC. FOOD QUALITY MANAGEMENT)

BY

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(BSc. POSTHARVEST TECHNOLOGY)

NOVEMBER, 2018

DECLARATION

I hereby declare that this thesis is the effort of my own hardworking except for references to other people‟s work which have been truly acknowledged, this thesis submitted to the Board of Postgraduate Studies, Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, is the result of my own findings and has not been presented for any degree elsewhere.

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Lab work at the Department.

DEDICATION

I dedicate this thesis to my mother Madam Mary Addae, Mr.Kwabena, Addison ,

Mr.Roxward Aquah and all my sisters.

ABSTRACT

„Kenkey" is an important food to the Ghanaian community with relatively lower shelf life. In the face of modern day consumer"s quest for convenience, it is imperative that studies be conducted to extend the shelf life of the product. This work sought to vacuum package „Fanti kenkey" to extend its shelf life. One hundred and twelve (112) „Fanti kenkey" samples were used for the study. The samples were divided into two and one part vacuum packaged. Each was then stored under ambient and refrigerated condition for 28 days. Samples (4 for each treatment) were picked at four (4) days interval for physicochemical and microbial load determination. Results from the parameters determined were then used to predict shelf life of the samples using statsgraphic centurion version 18. Physicochemical changes such as water activity and moisture did not have any significant relationship on the shelf life as days increase. Hence, they were not used in the shelf life prediction. In contrast, changes based on pH and yeast and molds had significant effect on the shelf life of „Fanti kenkey" as days increase and therefore were used as major parameters for shelf life prediction. Shelf life predictions base on pH stored under four different treatments had approximately 29 days, 25 days, 24 days and 12 days for unvacuum package refrigerated condition, vacuum package ambient condition, vacuum package refrigerated and unvacuum package ambient respectively. On the other hand, shelf life prediction base on yeast and molds recorded the highest shelf life of about 30days for vacuum packaged „Fanti kenkey‟ stored under refrigerated condition and 25 days for vacuum packaged „Fanti kenkey‟ stored under normal ambient. Unvacuum packaged „Fanti kenkey‟ stored under refrigerated condition and unvacuum package „Fanti kenkey‟ stored under ambient recorded 9 days and 5 days respectively. In conclusion, vacuum packaging has the potential to increase shelf life of „Fanti-kenkey‟ and could be exploited to satisfy the busy modern day people and enhance its appeal by local and international consumers.

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CHAPTER ONE

INTRODUCTION

1.1 Background

Maize is the main cereal crop produced in Ghana and also one of the crops that is most extensively processed into a wide variety of traditional products (SRID, 2011). Kenkey is fermented maize dumpling produced by traditional food processors. It has moisture content between 52-55 % with pH around 3.7 and a shelf life of 3-4 days (Halm *et al.,* 2004a). „Fanti kenkey‟ has socio-economic importance of being a source of livelihood for many families engaged in its production and retailing, and an affordable principal meal consumed regularly by a large segment of the Ghanaian population. It is a vital diet in the food for people with low income and serves as an affordable heavy meal, which provides a feeling of satiety (Halm *et al*., 2004). In view of the socio-economic importance of Kenkey and its standing among other traditional foods, it is critical that Kenkey does not become marginalized in the face of economic development, modernization and the advent of foreign fast foods. Consequently, scientific investigations has been done on indigenous African fermented foods in the last few decades. Much of the research effort on Kenkey focused on the microbiological and physicochemical changes that occur during fermentation and at other stages of processing as well as management of the safety of the product during processing (Amponsah, 2010; Annan, 2002; Halm, 2006). Some of these researches have led to recommendations for improved methods for steeping, fermentation, cooking and packaging of „kenkey‟ (Nche *et al.,* 1996). Since Kenkey processing is largely artisanal and the operations are not formally standardized, the important areas for ensuring compliance with HACCP and Good Manufacturing Practice (GMP) have been identified (Amoa-Awua, 1996). Most of the above studies have been carried out with the view of upgrading the procedures for the standardization of Kenkey production, even targeting industrial production to satisfy its high demand. Several factors threaten Kenkey‟s continued relevance and sustainability in the Ghanaian society and economy. These include changing trends in the food habits of the younger urban population who are attracted to trendy fast food restaurants. Based on these considerations, this work sought to vacuum package „Fanti Kenkey‟ to extend its shelf life such that it would have both local and international consumer appeal and convenience

1.2 Problem Statement

Despite the socio-economic importance of „Fanti kenkey‟, it has a very short shelf life, which does not permit consumers who shop periodically to purchase them in bulk and store for a longer time. There is limited information on the exploitation of other packaging materials and methods that would make „Fanti kenkey‟ convenient and appealing to both local and international consumers.

1.3 Justification

This work will provide information on enhanced means of extending shelf life of „Fanti kenkey‟ by vacuum packing and also adding value to it in terms of convenience and appeal. These could draw favorable interest and attention to „Fanti kenkey‟ both locally and internationally.

1.4 Objective

To investigate the shelf life of vacuum packaged „Fanti kenkey‟

1.5 Specific Objective

- To vacuum packaged „Fanti kenkey‟ and study its shelf life

- To determine the physico-chemical changes (pH, moisture and water activity) and microbial load (yeast and moulds) of stored vacuum packaged „Fanti kenkey"

CHAPTER TWO

LITERATURE REVIEW

2.1 Maize (*Zea mays*)

Maize (*Zea mays*) is an American- Indian word that means life sustainer. It placed third in the world amongst the cereals followed by wheat and rice which provide nutrients for both human and animal consumption (Hounhouigan *et al.,* 1993). It is used to produce starch, protein, alcoholic beverages, oil, food sweeteners and fuel (FAO, 1992). About half of the maize produced in the world is cultivated in developing countries, and served as a staple food for most West African countries and also provide stalks feed for farm animals (Ofori and Kyei- Baffour, 2009). Maize can be consumed in different forms. It required various units of operations to produce it (Sefa-Dedeh, 1993). In the year 2012, the production of maize in Ghana, was 2 million metric tons, which account for 3% of the Agricultural Gross Domestic (SRID, 2011).

2.2 The Origin of Maize

Maize originated from the Mesoamerican region, located in the Mexican highlands and spread rapidly thereof. It spreads around the world and to the temperate zones after the European discovery of the America in the 15th century, (Farnham *et al.*, 2003; Paliwal, 2000). At the end of fifteenth century, maize was introduced into Europe through Spain after Christopher Columbus had discovered America continent. It continues to spreads through the warmer climates of the Mediterranean and later to northern Europe (FAO, 1992).

2.3 Maize Production in Ghana

Maize is an important staple cereal crop in Ghana. It is cultivated in every rural household in every parts of the country (Morris *et al*., 1999). Its production has increased tremendously since 1991 as compared to other cereals grown in the country.

USDA data (available through Index Mundi show that Ghana"s 2011 production was about 1.5million metric tonnes compared to 1.62 MMT in 2009 and 1.67MT in 2010 (SRID, 2011).

2.4 Maize varieties and maize consumption trends in Ghana

According to the Ghana Grain Development Project in 1999, about 12 different varieties of maize have been developed in the country. These varieties include *aburotia, dobidi, kawanzie, golden crystal safita-2, okomasa, abeleehi, dorke, obatanpa, mamaba dadaba* and *cidaba*. Some of the varieties (*obatanpa mamaba dadaba* and *cidaba*) have been enriched especially with protein to help improve the nutritional status of consumers (GGDP, 1991). Maize is a common cereal crop consumed in Ghana (SRID, 2011). A survey conducted in 1990 showed that 94% of all households consumed maize (Alderman and Higgins, 1992). A survey in Accra by Allotey (1996), showed that about 0.05 to 1.2 metric tons of maize was processed weekly at most production sites in the country. Maize is consumed in Ghana in different forms. This shows why all maize product are sold from the street food (Alderman and Higgins, 1992; Morris *et al*., 1999). Traditional food products that are prepared using maize include *banku*, *koko*, and *aboloo* but the most popular one is *Kenkey*, which a sour stiff dumpling prepared from fermented maize dough, wrapped in leaves and boiled (Johnson and Halm, 1998).

2.5 Kenkey

„Kenkey‟ is one of the most common indigenous fermented product produced in Ghana. It is produced in most of the coastal areas in West Africa. Two ethnic groups are known to produce it in Ghana, the Ga people in the Greater Accra region and the Fanti people in the Central and Western regions. The development of more food products from fermented maize might have developed to feed the local population than root and tuber crops such as yam. Kenkey is common and mostly seen amongst the poorer people both in the cities and the rural areas. There are two types of Kenkey produced in Ghana, Ga-Kenkey which popularly called *Komi* and „Fanti kenkey‟ also called dokono within the Fantis. It has a pH of about 3.7 and a moisture level of between 52-55% (Halm *et al.*, 2004). It is eaten with pepper and tomato sauce with fish. These two types of Kenkey have different sensory qualities even though both are produced through fermentation of the maize into dough. It is either wrapped with a banana leaves for „Fanti kenkey‟ or maize husks for Ga-Kenkey and cooked. „Fanti kenkey‟ requires longer period of fermentation than GaKenkey where salt is added to give it a different taste during the processing. There are other types of Kenkey produced in Ghana. They are produced from the polished maize rather than the whole grains**.** Nsihu is an example of polished Kenkey produced in the Central region. It can also be found in the Volta and Western regions of Ghana. It is produced by polishing the maize (Sefa-Dedeh, 1993).

2.6 Traditional method of producing kenkey in Ghana

The traditional methods for the production of both Fanti and Ga-Kenkey are shown below;

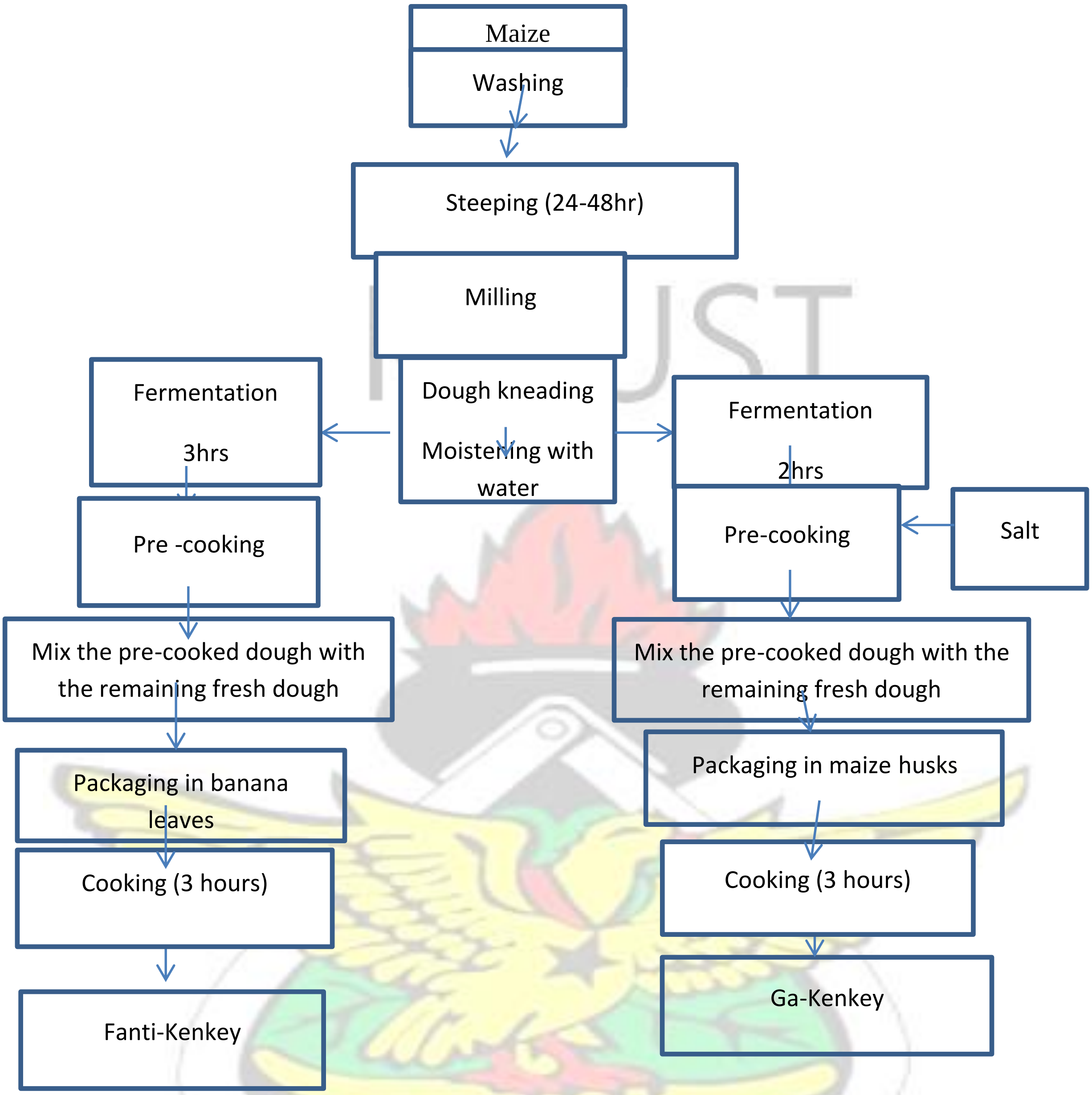

Figure 2.1: Stages in various unit operations in the production of Fanti-Kenkey from maize

(Source: Amoa-Awua, 1996).

2.7 Different Types of Kenkey Produced In Ghana

There are several types of Kenkey that are produced in Ghana. The „Fanti kenkey" which is wrapped in banana leaves, Ga-Kenkey and Nsiho or Akphorhe are wrapped in corn husks (Muller and Nyarko-Mensah, 1972).

Plate 2.1:. Fanti-kenkey wrapped in banana leaves

Plate 2.2: Sugared Kenkey

Plate 2.3: Nsiho **Plate 2.4: Ga-kenkey**

2.8 Moulding and packaging of Fanti Kenkey

In the normal situation in Ghana, ,, Fanti-kenkey" is moulded into cubic shape and covered with a polyethylene bag and then wrapped with a banana leaves whiles GaKenkey, the mixture is moulded into round-like shapes and also wrapped with a maize husks.

2.9 The Microbiology of fermented Kenkey

The microbiology of fermented maize dough which is used for Kenkey production has been studied in detail (Jespersen, 2003; Halm *et al*., 1993). Olsen *et al*. (1995) also confirm that the processing stage of Kenkey has its own micro-environment with a strong antimicrobial activity. It has also been revealed that the Fanti-Kenkey production stages require four different microbiological environments which include the maize steeping of the maize grains in water for 24h, milling of the steeped maize and preparation and fermentation of the dough for 48h **(**Halm *et al.,* 1993). On the maize and early phase of steeping, the microbial flora consists of mixed population of lactic acid bacteria, aerobic mesophilic bacteria, yeasts, and molds. It has been reported that L. *plantarum* and *Pediococcus* spp. dominate the latter stages of maize dough fermentation (Nche *et al*. 1996). *Lactobacillus fermentum* has been reported to play a dominant role in fermented maize dough (Sefa-

Dedeh, 1993; Halm *et al*., 1993). Apart from lactic acid bacteria, yeasts also contribute to the microbial flora in fermented maize (Jespersen *et al*., 1994; Halm *et al*., 1993; Hounhouigan *et al*., 1993). According to Obiri-Danso (1994), the main yeasts isolated from fermented maize dough were *Saccharomyces* and *Candida*. The presence of these varieties of microorganisms in the steep water and in the dough could result in the production of a foul smell in the steeped maize water and/ or the fermented dough (Jespersen, 2003).

2.10 The Economic Importance of Fanti-Kenkey

Commercial production and sale of „Fanti kenkey" in the street is the source of livelihood for a lot of people who produce it. The activities of „Fanti kenkey" vendors in Ghana make a remarkable contribution to the Ghanaian economy „Fanti kenkey" is cheap and affordable for the middle income people. It provides employment opportunities for the informal sector and give extra income for the households (Tortoe *et al*., 2008). „Fanti kenkey" production contributes greatly to the food security to most people engage in it production. The „Fanti kenkey" vending business is usually done by women in many homes with a small structure and a table in most part of the country. They normally start with little capital, which contributes significantly to food security in the country. It serves as a source of employment for most women and also a source of nutritious, affordable and tasty foods to millions of people (Tortoe *et al*. 2008).

2.11 Commercialization of Fanti-Kenkey

„Fanti kenkey" which is an indigenous fermented food has many in-built importance such as anti-microbial properties because of its lactic acid fermentation. Due to this reason, value needs to be added to it and packaged in a convenient manner to withstand competition with fast foods that are gaining root in most of the urban cities in Ghana. It is imperative that the quality such as packaging and shelf life and production methods of „Fanti kenkey" should be considered with the topmost priority (Amoa-Awua *et al*., 1996).

2.12 Nutritional Quality of Fanti-Kenkey

Maize is staple crop, which provide source of many calories, and protein content of the diet of many consumers. On dry matter basis, the proximate composition of „Fanti kenkey" is about 8.9–9.8% protein, 1.3–3.2% fat, 0.5–1.9% ash, 10.6–78.6 mg/100g calcium, 202.4–213.8 mg/100 g phosphorus, 6.5–12.6% mg/100g iron, and 74.3–87.1% total carbohydrate (Ahenkora *et al.,* 1995; Obiri-Danso *et al.,* 1997; Annan-Prah, 1997). Maize has a low protein and deficient in lysine and tryptophan (Obiri-Danso *et al.*, 1997).

High lysine can be developed from locally produced maize variety of maize known as "Obantanpa" which has the ability to increase the level of and the nutritive value in maize food products (Ahenkora *et al.,* 1995; Obiri-Danso *et al.*, 1997). Moreover, the soaking, fermentation and cooking increase the availability of lysine in maize and, eventually improves the nutritional quality of „Fanti kenkey" (Niche *et al.,* 1995). However, phosphorus level is decreased because of anti-nutritive factors like phytic acid which binds to the mineral, and cause a reduction in bioavailability of the phosphorus and calcium. „Fanti kenkey" has a very high fiber content and low in glycaemic level. Because of it low glycemic index, it is usually recommended for most diabetics. This is because it releases carbohydrate content slow over a long period and help the body to handle its carbohydrate requirement for a perfect glycaemic index control. The fermentation process of „Fanti kenkey" improves it nutritional content, which in turn increases it synthesis of Vitamin B (e.g., thiamine), protein digestibility, and bioavailability of nutrients, among others. Research conducted by Nche *et al,* (1996), reported that soaking of maize shows a significant increases in lysine availability for about 20%.When it was further soaked, the lysine level move to 68%. It was also revealed that fermentation for 2 days further increased lysine availability by 22%. Furthermore, when the fermentation and cooking was prolonged, there was significant improvement of lysine availability.

2.13 Shelf life of Fanti-Kenkey

Fanti-Kenkey has moisture content between 52-55%, and a pH of 3.7. Its shelf life has been estimated to be within 3-4 days according to Halm *et al*. (2004a). A research conducted by Mensah *et al.* (2012) revealed that Fanti-Kenkey has a shelf life of 6-10 days and also showed that Ga-Kenkey has a shelf life of 2-5 days.

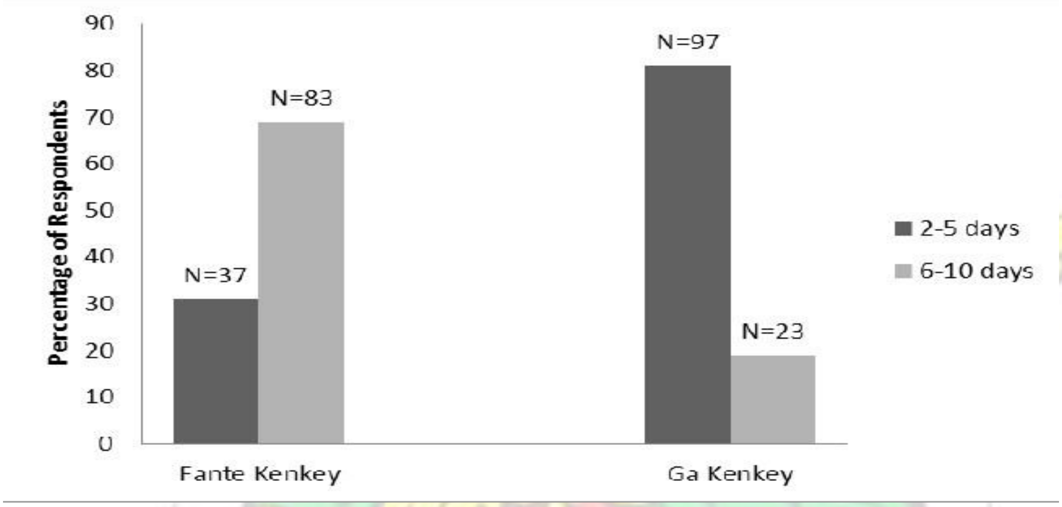

Figure 2.2 Shelf-life of Fanti-Kenkey and Ga--Kenkey

Source: (Mensah *et al.*, 2012)

2.14 Vacuum packaging

Vacuum packaging is a method of packaging that takes away air from the packaging material prior to sealing. This is done by putting the product into a thick poly films bags, and removing the air inside and sealing the package. The purpose of vacuum packaging is to take away oxygen from the packaging material to extend the shelf life of the food products. Vacuum packaging also lowers atmospheric oxygen and deterred the growth of aerobic bacteria or fungi. This also prevents the evaporation of volatile compounds.

Vacuum packaging is used also to preserve dry foods for long time. Examples are cereals, cured meats, cheese, nuts smoked fish, coffee and potato chips. Vacuum package can also be used to pack fresh vegetables and liquids (Perdue, 2009).

2.15 Operations and Types of vacuum packaging machines

The double chamber sealer is a type of vacuum package machine usually used for medium volume packaging .It can be used to also vacuum package seal liquid (Plate 5).

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Plate 2.5: Double chamber vacuum packaging machine

Source: https://www.indiamart.com/proddetail/double-chamber-vacuum-packaging-machine-20026971733.html

The Single chamber sealers are another type of vacuum package machine that are used for low-to-medium-volume packaging.

Plate 2.6: Tabletop Vacuum Packaging Machine

Source:

https://commons.wikimedia.org/wiki/File:Tabletop_Vacuum_Packaging_Machine.png

The automatic belt vacuum package machine is used in industries for the production of larger vacuum packaged products (Plate7).

Plate 2.7: Automatic Belt Vacuum Chamber Machine

Source:

https://commons.wikimedia.org/wiki/File:VC999_K9_Automatic_Belt_Vacuum_Chamber_Machine.jpg

Plate 2.8: Thermoforming (rollstock) Vacuum Packaging Machine

Source: http://cadonx.wixsite.com/engineers/packaging-machines?lightbox=image_kq8

2.16 Shelf life of vacuum packaged products

Based on the packaging material used, the shelf life of vacuum packaged products can exceed normal bagged or wrapped packages. In the refrigerator beef and pork can be kept for about 70 to 80 days when refrigeration is optimally low (28-32°F). However, it can be in a freezer from 6 to 12months base on the sealing and the type of packaging (Voges *et al.*, 2006).

2.17 Factors affecting shelf life of Kenkey

2.17.1 Factors affecting microbial shelf-life of food products

Food deterioration is caused by certain internal and environmental factors such as the food matrix, microbial activities, temperature, pH, water activity (aw) and processing time, etc. Both intrinsic and extrinsic factors can influence microbial growth along the food value chain.

2.18 Microbiological quality of raw materials

Any food products can be a source of microbial contamination in the food processing industry. The growth of the pathogens and spoilage flora can be affected by the initial contamination and efficacy of processing steps to take away every bacterium in foods. When the contamination is very high less time is required by the specific spoilage organisms to get to the minimum spoilage level and hence reduce shelf life. A good raw material can be achieved by implementing stringent measures at the suppliers point. The shelf life can be extended when there is good quality materials, processing operations, formulation of foods and storage conditions.

2.19 Types of models used in estimating shelf life

A lot of approaches have been applied in estimating shelf life of foods. Storage temperature which can be correlated with several measured responses such as sensory, microbial, biochemical and chemical factors can help calculate shelf life of foods. Regression models can be effectively applied to food products that are stored at a particular condition (Dalgaard *et al*., 1997). Also Ofosu *et al*. (2011) used polynomial regression models to estimate the shelf life of avocado fruit spread. The authors measured deteriorating factors such as the peroxide value, sensory properties and microbial quality of the avocado fruit spread and fitted the data using polynomial regression curves. The shelf life of the avocado fruit was estimated by applying Polhemus (2005) deduction which states that "the largest number of weeks for which the degrading parameter has reached 90% must be used in predicting the shelf life of a product. Tsironi and Taoukis (2014), applied predictive models in estimating the effect of processing and storage temperature on the shelf life of Gilthead Sea beam fillets that had been dehydrated osmotically. Tsironi and Taoukis (2014), used a multivariate statistical method to correlate chromatographic and spectroscopic measurements of food products with sensory properties. Dalgaard *et al*. (1997) also stated that predictive models give a better estimation of shelf life of frozen foods such as fish than regression models. The authors stressed the reliability of predictive models in shelf life prediction. In their research, they studied the deterioration of sea foods by measuring food spoilage indices such as sensory and chemical parameters.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Source of materials and sample preparation

Chemical reagents, laboratory tools and instruments were obtained from the Food Science and Technology Laboratory – KNUST. Hundred and twelve (112) freshly prepared samples of Fanti-Kenkey were purchased from a Fanti-Kenkey processor at Ayeduase and sent to the Department of Food Science and Technology laboratory (KNUST) for analysis.

3.2 Physical observation

As a normal practice for kenkey consumers, the product is usually observed for any signs of mold growth prior to consumption or purchase. The physical observation was done to look for any quality changes that could impact on the shelf stability of the product. Some parameters considered included yeast and mold growth by sight, and texture changes through the sense of touch.

3.3 Preparation of Fanti-Kenkey for vacuum packaging

The purchased fresh Fanti-Kenkey was allowed to cool down to ambient prior to vacuum packaging. Fifty six (56) samples of the Fanti-Kenkey were packaged using the vacuum package machine (Henkelman, JUMBO 42) machine at a temperature of 25^{o}C and a sealing time of 1.3s using poly films bags as a packaging material. Fifty six (56) samples were also left unvacuum as controls and kept under two storage conditions - ambient and refrigeration.

Plate 3.1: Fresh Fanti kenkey

Plate 3.2: Vacuum packaged Fanti-Kenkey

3.4 The shelf life studies

A 2×2 factorial in complete randomized design (CRD) was used for the experiment with 4 factors (vacuum package refrigerated, unvacuum refrigerated, vacuum package ambient and unvacuum ambient) and sixteen (16) treatment samples. Shelf life duration was 3 weeks. Seven (7) analytical points with a sampling time of (0, 4, 8, 12,16,20,24 and 28 days) were used with an interval of 4 days. Two storage conditions (ambient and refrigeration) were used for the shelf life studies. Four (4) samples representing the factors above were taken at each analytical point for both microbial and chemical analysis.

3.5 Microbial analysis (Coliforms, Yeast and molds)

3.5.1 Sample Preparation

Twelve (12) samples of the Fanti-Kenkey were transported to microbiology laboratory prior to analysis.

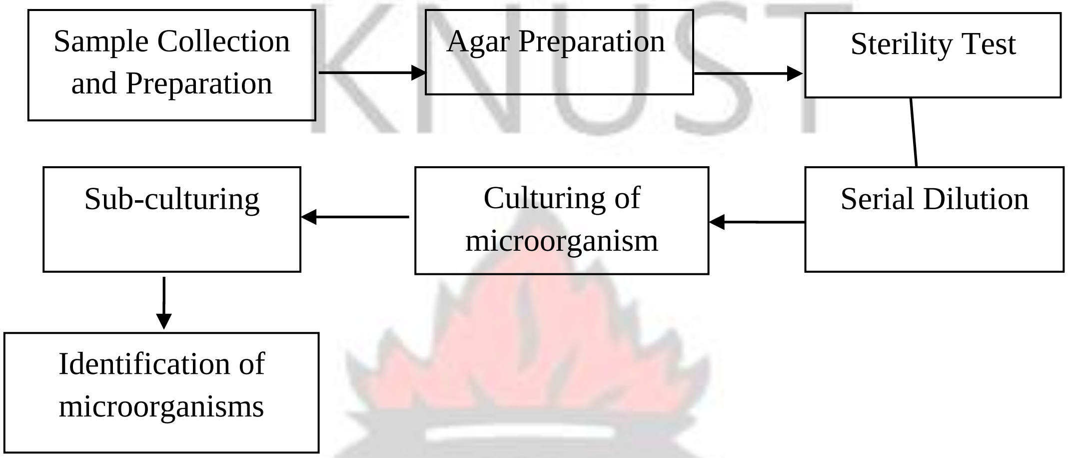

Figure 3.1: A flow chart showing the steps in determining microbial load

3.5.2 Chemical Reagents

The agars used were products of OXOID Laboratories, Basingstoke Hampshire, England. They included MacConkey agar for total Coliform count and Malt Extract agar for the isolation and enumeration of fungi.

3.5.3 Preparation of MacConkey agar

Agar powder (26 g) was suspended in 500ml of distilled water and brought to boil to dissolve completely. It was sterilized by autoclaving at 121 °C for 15 min and allowed to cool to 50 ^{o}C and poured into sterile Petri dishes.

3.5.4 Preparation of Malt Extract agar

Malt Extract Agar was prepared by dissolving 50g of agar powder in 1000ml of distilled water and brought to melt by microwaving for 5 min. The agar was sterilized at 121°C for

15 min and allowed to cool to 50^0C, after which 50µg of Chloramphenicol was added and swelled to dissolve prior to distribution into sterile Petri dishes.

3.5.5 Serial dilution

Serial dilution was done to reduce a dense culture of cells to a more usable concentration. A mass of 10g of each sample were weighed and placed in 90ml of 0.1% peptone water solution. Serial dilution was performed for 10^{-1}, 10^{-2}, 10^{-3}, 10^{-4}, 10^{-5} and 10^{-6}. The serial dilution done for 10^{-3} provided very clear and distinct isolate, hence it was selected for the subsequent analysis.

3.5.6 Determination of Total Coliform Count

The Total Coliform Count was carried out using plate method on MacConkey agar (MA). Serial dilutions of 10^{-1} to 10^{-6} were prepared by diluting 10 g of sample into 90 ml of sterilized peptone water for the stock dilution. One milliliter aliquots from each of the dilution were inoculated into Petri dishes with already prepared SMA. The inoculum was spread on a sterile bent rod and allowed to stand in room temperature for 15 mins. The plates were inverted and incubated at 35 ºC for 24 hours.

3.5.7 Determination of Yeast and Mold Count

The spread plate technique was used using 1ml aliquot of each dilution in triplicate on sterile plates of MEA. The inoculated plates were incubated at ambient temperature (25 ºC) for 120 h and observed intermittently for the development of mold colonies. Detected colonies were enumerated and distinct colonies sub-cultured for identification at the

Cocoa Research Institute of Ghana (CRIG).

3.6 Physico-chemical analysis

3.6.1 Water activity

Homogenized samples were placed in the disposable cup of the Aqualab Water Activity Meter 4TE to completely cover the bottom of the disposable cup to half full. The sample chamber knob was turned to open position to pull the drawer open. The sample chamber was then closed to turn the knob to read position. The displayed results were then recorded together with its temperature. Distilled water was used as a quality control check prior to start of sample analysis.

3.7 Moisture

Moisture content and total solids: Oven drying method

Five grams (5g) of „Fanti kenkey" was weighed using an analytical balance to previously dried and weighed dish. This was placed in an oven thermostatically controlled at 105ºC degrees for 5h.The dish was later removed and placed into a desiccator to cool to room temperature and weigh. It was allowed to cool for 30minutes and finally weighed.

Moisture determination was duplicated and the average found.

Calculation:

$$\%TMD = \frac{M_3 - M_1 \times 100}{M_2 - M_1}$$

Where M_1= tare weight of petri dish

M_2 = initial weight of sample and petri dish

M_3 = dry weight of sample and petri dish

3.8 pH

The pH was determined using electronic pH meter model Mettler-Toledo AG (SevenCompact^{TM} pH/Lon S220). Ten grams (10g) of the homogenized „Fanti kenkey" was weighed into a clean dry Erlenmeyer flask and 100 ml of freshly boiled distilled water cooled to 25°C were added. Twenty milliliters (20ml) were measured and transfer into small beakers. pH meter standardized using buffer solutions of pH 4.00, 9.01 and 7.00. The pH of the mixture was measured in duplicate using a pH meter (model Mettler-Toledo AG). The pH readings were taken and recorded.

3.9 Statistical analysis

A 2×2 factorial in complete randomized design (CRD) was used for the experiment. Using Statgraphics Centurion version 18, One-way ANOVA was employed to compare the means of all determined parameters. The means and standard deviations of the readings for each test parameter were calculated using Excel 2016. All statistical tests were carried out at 95 % confidence level.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Physical observation

The first sign of yeast and mold growth was observed for the unvacuum-packaged (control 1) samples stored under ambient temperature conditions just after 4 days of storage. This was accompanied by softening of the said samples. In contrast the refrigerated unvacuum-packaged samples (control 2) had no signs of yeast and mold growth but hardening of the kenkey. This could be due to the inhibition of microbial growth in food samples at low temperatures. Unvacuum samples stored under refrigerated conditions showed signs of growth after 12 days of storage. The vacuum-packaged samples stored under ambient conditions showed mould growth after the 28th day of storage. The vacuum-packaged and refrigerated samples however had no visible growth even after the 32nd day when the experiment was halted. This suggests that the combined effect of vacuum packaging and refrigeration could have significant effect on the shelf stability of kenkey in terms of physical appearance. This is because levels of oxygen in the packaging are reduced, impeding the ability of aerobic microorganisms to grow and spoil the product (Chetti *et al.*, 2014).

4.2 Shelf life based on pH pH is a critical parameter that signify quality deterioration in many foods. The changes in pH that was observed in the study can be seen as one which variably affected the shelf stability of the products. A general decline in pH was observed for samples stored under all the different conditions of storage (Fig 4.1). This general decline could be attributed to organic acids that were produced due to microbial growth. A sharp decrease in the pH values were however observed after the first 4 days of storage for all samples. There was a statistically significant ($p<0.05$) difference between pH values recorded for vacuum packaged samples (stored under both refrigerated and ambient conditions) and storage time (days). A similar significant relationship also existed between pH of the control samples (stored under refrigerated conditions) and the storage time (days).

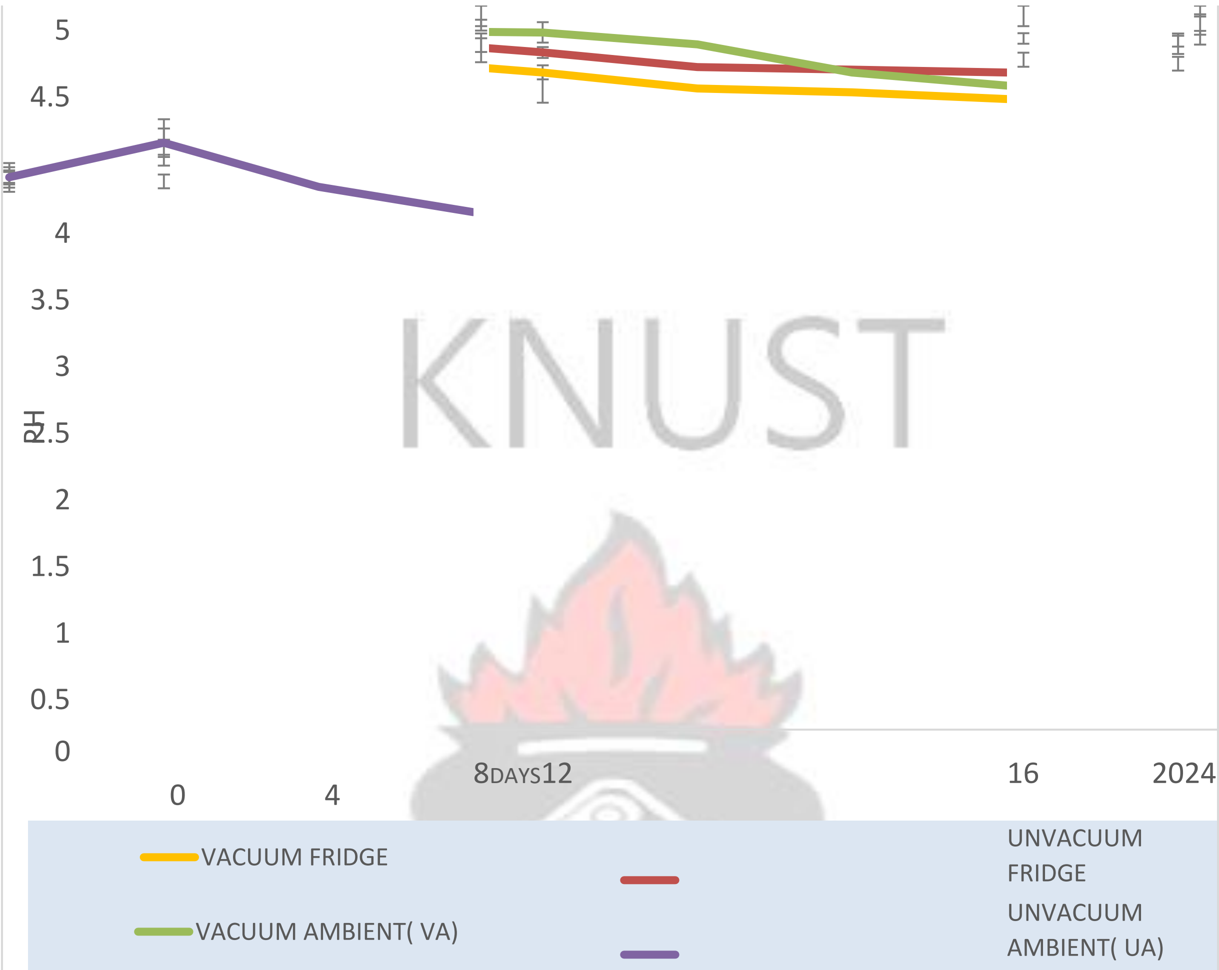

Figure 4.1: Changes in pH in 'Fanti kenkey' stored under two storage conditions.

Furthermore, there was a strong correlation coefficient obtained for the for pH and storage time for almost all parameters (Table 4.1). This implies that the relationship between the two variables (pH and storage time) in the two stated storage instances for the vacuumed and unvacum samples could be effectively modelled. Such a model could then be used to make significant predictions of the shelf stability of the samples under these conditions. However, at $p<0.05$, values obtained for pH for unvacuum-packaged kenkey samples stored at ambient conditions (Control 1) showed no significant difference. The resulting model for this kind of relationship cannot be relied upon to make significant predictions.

Table 4.1: Evaluation of pH trend for shelf life prediction of 'Fanti kenkey' stored under two different conditions

parameter	Condition	p-value	Correlation coefficient	Inference
pH	Vacuum packaged& refrigerated	0.0001	-0.97828	There is a statistically significant relationship between variables at the 95.0% or higher confidence level
pH	Vacuum and packaged ambient	0.0184	-0.838416	``
pH	Unvacum and refrigerated	0.0115	-0.867042	``
pH	Unvacuum-ambient	0.1663	-0.833664	There is not a statistically significant relationship between Variables at 95.0% or higher confidence level

From Table 4.2, the fitted models predicted a highest shelf life of approximately 29 days for unvacuum-packaged kenkey stored under refrigerated conditions and 25 and 24 days for the vacuum packed samples both ambient and refrigerated respectively. The low shelf life predicted due to pH for the vacuum packed and refrigerated samples is perhaps due to the gradual reduction in microbial population throughout the storage period (Fig.4.1).

Table 4.2: pH predictions of shelf life of 'Fanti kenkey' under four storage

conditions

CONDITION	MODEL	CRITICAL LIMIT	PREDICTED SHELF LIFE
Vacuum Packed And Refrigerated	Days = 238.1 - 61.25*pH	3.5	**23.725**
Vacuum Packed And Ambient	Days = sqrt(-3265.6 + 13530.6/pH)	3.5	**24.501**
Normal Refrigerated	Days = sqrt(-6513.64 + 25745.9/pH)	3.5	**29.023**
Normal Ambient	Days = sqrt(-913.79 + 3708.03/pH)	3.5	**12.068**

This is emphasized with a similar mold and yeast trend (Fig.4.3). Predicted shelf life for vacuum packed samples stored under ambient conditions however corresponds with the physical observation carried out as mold growth was first noticed on the 25th day of storage of the samples. A critical limit of 3.5 was obtained and used in estimating the shelf lives. This value was obtained after preliminary investigations when the pH of consumer accepted spoilt kenkey samples were evaluated. The value is however consistent with (Halm *et al.*, 1993) who reported pH values of Ghanaian kenkey in a range of 3.7 – 5.9 depending on the stage of fermentation.

4.3 Shelf life based on water activity and moisture

Moisture content and water activity are important parameters in predicting the shelf life of foods. It is well known that every type of microorganism has an optimum moisture and water activity level with which it can grow (Roos, 1993). During storage, changes to water activity levels largely related to moisture migration may occur. These changes could shift water activity levels for proliferation of spoilage microorganisms. Halm *et al.*, (1993) in their study indicated *saccharomyces spp* the predominant microbial flora in kenkey. These group of microorganisms according to Decagon (2006) are known to grow with an optimum water activity level of around 0.80-0.90.

The results for water activity obtained for the study however indicated a highest water activity of 1.0007 for control samples stored under ambient conditions after 4 days of storage and a lowest of 0.9935 for vacuum packed samples stored at ambient temperature conditions after 12 days of storage (Fig. 4.2). These two data points together with the observed trend (Fig. 4.2) suggests no major significant ($p<0.05$) changes were observed in the water activity levels during the storage period (30 days). This in the vacuum packaged samples can be attributed to the polyfilm material which is highly impervious to moisture and hence did not allow moisture migration (Chetti *et al.*, 2014). The relative humidity observed within the period of storage could also account for insignificant changes in water activity levels. No significant difference ($p<0.05$) was also observed for the water activity of the unvacuum Fanti-Kenkey under the ambient and refrigerated conditions. This could be due to the banana leaves that served as a barrier against moisture migration in the samples.

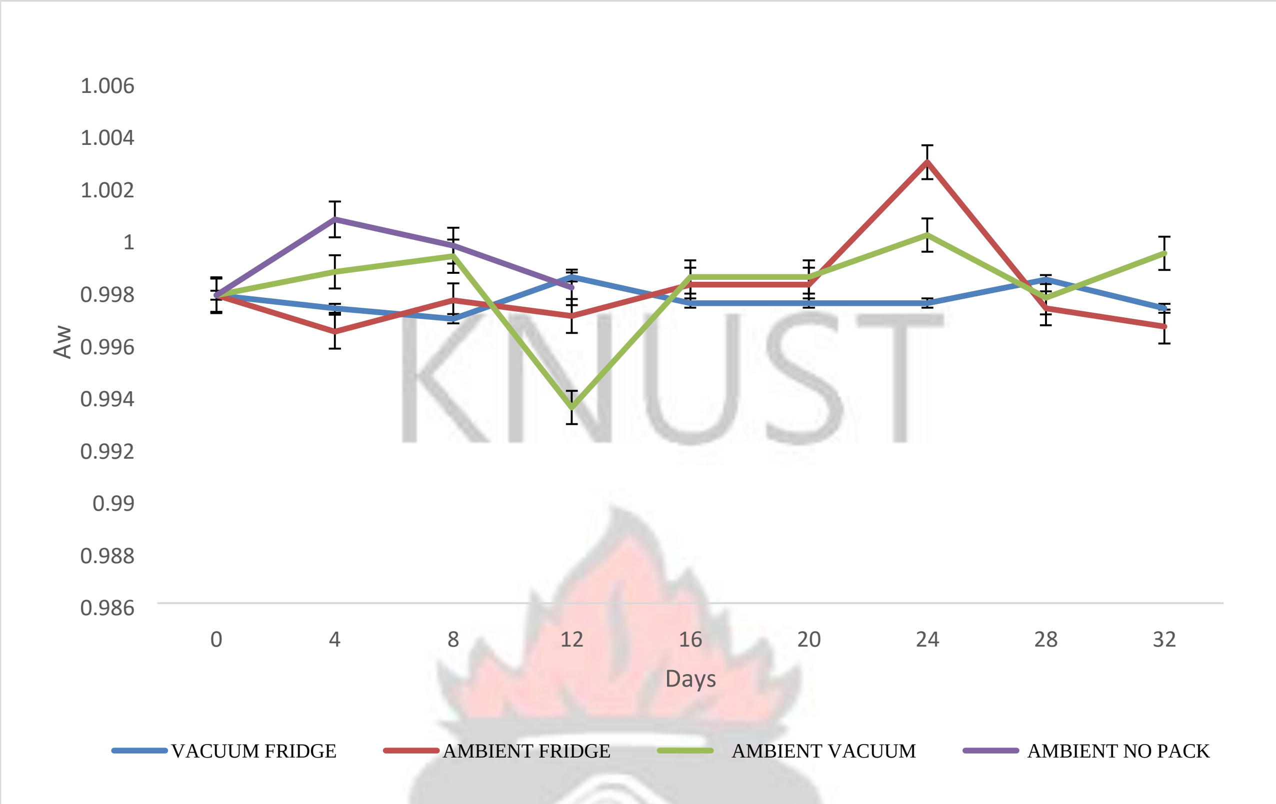

Figure 4.2: Changes in Water Activity of 'Fanti kenkey' stored under Two Different Conditions of Storage

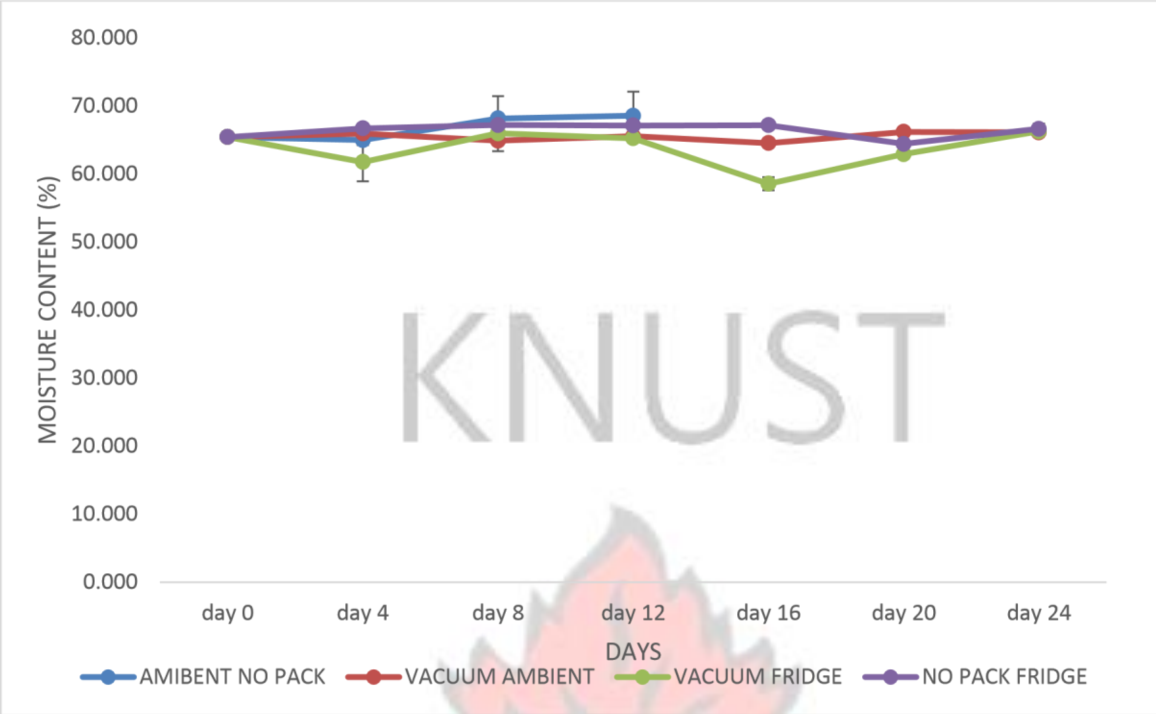

Figure 4.3: Changes in Moisture of 'Fanti kenkey' stored under Two Different Conditions of Storage

The correlation coefficients again suggested that there was no significant relationship between the water activity levels and storage time (days) (Table 4.3). In most instances a strong negative or positively correlated data is need for fitting a resistant model. Hence such data could not be modeled for significant prediction. The moisture content followed a similar trend and hence these two parameters were not used for the shelf life prediction.

Table 4.3: Evaluations of moisture and water activity trends for shelf life prediction 'Fanti kenkey' stored under two different conditions

Parameter	Condition	pvalue	Correlation coefficient	Inference
Moisture	Vacuum packaged& refrigerated	0.7357	-0.091638	There is not a statistically significant relationship between day and vacuum fridge at the 95.0% or higher confidence level.

Moisture	Vacuum and packaged ambient	0.9851	0.0050688	``
Moisture	Unvacuum and refrigerated	0.8803	-0.010836	``
Moisture	Unvacuum and ambient	0.9075	0.0494154	``
Water activity	Vacuum packaged& refrigerated	0.7366	0.131156	There is not a statistically significant relationship between day and vacuum fridge at the 95.0% or higher confidence level
Water activity	Vacuum packaged and ambient	0.5357	0.238991	``
Water activity	Unvacuum and refrigerated	0.5561	0.227497	``
Water activity	Unvacuum ambient	0.7193	-0.280693	``

4.5 Shelf life based on mold and yeast growth

Microbial-induced deterioration has been known to be the cause of most food spoilage. In general, increase in the load of yeast and mold over time is known to be the major factor of „Fanti-kenkey" spoilage (Halm *et al.*, 2004a). This is evident with moldy growth that is mostly visible on such spoiled product. The growth dynamics showed a general increase in microbial numbers with increasing days. Samples stored in the refrigerator showed a gradual minimal increase over the study period with vacuum packaged recording relatively lower microbial numbers with time (Fig. 4.3). The vacuum packaged and refrigerated samples had a gradual decrease in microbial numbers right from the 4th day of storage. The sharpest decline was however obtained after the 12th day of storage after which a steady decline in microbial population was observed until the 28th day of storage where the population started increasing. This trend can be attributed to an inactivation effect of the vacuum packaging on aerobic microorganisms which caused the gradual reduction in the microbial numbers.

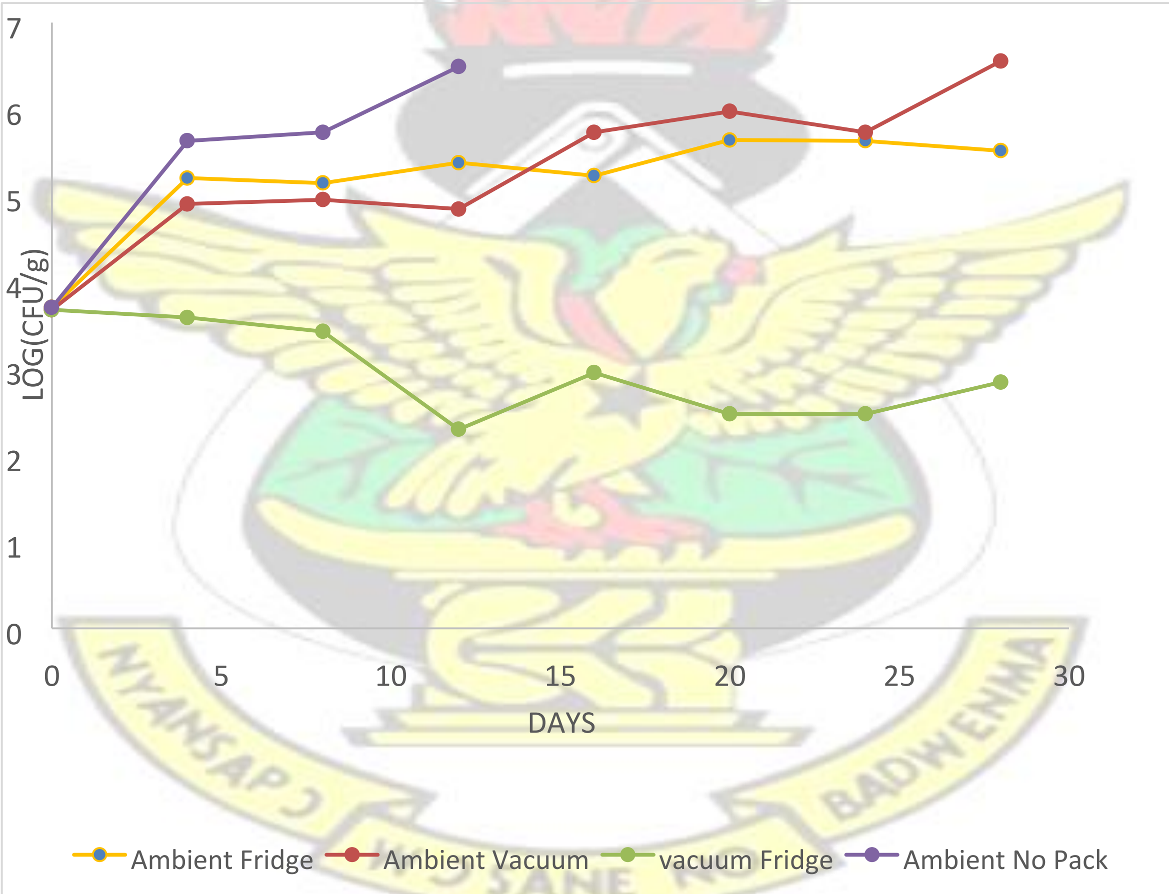

Figure 4.4: Growth dynamics for yeast and mold for 'Fanti kenkey' stored under two different conditions

The vacuum packaged samples stored under ambient conditions however showed sharp increase after the first four days of storage, this was followed by a sharp decline until the 12th day of storage where microbial numbers kept increasing. The sharp increase perhaps could be attributed to the ambient temperatures which further allowed certain microorganisms to proliferate even after the vacuum packaging. The observed decline can be explained as a microbial inactivation process as observed for the vacuum packaged and refrigerated samples. The latter continuous increase in microbial population could be due to the latter colonization and proliferation of anaerobic and microaerophilic microorganisms.

The Unvacuum packaged samples stored under both ambient and refrigerated conditions showed a general increase in microbial numbers with the samples under ambient conditions recording relatively high microbial numbers.

For the unvacuum samples stored under ambient conditions it is important to note that the recorded growth had exceeded the critical limits (too numerous to count) after the 8th day (Fig. 4.2) and hence the experiment was halted. This observation is however consistent with observations of routine consumers of kenkey whose kenkey samples mostly last 4-7 days after production (Halm *et al*., 2004a).

These trends emphasize the positive effect of refrigeration and vacuum packaging on the shelf stability of kenkey. The reduced oxygen content in the vacuum packaged conditions largely inhibited the growth of the yeast and mold hence the relatively lower growth rates as observed. The temperature effect also showed with the reduced growth rate for the samples stored under te refrigerated conditions.

Different models as that could efficiently describe each data set and trends was used in modeling the growth of the microbes under each of the stated conditions. Using 10^6 Cfu/g as critical limit for the shelf life estimation as reported by Halm *et al.* (1993), the various shelf lives were predicted. Fanti-Kenkey with vacuum package, stored under refrigerated conditions had the longest shelf stability (30days) whereas unvacuum Fanti-Kenkey had the shortest (5days). The results however suggest a stronger effect of the vacuum packaged on yeast and mold growth as compared to the refrigeration. This is typically evident when the growth trends of refrigerated samples are compared to that of vacuum packaged samples stored under ambient. It is even more evident with the predicted shelf lives with the 5 days difference between vacuum packaged refrigerated and vacuum packaged ambient (Table 4.3).

Table 4.4: Microbial predictions of shelf life of 'Fanti kenkey' under four storage conditions

CONDITION	MODEL	CRITICAL LIMIT	PREDICTED SHELF LIFE
Vacuum Packed And Refrigerated	Microbial limit = sqrt(1.43502E7 - 2.94709E6*sqrt(days))	10_6	29.41915
Vacuum Packed And Ambient	Microbial limit = (95.8036 + 1.95057*days^2) ^2	10^6	25.1002
Unvaccum Refrigerated	Microbial limit = (89.4229 + 113.527*sqrt(days))^2	10^6	9.01387
Unvacuum Ambient	Microbial limit = exp(8.56147 + 1.78824*sqrt(days))	10^6	4.770

A strong positive correlation between counts and days (0.98) was observed for samples stored normally under ambient condition. A Logarithmic-Y Square Root-X model was best fitted for the data. The model gave an adjusted R- squared statistics of 95.52%. This implies the model fitted explains 95.93% of the variability in normal packaging and ambient temperature data. Again the model was examined for unusual residuals: there was no studentized residual greater than 2. Studentized residuals measure the number of standard deviations each observed value of normal ambient deviates from a model fitted using all of the data except that observation.

A Double square root model with a Correlation Coefficient (0.93) and an R-squared value of 86.42% was also best fitted for the normally packaged and refrigerated kenkey. The model indicated a predicted shelf-life value of approximately 9 days. A predicted shelf life value of 30 and 25 days, respectively for the vacuum packaged and refrigerated and vacuum packaged ambient was recorded. A Square Root-Y Squared-X model was best fitted for the vacuum packaged ambient whereas the decreasing trend observed in the vacuum packaged refrigerated samples made it possible for a Squared-Y Square Root-X typical model to be fitted. These gave R-squared value of 84.68% and 62.83% percent respectively. The decreasing trend (Fig.4.3) in the vacuum packaged refrigerated samples suggest a microbial inactivation process, perhaps the combined effect of vacuum packaging and refrigeration has an inactivation effect on certain yeast and molds.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The results of the study showed that changes based on physico-chemical parameters such as water activity and moisture did not have any statistical effect on the shelf life prediction as days increase. Hence they were not used in the shelf life prediction. In contrast shelf life evaluation based on pH and yeast and molds had a strong effect on the shelf life of „Fanti-kenkey‟ and therefore were used as major parameters for shelf life prediction. In conclusion, vacuum packaging has the potential to increase shelf life of „Fanti-kenkey‟ and could be exploited to satisfy the busy modern day people and enhance its appeal by local and international consumers.

5.2 Recommendations

Following the findings from the study, it is recommended that the study be extended to other types of kenkey in the Ghanaian community. It is also recommended that other types of shelf life methods be used to validate the result of this study. Again, it is recommended that other chemical changes (like Titratable acidity, Redox potential) and other microbial analysis like competitive flora and production of metabolites be used to predict the shelf life of kenkey.

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APPENDICES

Appendix A 1: Water activity of Unvacuum package ambient

Dependent variable: AW (UA)

Independent variable: DAYS (UA)

Linear model: Y = a + b*X

Coefficients

	Least Squares	*Standard*	*T*	
Parameter	*Estimate*	*Error*	*Statistic*	*P-Value*
Intercept	0.99909	0.00140087	713.19	0.0000
Slope	-0.0000025	0.0001872	-0.0133547	0.9906

Analysis of Variance

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Model	5.E-10	1	5.E-10	0.00	0.9906
Residual	0.000005607	2	0.0000028035		
Total (Corr.)	0.0000056075	3			

Correlation Coefficient = -0.00944279

R-squared = 0.00891663 percent

R-squared (adjusted for d.f.) = -49.9866 percent

Standard Error of Est. = 0.00167437

Mean absolute error = 0.001125

Durbin-Watson statistic = 2.13596 (P=0.1369)

Lag 1 residual autocorrelation = -0.298555

The StatAdvisor

The output shows the results of fitting a linear model to describe the relationship between AW and DAYS. The equation of the fitted model is

AW = 0.99909 - 0.0000025*DAYS

Since the P-value in the ANOVA table is greater or equal to 0.05, there is not a statistically significant relationship between AW and DAYS at the 95.0% or higher confidence level.

The R-Squared statistic indicates that the model as fitted explains 0.00891663% of the variability in AW. The correlation coefficient equals -0.00944279, indicating a relatively weak relationship between the variables. The standard error of the estimate shows the standard deviation of the residuals to be 0.00167437. This value can be used to construct prediction limits for new observations by selecting the Forecasts option from the text menu.

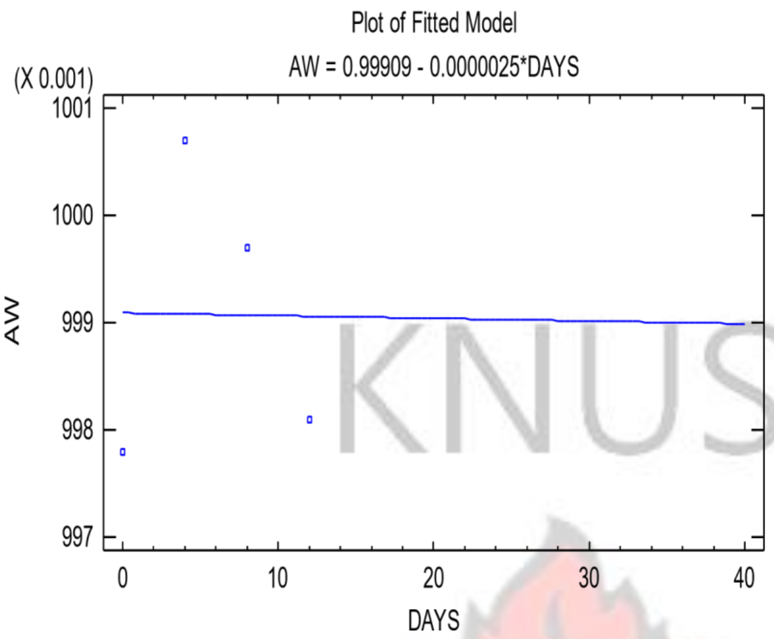
The mean absolute error (MAE) of 0.001125 is the average value of the residuals. The Durbin-Watson (DW) statistic tests the residuals to determine if there is any significant correlation based on the order in which they occur in your data file. Since the P-value is greater than 0.05, there is no indication of serial autocorrelation in the residuals at the 95.0% confidence level.

Model	*Correlation*	*R-Squared*
Double squared	-0.2807	7.88%
Squared-X	-0.2805	7.87%
Square root-Y squaredX	-0.2804	7.86%
Logarithmic-Y squaredX	-0.2804	7.86%

Reciprocal-Y squared-X	0.2802	7.85%
Reciprocal-Y square root-X	-0.2659	7.07%
Logarithmic-Y square root-X	0.2657	7.06%
Double square root	0.2656	7.05%
Square root-X	0.2655	7.05%
Squared-Y square rootX	0.2653	7.04%
Squared-Y	-0.0096	0.01%
Linear	-0.0094	0.01%
Square root-Y	-0.0093	0.01%
Exponential	-0.0092	0.01%
Reciprocal-Y	0.0090	0.01%
Logarithmic-X	<no fit>	
Square root-Y logarithmic-X	<no fit>	
Multiplicative	<no fit>	
Reciprocal-Y logarithmic-X	<no fit>	
Squared-Y logarithmicX	<no fit>	
Reciprocal-X	<no fit>	
Square root-Y reciprocal-X	<no fit>	
S-curve model	<no fit>	
Double reciprocal	<no fit>	
Squared-Y reciprocal-X	<no fit>	
Logistic	<no fit>	
Log probit	<no fit>	

The StatAdvisor

This table shows the results of fitting several curvilinear models to the data. Of the models fitted, the double squared model yields the highest R-Squared value with 7.87886%. This is 7.86994% higher than the currently selected linear model. To change models, select the Analysis Options dialog box.



Appendix B 1: Water activity for Unvacuum refrigerated

Dependent variable: AW (UF)

Independent variable: DAYS (UF)

Linear model: Y = a + b*X

Coefficients

	Least Squares	*Standard*	*T*	

Parameter	*Estimate*	*Error*	*Statistic*	*P-Value*
Intercept	0.997353	0.00124523	800.937	0.0000
Slope	0.0000404167	0.0000653878	0.618107	0.5561

Analysis of Variance

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Model	0.00000156817	1	0.00000156817	0.38	0.5561
Residual	0.0000287318	7	0.00000410455		
Total (Corr.)	0.0000303	8			

Correlation Coefficient = 0.227497

R-squared = 5.17547 percent

R-squared (adjusted for d.f.) = -8.37089 percent

Standard Error of Est. = 0.00202597

Mean absolute error = 0.00116926

Durbin-Watson statistic = 2.07913 (P=0.3679)

Lag 1 residual autocorrelation = -0.11593

The StatAdvisor

The output shows the results of fitting a linear model to describe the relationship between AW and DAYS. The equation of the fitted model is

AW = 0.997353 + 0.0000404167*DAYS

Since the P-value in the ANOVA table is greater or equal to 0.05, there is not a statistically significant relationship between AW and DAYS at the 95.0% or higher confidence level.

The R-Squared statistic indicates that the model as fitted explains 5.17547% of the variability in AW. The correlation coefficient equals 0.227497, indicating a relatively weak relationship between the variables. The standard error of the estimate shows the standard deviation of the residuals to be 0.00202597. This value can be used to construct prediction limits for new observations by selecting the Forecasts option from the text menu.

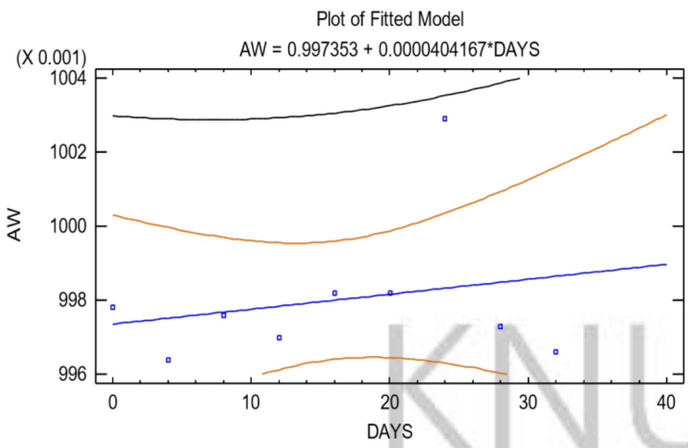
The mean absolute error (MAE) of 0.00116926 is the average value of the residuals. The Durbin-Watson (DW) statistic tests the residuals to determine if there is any significant correlation based on the order in which they occur in your data file. Since the P-value is greater than 0.05, there is no indication of serial autocorrelation in the residuals at the 95.0% confidence level.

Model	*Correlation*	*R-Squared*
Squared-Y	0.2277	5.18%
Linear	0.2275	5.18%
Square root-Y	0.2274	5.17%
Exponential	0.2273	5.17%
Reciprocal-Y	-0.2272	5.16%
Squared-Y square rootX	0.2246	5.05%
Square root-X	0.2245	5.04%

Double square root	0.2244	5.04%
Logarithmic-Y square root-X	0.2243	5.03%
Reciprocal-Y square root-X	-0.2242	5.03%
Double squared	0.1370	1.88%
Squared-X	0.1368	1.87%
Square root-Y squaredX	0.1367	1.87%
Logarithmic-Y squaredX	0.1366	1.87%
Reciprocal-Y squared-X	-0.1363	1.86%
Logarithmic-X	<no fit>	
Square root-Y logarithmic-X	<no fit>	
Multiplicative	<no fit>	
Reciprocal-Y logarithmic-X	<no fit>	
Squared-Y logarithmicX	<no fit>	
Reciprocal-X	<no fit>	
Square root-Y reciprocal-X	<no fit>	
S-curve model	<no fit>	
Double reciprocal	<no fit>	
Squared-Y reciprocal-X	<no fit>	
Logistic	<no fit>	
Log probit	<no fit>	

The StatAdvisor

This table shows the results of fitting several curvilinear models to the data. Of the models fitted, the squared-Y model yields the highest R-Squared value with 5.1825%. This is 0.00703442% higher than the currently selected linear model. To change models, select the Analysis Options dialog box.



Appendix C 1: Water activity for Vacuum package ambient

Simple Regression - AW vs. DAYS

Dependent variable: AW (VA)

Independent variable: DAYS (VA)

Linear model: Y = a + b*X

Coefficients

	Least Squares	*Standard*	*T*	
Parameter	*Estimate*	*Error*	*Statistic*	*P-Value*
Intercept	0.9975	0.00121854	818.601	0.0000
Slope	0.0000416667	0.0000639863	0.651181	0.5357

Analysis of Variance

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Model	0.00000166667	1	0.00000166667	0.42	0.5357
Residual	0.0000275133	7	0.00000393048		
Total (Corr.)	0.00002918	8			

Correlation Coefficient = 0.238991

R-squared = 5.71167 percent

R-squared (adjusted for d.f.) = -7.75809 percent

Standard Error of Est. = 0.00198254

Mean absolute error = 0.00121481

Durbin-Watson statistic = 2.56999 (P=0.6875)

Lag 1 residual autocorrelation = -0.292464

The StatAdvisor

The output shows the results of fitting a linear model to describe the relationship between AW and DAYS. The equation of the fitted model is

AW = 0.9975 + 0.0000416667*DAYS

Since the P-value in the ANOVA table is greater or equal to 0.05, there is not a statistically significant relationship between AW and DAYS at the 95.0% or higher confidence level.

The R-Squared statistic indicates that the model as fitted explains 5.71167% of the variability in AW. The correlation coefficient equals 0.238991, indicating a relatively weak relationship between the variables. The standard error of the estimate shows the standard deviation of the residuals to be 0.00198254. This value can be used to construct prediction limits for new observations by selecting the Forecasts option from the text menu.

The mean absolute error (MAE) of 0.00121481 is the average value of the residuals. The Durbin-Watson (DW) statistic tests the residuals to determine if there is any significant correlation based on the order in which they occur in your data file. Since the P-value is greater than 0.05, there is no indication of serial autocorrelation in the residuals at the 95.0% confidence level.

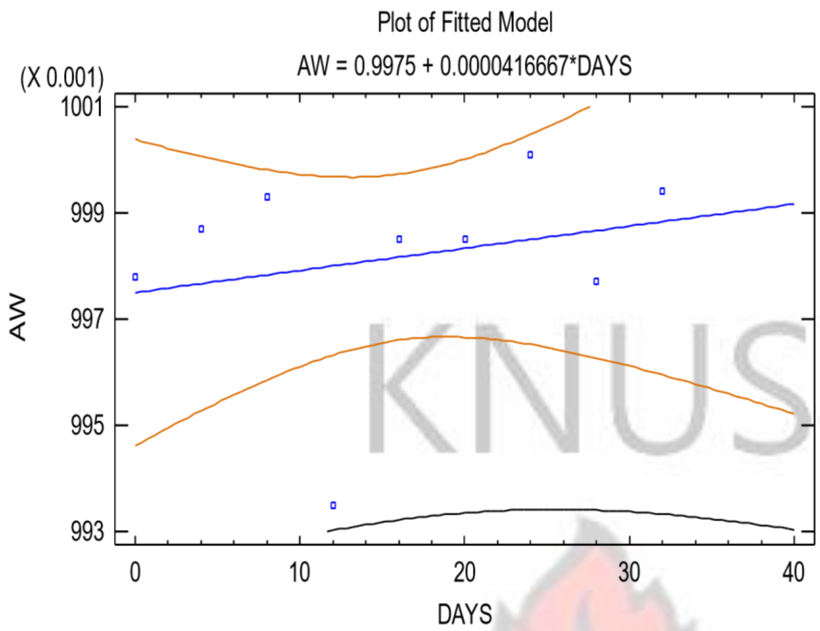
Comparison of Alternative Models

Model	*Correlation*	*R-Squared*
Double squared	0.2945	8.67%
Squared-X	0.2943	8.66%
Square root-Y squaredX	0.2943	8.66%
Logarithmic-Y squaredX	0.2942	8.65%
Reciprocal-Y squared-X	-0.2940	8.65%
Squared-Y	0.2392	5.72%
Linear	0.2390	5.71%
Square root-Y	0.2389	5.71%
Exponential	0.2388	5.70%
Reciprocal-Y	-0.2385	5.69%
Squared-Y square rootX	0.1792	3.21%
Square root-X	0.1788	3.20%
Double square root	0.1787	3.19%
Logarithmic-Y square root-X	0.1785	3.19%

Reciprocal-Y square root-X	-0.1782	3.17%
Logarithmic-X	<no fit>	
Square root-Y logarithmic-X	<no fit>	
Multiplicative	<no fit>	
Reciprocal-Y logarithmic-X	<no fit>	
Squared-Y logarithmicX	<no fit>	
Reciprocal-X	<no fit>	
Square root-Y reciprocal-X	<no fit>	
S-curve model	<no fit>	
Double reciprocal	<no fit>	
Squared-Y reciprocal-X	<no fit>	
Logistic	<no fit>	
Log probit	<no fit>	

The StatAdvisor

This table shows the results of fitting several curvilinear models to the data. Of the models fitted, the double squared model yields the highest R-Squared value with 8.67218%. This is 2.96051% higher than the currently selected linear model. To change models, select the Analysis Options dialog box.



Appendix D 1: Water activity for vacuum package refrigerated

<u>Simple Regression - AW vs. DAYS</u>

Dependent variable: AW (VF)

Independent variable: DAYS (VF)

Linear model: Y = a + b*X

Coefficients

	Least Squares	*Standard*	*T*	
Paramet er	*Estimate*	*Error*	*Statistic*	*P- Value*
Intercept	0.997533	0.00034004	2933.58	0.0000
Slope	0.00000625	0.000017855 7	0.35002 9	0.7366

Analysis of Variance

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Model	3.75E-8	1	3.75E-8	0.12	0.7366
Residual	0.0000021425	7	3.06071E-7		
Total (Corr.)	0.00000218	8			

Correlation Coefficient = 0.131156

R-squared = 1.72018 percent

R-squared (adjusted for d.f.) = -12.3198 percent

Standard Error of Est. = 0.000553237

Mean absolute error = 0.000411111

Durbin-Watson statistic = 2.8098 (P=0.8214)

Lag 1 residual autocorrelation = -0.465318

The StatAdvisor

The output shows the results of fitting a linear model to describe the relationship between AW and DAYS. The equation of the fitted model is

AW = 0.997533 + 0.00000625*DAYS

Since the P-value in the ANOVA table is greater or equal to 0.05, there is not a statistically significant relationship between AW and DAYS at the 95.0% or higher confidence level.

The R-Squared statistic indicates that the model as fitted explains 1.72018% of the variability in AW. The correlation coefficient equals 0.131156, indicating a relatively weak relationship between the variables. The standard error of the estimate shows the standard deviation of the residuals to be 0.000553237. This value can be used to construct prediction limits for new observations by selecting the Forecasts option from the text menu.

The mean absolute error (MAE) of 0.000411111 is the average value of the residuals. The Durbin-Watson (DW) statistic tests the residuals to determine if there is any significant correlation based on the order in which they occur in your data file. Since the P-value is greater than 0.05, there is no indication of serial autocorrelation in the residuals at the 95.0% confidence level.

Comparison of Alternative Models

Model	*Correlation*	*R-Squared*
Reciprocal-Y	-0.1312	1.72%
Exponential	0.1312	1.72%
Square root-Y	0.1312	1.72%
Linear	0.1312	1.72%
Squared-Y	0.1311	1.72%
Logistic	0.1252	1.57%
Reciprocal-Y squared-X	-0.1105	1.22%
Logarithmic-Y squaredX	0.1105	1.22%
Square root-Y squaredX	0.1104	1.22%
Squared-X	0.1104	1.22%
Double squared	0.1104	1.22%
Squared-Y square rootX	0.0866	0.75%
Square root-X	0.0866	0.75%
Double square root	0.0866	0.75%
Logarithmic-Y square root-X	0.0866	0.75%

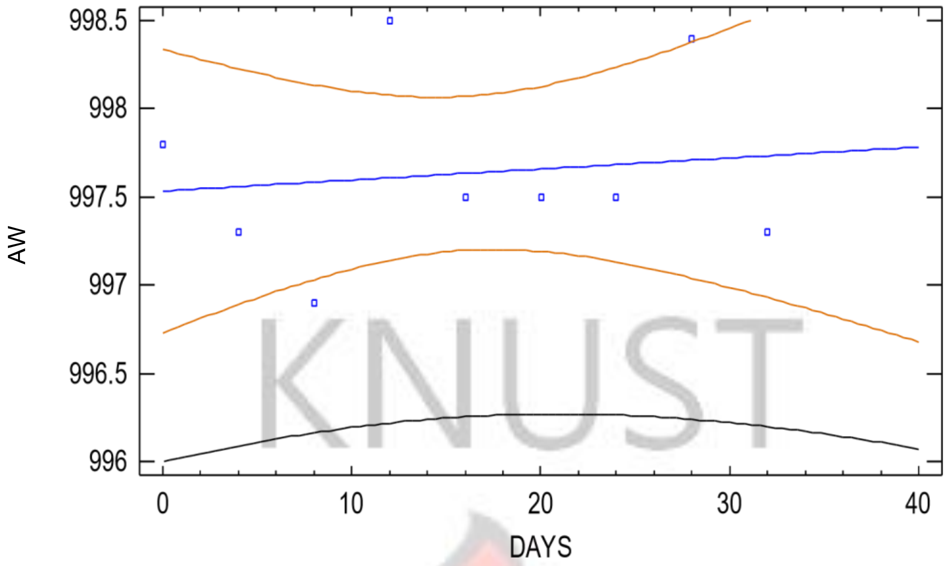
Reciprocal-Y square root-X	-0.0866	0.75%
Logarithmic-X	<no fit>	
Square root-Y logarithmic-X	<no fit>	
Multiplicative	<no fit>	
Reciprocal-Y logarithmic-X	<no fit>	
Squared-Y logarithmicX	<no fit>	
Reciprocal-X	<no fit>	
Square root-Y reciprocal-X	<no fit>	
S-curve model	<no fit>	
Double reciprocal	<no fit>	
Squared-Y reciprocal-X	<no fit>	
Log probit	<no fit>	

The StatAdvisor

This table shows the results of fitting several curvilinear models to the data. Of the models fitted, the reciprocal-Y model yields the highest R-Squared value with 1.72121%. This is 0.00102202% higher than the currently selected linear model. To change models, select the Analysis Options dialog box.

Plot of Fitted Model

(X 0.001) AW = 0.997533 + 0.00000625*DAYS



Appendix A 2: Moisture model for unvacuum package ambient

Simple Regression - Moisture vs. DAYS

Dependent variable: Moisture (UA)

Independent variable: DAYS (UA)

Linear model: Y = a + b*X

Coefficients

	Least Squares	*Standard*	*T*	
Parameter	*Estimate*	*Error*	*Statistic*	*P-Value*
Intercept	63.762	7.09999	8.98057	0.0122
Slope	-0.312888	0.948776	-0.32978	0.7729

Analysis of Variance

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Model	7.83189	1	7.83189	0.11	0.7729
Residual	144.028	2	72.0141		
Total (Corr.)	151.86	3			

Correlation Coefficient = -0.227097

R-squared = 5.15731 percent

R-squared (adjusted for d.f.) = -42.264 percent

Standard Error of Est. = 8.48611

Mean absolute error = 4.99708

Durbin-Watson statistic = 2.76757 (P=0.5245)

Lag 1 residual autocorrelation = -0.524132

The StatAdvisor

The output shows the results of fitting a linear model to describe the relationship between Moisture and DAYS. The equation of the fitted model is

Moisture = 63.762 - 0.312888*DAYS

Since the P-value in the ANOVA table is greater or equal to 0.05, there is not a statistically significant relationship between Moisture and DAYS at the 95.0% or higher confidence level.

The R-Squared statistic indicates that the model as fitted explains 5.15731% of the variability in Moisture. The correlation coefficient equals -0.227097, indicating a relatively weak relationship between the variables. The standard error of the estimate shows the standard deviation of the residuals to be 8.48611. This value can be used to construct prediction limits for new observations by selecting the Forecasts option from the text menu.

The mean absolute error (MAE) of 4.99708 is the average value of the residuals. The Durbin-Watson (DW) statistic tests the residuals to determine if there is any significant correlation based on the order in which they occur in your data file. Since the P-value is greater than 0.05, there is no indication of serial autocorrelation in the residuals at the 95.0% confidence level.

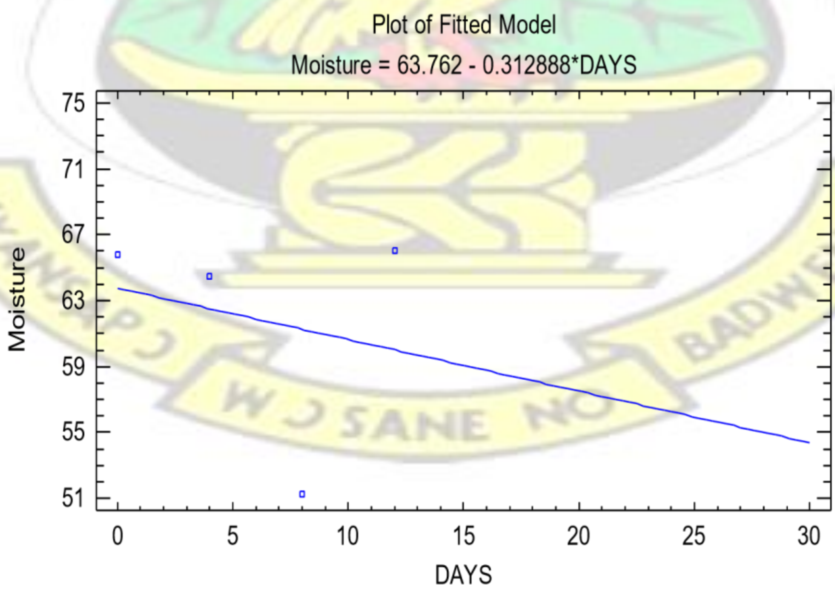
Comparison of Alternative Models

Model	*Correlation*	*R-Squared*
Reciprocal-Y square root-X	0.3306	10.93%
Logarithmic-Y square root-X	-0.3298	10.88%
Double square root	-0.3294	10.85%
Square root-X	-0.3290	10.82%
Squared-Y square rootX	-0.3280	10.76%
Reciprocal-Y	0.2340	5.48%
Exponential	-0.2307	5.32%
Square root-Y	-0.2289	5.24%
Linear	-0.2271	5.16%
Squared-Y	-0.2232	4.98%
Reciprocal-Y squared-X	0.0417	0.17%
Logarithmic-Y squaredX	-0.0364	0.13%
Square root-Y squaredX	-0.0336	0.11%
Squared-X	-0.0306	0.09%
Double squared	-0.0244	0.06%

Logarithmic-X	<no fit>	
Square root-Y logarithmic-X	<no fit>	
Multiplicative	<no fit>	
Reciprocal-Y logarithmic-X	<no fit>	
Squared-Y logarithmicX	<no fit>	
Reciprocal-X	<no fit>	
Square root-Y reciprocal-X	<no fit>	
S-curve model	<no fit>	
Double reciprocal	<no fit>	
Squared-Y reciprocal-X	<no fit>	
Logistic	<no fit>	
Log probit	<no fit>	

The StatAdvisor

This table shows the results of fitting several curvilinear models to the data. Of the models fitted, the reciprocal-Y square root-X model yields the highest R-Squared value with 10.9282%. This is 5.77093% higher than the currently selected linear model. To change models, select the Analysis Options dialog box.



Appendix B 2:Moisture model for vacuum package refrigerated

Simple Regression - Moisture vs. DAYS

Dependent variable: Moisture (UF)

Independent variable: DAYS (UF)

Linear model: Y = a + b*X

Coefficients

	Least Squares	*Standard*	*T*	
Parameter	*Estimate*	*Error*	*Statistic*	*P-Value*
Intercept	66.7826	0.753925	88.5799	0.0000
Slope	0.0208661	0.0450556	0.463118	0.6596

Analysis of Variance

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Model	0.292584	1	0.292584	0.21	0.6596
Residual	8.185	6	1.36417		
Total (Corr.)	8.47758	7			

Correlation Coefficient = 0.185776

R-squared = 3.45127 percent

R-squared (adjusted for d.f.) = -12.6402 percent

Standard Error of Est. = 1.16798

Mean absolute error = 0.832174

Durbin-Watson statistic = 2.15787 (P=0.3941)

Lag 1 residual autocorrelation = -0.15291

The StatAdvisor

The output shows the results of fitting a linear model to describe the relationship between Moisture and DAYS. The equation of the fitted model is

Moisture = 66.7826 + 0.0208661*DAYS

Since the P-value in the ANOVA table is greater or equal to 0.05, there is not a statistically significant relationship between Moisture and DAYS at the 95.0% or higher confidence level.

The R-Squared statistic indicates that the model as fitted explains 3.45127% of the variability in Moisture. The correlation coefficient equals 0.185776, indicating a relatively weak relationship between the variables. The standard error of the estimate shows the standard deviation of the residuals to be 1.16798. This value can be used to construct prediction limits for new observations by selecting the Forecasts option from the text menu.

The mean absolute error (MAE) of 0.832174 is the average value of the residuals. The Durbin-Watson (DW) statistic tests the residuals to determine if there is any significant correlation based on the order in which they occur in your data file. Since the P-value is greater than 0.05, there is no indication of serial autocorrelation in the residuals at the

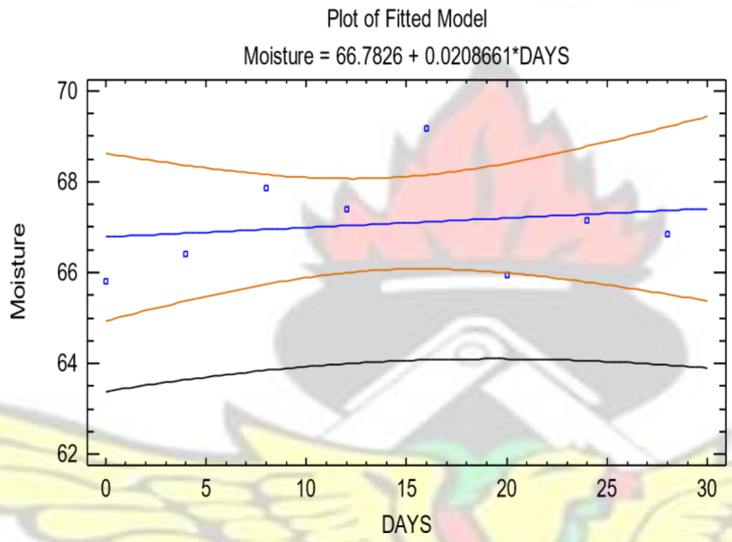
95.0% confidence level.

Comparison of Alternative Models

Model	*Correlation*	*R-Squared*
Reciprocal-Y square root-X	-0.3445	11.87%
Logarithmic-Y square root-X	0.3416	11.67%
Double square root	0.3401	11.57%
Square root-X	0.3387	11.47%
Squared-Y square rootX	0.3358	11.28%
Reciprocal-Y	-0.1904	3.63%
Exponential	0.1881	3.54%
Square root-Y	0.1869	3.49%
Linear	0.1858	3.45%
Squared-Y	0.1835	3.37%
Reciprocal-Y squared-X	-0.0230	0.05%
Logarithmic-Y squaredX	0.0207	0.04%
Square root-Y squaredX	0.0196	0.04%
Squared-X	0.0185	0.03%
Double squared	0.0162	0.03%
Logarithmic-X	<no fit>	
Square root-Y logarithmic-X	<no fit>	
Multiplicative	<no fit>	
Reciprocal-Y logarithmic-X	<no fit>	
Squared-Y logarithmicX	<no fit>	
Reciprocal-X	<no fit>	
Square root-Y reciprocal-X	<no fit>	
S-curve model	<no fit>	
Double reciprocal	<no fit>	
Squared-Y reciprocal-X	<no fit>	
Logistic	<no fit>	
Log probit	<no fit>	

The StatAdvisor

This table shows the results of fitting several curvilinear models to the data. Of the models fitted, the reciprocal-Y square root-X model yields the highest R-Squared value with 11.8661%. This is 8.41484% higher than the currently selected linear model. To change models, select the Analysis Options dialog box.



Appendix C 2: Moisture model for vacuum package ambient

Simple Regression - Moisture vs. DAYS

Dependent variable: Moisture (VA)

Independent variable: DAYS (VA)

Linear model: Y = a + b*X

Coefficients

	Least Squares	*Standar d*	*T*	

Parameter	*Estimate*	*Error*	*Statistic*	*P-Value*
Intercept	65.5092	0.713186	91.8543	0.0000
Slope	0.00191101	0.042621	0.0448373	0.9657

Analysis of Variance

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Model	0.00245412	1	0.00245412	0.00	0.9657
Residual	7.32434	6	1.22072		
Total (Corr.)	7.32679	7			

Correlation Coefficient = 0.0183017

R-squared = 0.0334952 percent

R-squared (adjusted for d.f.) = -16.6276 percent

Standard Error of Est. = 1.10486

Mean absolute error = 0.655083

Durbin-Watson statistic = 2.31799 (P=0.4953)

Lag 1 residual autocorrelation = -0.169196

The StatAdvisor

The output shows the results of fitting a linear model to describe the relationship between Moisture and DAYS. The equation of the fitted model is

Moisture = 65.5092 + 0.00191101*DAYS

Since the P-value in the ANOVA table is greater or equal to 0.05, there is not a statistically significant relationship between Moisture and DAYS at the 95.0% or higher confidence level.

The R-Squared statistic indicates that the model as fitted explains 0.0334952% of the variability in Moisture. The correlation coefficient equals 0.0183017, indicating a relatively weak relationship between the variables. The standard error of the estimate shows the standard deviation of the residuals to be 1.10486. This value can be used to construct prediction limits for new observations by selecting the Forecasts option from the text menu.

The mean absolute error (MAE) of 0.655083 is the average value of the residuals. The Durbin-Watson (DW) statistic tests the residuals to determine if there is any significant correlation based on the order in which they occur in your data file. Since the P-value is greater than 0.05, there is no indication of serial autocorrelation in the residuals at the 95.0% confidence level.

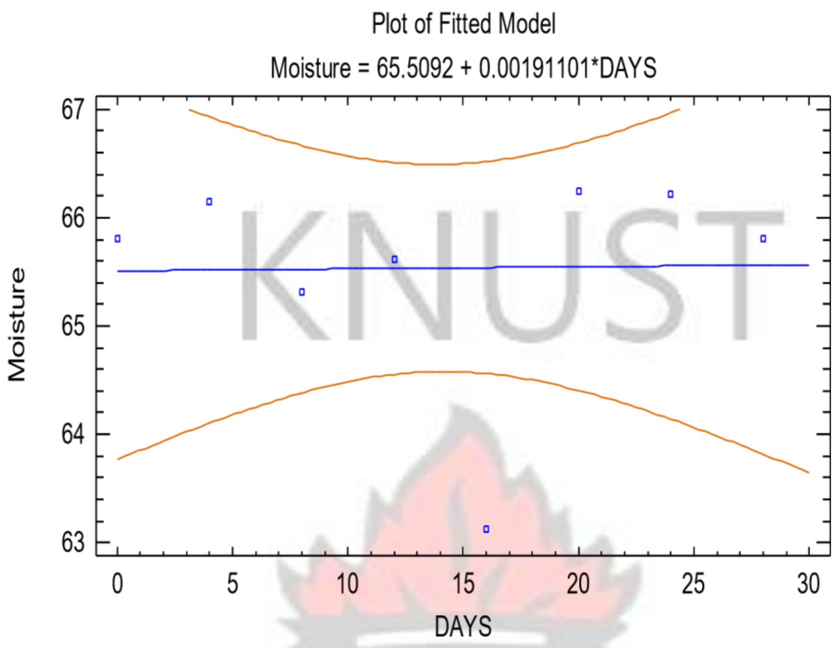
Comparison of Alternative Models

Model	*Correlation*	*R-Squared*
Double squared	0.1386	1.92%
Squared-X	0.1369	1.87%
Square root-Y squaredX	0.1360	1.85%

Logarithmic-Y squaredX	0.1352	1.83%
Reciprocal-Y squared-X	-0.1334	1.78%
Reciprocal-Y square root-X	0.0676	0.46%
Logarithmic-Y square root-X	-0.0659	0.43%
Double square root	-0.0650	0.42%
Square root-X	-0.0641	0.41%
Squared-Y square rootX	-0.0623	0.39%
Squared-Y	0.0202	0.04%
Linear	0.0183	0.03%
Square root-Y	0.0173	0.03%
Exponential	0.0164	0.03%
Reciprocal-Y	-0.0145	0.02%
Logarithmic-X	<no fit>	
Square root-Y logarithmic-X	<no fit>	
Multiplicative	<no fit>	
Reciprocal-Y logarithmic-X	<no fit>	
Squared-Y logarithmicX	<no fit>	
Reciprocal-X	<no fit>	
Square root-Y reciprocal-X	<no fit>	
S-curve model	<no fit>	
Double reciprocal	<no fit>	
Squared-Y reciprocal-X	<no fit>	
Logistic	<no fit>	
Log probit	<no fit>	

The StatAdvisor

This table shows the results of fitting several curvilinear models to the data. Of the models fitted, the double squared model yields the highest R-Squared value with 1.92182%. This is 1.88832% higher than the currently selected linear model. To change models, select the Analysis Options dialog box.



Appendix D 2: Moisture model for vacuum package refrigerated

Simple Regression - Moisture vs. DAYS

Dependent variable: Moisture (VF)

Independent variable: DAYS (VF)

Linear model: Y = a + b*X

Coefficients

	Least Squares	*Standard*	*T*	
Parameter	*Estimate*	*Error*	*Statistic*	*P-Value*
Intercept	64.7471	1.24682	51.9297	0.0000

Slope	-0.019681	0.074512	-0.264131	0.8005

Analysis of Variance

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Model	0.260292	1	0.260292	0.07	0.8005
Residual	22.3858	6	3.73097		
Total (Corr.)	22.6461	7			

Correlation Coefficient = -0.10721

R-squared = 1.14939 percent

R-squared (adjusted for d.f.) = -15.3257 percent

Standard Error of Est. = 1.93157

Mean absolute error = 1.44196

Durbin-Watson statistic = 1.46059 (P=0.0810)

Lag 1 residual autocorrelation = 0.185866

The StatAdvisor

The output shows the results of fitting a linear model to describe the relationship between Moisture and DAYS. The equation of the fitted model is

Moisture = 64.7471 - 0.019681*DAYS

Since the P-value in the ANOVA table is greater or equal to 0.05, there is not a statistically significant relationship between Moisture and DAYS at the 95.0% or higher confidence level.

The R-Squared statistic indicates that the model as fitted explains 1.14939% of the variability in Moisture. The correlation coefficient equals -0.10721, indicating a relatively weak relationship between the variables. The standard error of the estimate shows the standard deviation of the residuals to be 1.93157. This value can be used to construct prediction limits for new observations by selecting the Forecasts option from the text menu.

The mean absolute error (MAE) of 1.44196 is the average value of the residuals. The Durbin-Watson (DW) statistic tests the residuals to determine if there is any significant correlation based on the order in which they occur in your data file. Since the P-value is greater than 0.05, there is no indication of serial autocorrelation in the residuals at the 95.0% confidence level.

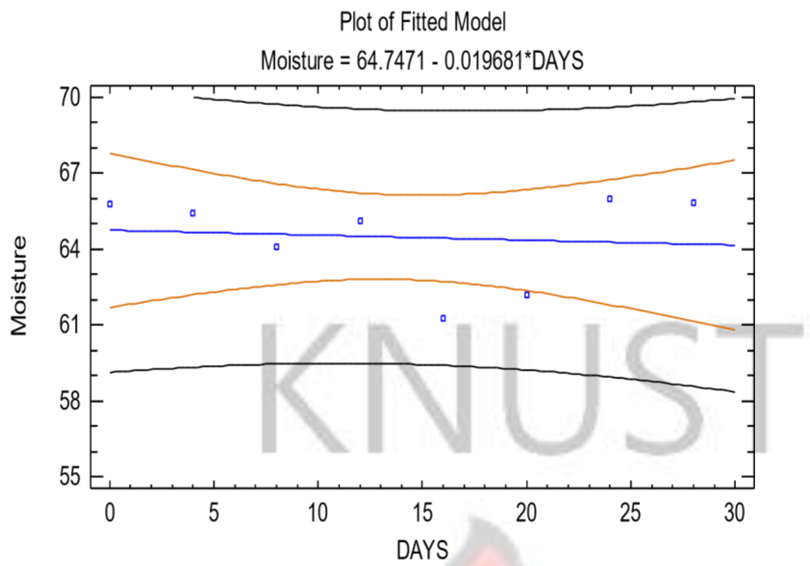
Comparison of Alternative Models

Model	*Correlation*	*R-Squared*
Reciprocal-Y square root-X	0.2375	5.64%
Logarithmic-Y square root-X	-0.2362	5.58%
Double square root	-0.2355	5.55%
Square root-X	-0.2348	5.51%
Squared-Y square rootX	-0.2334	5.45%
Reciprocal-Y	0.1126	1.27%
Exponential	-0.1099	1.21%
Square root-Y	-0.1086	1.18%
Linear	-0.1072	1.15%
Squared-Y	-0.1044	1.09%

Double squared	0.0872	0.76%
Squared-X	0.0837	0.70%
Square root-Y squaredX	0.0820	0.67%
Logarithmic-Y squaredX	0.0803	0.64%
Reciprocal-Y squared-X	-0.0769	0.59%
Logarithmic-X	<no fit>	
Square root-Y logarithmic-X	<no fit>	
Multiplicative	<no fit>	
Reciprocal-Y logarithmic-X	<no fit>	
Squared-Y logarithmicX	<no fit>	
Reciprocal-X	<no fit>	
Square root-Y reciprocal-X	<no fit>	
S-curve model	<no fit>	
Double reciprocal	<no fit>	
Squared-Y reciprocal-X	<no fit>	
Logistic	<no fit>	
Log probit	<no fit>	

The StatAdvisor

This table shows the results of fitting several curvilinear models to the data. Of the models fitted, the reciprocal-Y square root-X model yields the highest R-Squared value with 5.64278%. This is 4.49339% higher than the currently selected linear model. To change models, select the Analysis Options dialog box.



Appendix A 3:pH model for unvacuum package ambient

Simple Regression - pH vs. Days

Dependent variable: pH (UA)

Independent variable: Days (UA)

Linear model: Y = a + b*X

Coefficients

	Least Squares	*Standard*	*T*	
Parameter	*Estimate*	*Error*	*Statistic*	*P-Value*
Intercept	3.999	0.164452	24.3171	0.0017
Slope	-0.02775	0.0219758	-1.26275	0.3340

Analysis of Variance

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Model	0.061605	1	0.061605	1.59	0.3340
Residual	0.07727	2	0.038635		
Total (Corr.)	0.138875	3			

Correlation Coefficient = -0.666033

R-squared = 44.36 percent

R-squared (adjusted for d.f.) = 16.5401 percent

Standard Error of Est. = 0.196558

Mean absolute error = 0.1125

Durbin-Watson statistic = 2.48276 (P=0.3178)

Lag 1 residual autocorrelation = -0.422415

The StatAdvisor

The output shows the results of fitting a linear model to describe the relationship between pH and Days. The equation of the fitted model is

pH = 3.999 - 0.02775*Days

Since the P-value in the ANOVA table is greater or equal to 0.05, there is not a statistically significant relationship between pH and Days at the 95.0% or higher confidence level.

The R-Squared statistic indicates that the model as fitted explains 44.36% of the variability in pH. The correlation coefficient equals -0.666033, indicating a moderately strong relationship between the variables. The standard error of the estimate shows the standard deviation of the residuals to be 0.196558. This value can be used to construct prediction limits for new observations by selecting the Forecasts option from the text menu.

The mean absolute error (MAE) of 0.1125 is the average value of the residuals. The Durbin-Watson (DW) statistic tests the residuals to determine if there is any significant correlation based on the order in which they occur in your data file. Since the P-value is greater than 0.05, there is no indication of serial autocorrelation in the residuals at the 95.0% confidence level.

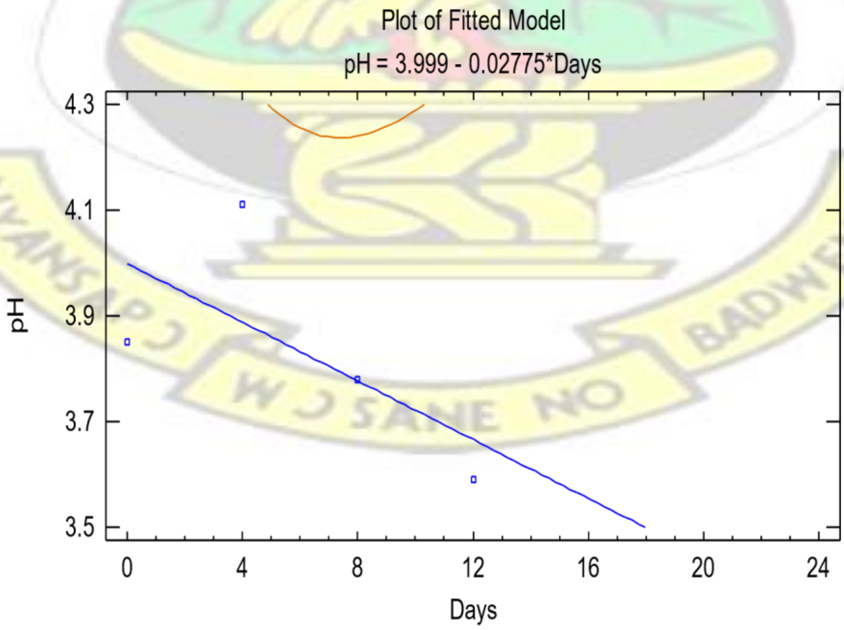
Comparison of Alternative Models

Model	*Correlation*	*R-Squared*
Reciprocal-Y squared-X	0.8337	69.50%
Logarithmic-Y squaredX	-0.8224	67.64%
Square root-Y squaredX	-0.8166	66.69%
Squared-X	-0.8108	65.74%
Double squared	-0.7988	63.80%
Reciprocal-Y	0.6898	47.58%
Exponential	-0.6781	45.98%
Square root-Y	-0.6721	45.17%
Linear	-0.6660	44.36%
Squared-Y	-0.6537	42.73%
Reciprocal-Y square root-X	0.4718	22.26%
Logarithmic-Y square root-X	-0.4590	21.07%
Double square root	-0.4524	20.47%
Square root-X	-0.4458	19.88%
Squared-Y square rootX	-0.4325	18.71%

Logarithmic-X	<no fit>	
Square root-Y logarithmic-X	<no fit>	
Multiplicative	<no fit>	
Reciprocal-Y logarithmic-X	<no fit>	
Squared-Y logarithmicX	<no fit>	
Reciprocal-X	<no fit>	
Square root-Y reciprocal-X	<no fit>	
S-curve model	<no fit>	
Double reciprocal	<no fit>	
Squared-Y reciprocal-X	<no fit>	
Logistic	<no fit>	
Log probit	<no fit>	

The StatAdvisor

This table shows the results of fitting several curvilinear models to the data. Of the models fitted, the reciprocal-Y squared-X model yields the highest R-Squared value with 69.4996%. This is 25.1396% higher than the currently selected linear model. To change models, select the Analysis Options dialog box.



Appendix B 3:pH model for unvacuum package refrigerated

Simple Regression - pH vs. Days

Dependent variable: pH (UF)

Independent variable: Days (UF)

Linear model: Y = a + b*X

Coefficients

	Least Squares	*Standard*	*T*	
Parameter	*Estimate*	*Error*	*Statistic*	*P-Value*
Intercept	3.95286	0.047348	83.4851	0.0000
Slope	-0.01	0.003283	-3.046	0.0286

Analysis of Variance

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Model	0.0448	1	0.0448	9.28	0.0286
Residual	0.0241429	5	0.00482857		
Total (Corr.)	0.0689429	6			

Correlation Coefficient = -0.80611

R-squared = 64.9814 percent

R-squared (adjusted for d.f.) = 57.9776 percent

Standard Error of Est. = 0.0694879

Mean absolute error = 0.0489796

Durbin-Watson statistic = 1.54083 (P=0.0945)

Lag 1 residual autocorrelation = 0.0103128

The StatAdvisor

The output shows the results of fitting a linear model to describe the relationship between pH and Days. The equation of the fitted model is

pH = 3.95286 - 0.01*Days

Since the P-value in the ANOVA table is less than 0.05, there is a statistically significant relationship between pH and Days at the 95.0% confidence level.

The R-Squared statistic indicates that the model as fitted explains 64.9814% of the variability in pH. The correlation coefficient equals -0.80611, indicating a moderately strong relationship between the variables. The standard error of the estimate shows the standard deviation of the residuals to be 0.0694879. This value can be used to construct prediction limits for new observations by selecting the Forecasts option from the text menu.

The mean absolute error (MAE) of 0.0489796 is the average value of the residuals. The

Durbin-Watson (DW) statistic tests the residuals to determine if there is any significant correlation based on the order in which they occur in your data file. Since the P-value is greater than 0.05, there is no indication of serial autocorrelation in the residuals at the 95.0% confidence level.

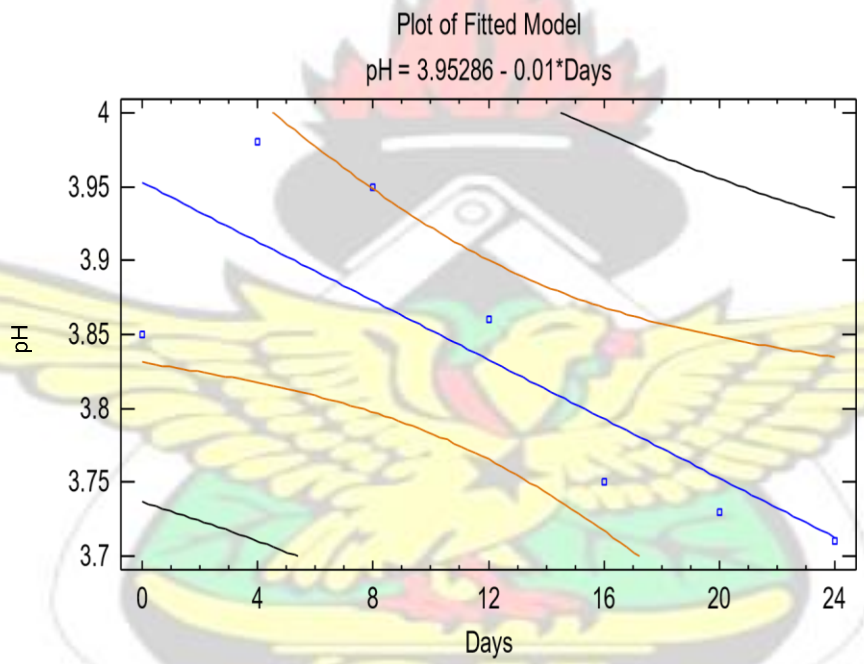
Comparison of Alternative Models

Model	*Correlation*	*R-Squared*
Reciprocal-Y squared-X	0.8670	75.18%
Logarithmic-Y squaredX	-0.8634	74.55%
Square root-Y squaredX	-0.8616	74.24%
Squared-X	-0.8598	73.92%
Double squared	-0.8560	73.28%
Reciprocal-Y	0.8129	66.07%
Exponential	-0.8095	65.53%
Square root-Y	-0.8078	65.26%
Linear	-0.8061	64.98%
Squared-Y	-0.8026	64.42%
Reciprocal-Y square root-X	0.6309	39.80%
Logarithmic-Y square root-X	-0.6270	39.31%
Double square root	-0.6250	39.07%
Square root-X	-0.6231	38.82%
Squared-Y square rootX	-0.6191	38.33%
Logarithmic-X	<no fit>	
Square root-Y logarithmic-X	<no fit>	
Multiplicative	<no fit>	
Reciprocal-Y logarithmic-X	<no fit>	
Squared-Y logarithmicX	<no fit>	
Reciprocal-X	<no fit>	
Square root-Y reciprocal-X	<no fit>	
S-curve model	<no fit>	
Double reciprocal	<no fit>	

Squared-Y reciprocal-X	<no fit>	
Logistic	<no fit>	
Log probit	<no fit>	

The StatAdvisor

This table shows the results of fitting several curvilinear models to the data. Of the models fitted, the reciprocal-Y squared-X model yields the highest R-Squared value with 75.1762%. This is 10.1948% higher than the currently selected linear model. To change models, select the Analysis Options dialog box.



Appendix C 3: pH model for vacuum package ambient

Simple Regression - pH vs. Days

Dependent variable: pH (VA)

Independent variable: Days (VA)

Linear model: Y = a + b*X

Coefficients

	Least Squares	Standard	T	
Parameter	*Estimate*	*Error*	*Statistic*	*P-Value*
Intercept	4.09929	0.108711	37.7081	0.0000
Slope	-0.01625	0.00753775	-2.15582	0.0836

Analysis of Variance

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Model	0.1183	1	0.1183	4.65	0.0836
Residual	0.127271	5	0.0254543		
Total (Corr.)	0.245571	6			

Correlation Coefficient = -0.69407

R-squared = 48.1734 percent

R-squared (adjusted for d.f.) = 37.808 percent

Standard Error of Est. = 0.159544

Mean absolute error = 0.117959

Durbin-Watson statistic = 1.74548 (P=0.1616)

Lag 1 residual autocorrelation = -0.155605

The StatAdvisor

The output shows the results of fitting a linear model to describe the relationship between pH and Days. The equation of the fitted model is

pH = 4.09929 - 0.01625*Days

Since the P-value in the ANOVA table is greater or equal to 0.05, there is not a statistically significant relationship between pH and Days at the 95.0% or higher confidence level.

The R-Squared statistic indicates that the model as fitted explains 48.1734% of the variability in pH. The correlation coefficient equals -0.69407, indicating a moderately strong relationship between the variables. The standard error of the estimate shows the standard deviation of the residuals to be 0.159544. This value can be used to construct prediction limits for new observations by selecting the Forecasts option from the text menu.

The mean absolute error (MAE) of 0.117959 is the average value of the residuals. The Durbin-Watson (DW) statistic tests the residuals to determine if there is any significant correlation based on the order in which they occur in your data file. Since the P-value is greater than 0.05, there is no indication of serial autocorrelation in the residuals at the 95.0% confidence level.

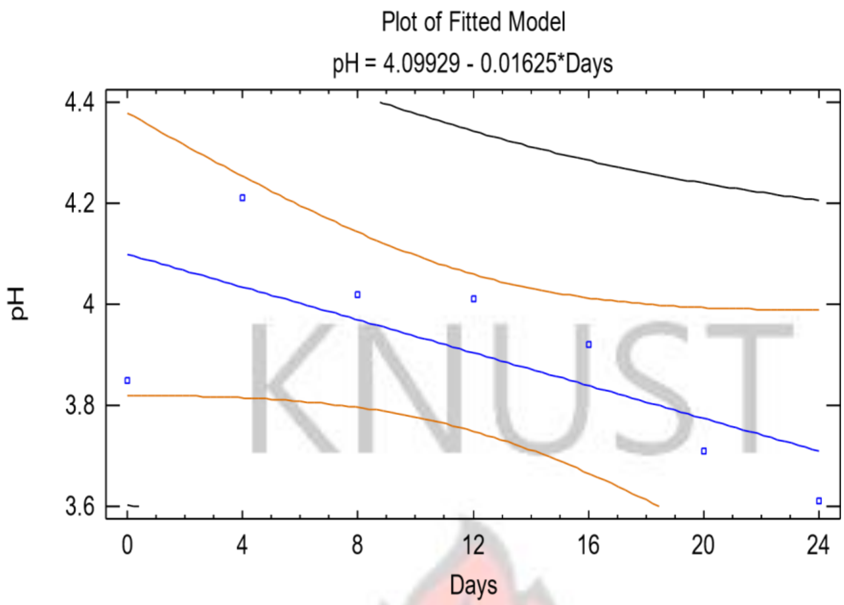
Comparison of Alternative Models

Model	*Correlation*	*R-Squared*
Reciprocal-Y squared-X	0.8384	70.29%
Logarithmic-Y squaredX	-0.8310	69.06%
Square root-Y squaredX	-0.8272	68.42%

Squared-X	-0.8232	67.76%
Double squared	-0.8149	66.40%
Reciprocal-Y	0.7047	49.67%
Exponential	-0.6996	48.94%
Square root-Y	-0.6969	48.56%
Linear	-0.6941	48.17%
Squared-Y	-0.6883	47.37%
Reciprocal-Y square root-X	0.4735	22.42%
Logarithmic-Y square root-X	-0.4678	21.88%
Double square root	-0.4649	21.62%
Square root-X	-0.4620	21.35%
Squared-Y square rootX	-0.4562	20.81%
Logarithmic-X	<no fit>	
Square root-Y logarithmic-X	<no fit>	
Multiplicative	<no fit>	
Reciprocal-Y logarithmic-X	<no fit>	
Squared-Y logarithmicX	<no fit>	
Reciprocal-X	<no fit>	
Square root-Y reciprocal-X	<no fit>	
S-curve model	<no fit>	
Double reciprocal	<no fit>	
Squared-Y reciprocal-X	<no fit>	
Logistic	<no fit>	
Log probit	<no fit>	

The StatAdvisor

This table shows the results of fitting several curvilinear models to the data. Of the models fitted, the reciprocal-Y squared-X model yields the highest R-Squared value with 70.2942%. This is 22.1208% higher than the currently selected linear model. To change models, select the Analysis Options dialog box.



Appendix D 3: pH model for vacuum package refrigerated

Simple Regression - pH vs. Days

Dependent variable: pH (VF)

Independent variable: Days (VF)

Linear model: Y = a + b*X

Coefficients

Parameter	*Least Squares Estimate*	*Standard Error*	*T Statistic*	*P-Value*
Intercept	3.87893	0.021354	181.648	0.0000
Slope	-0.015625	0.00148064	-10.5529	0.0001

Analysis of Variance

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Model	0.109375	1	0.109375	111.36	0.0001
Residual	0.00491071	5	0.000982143		
Total (Corr.)	0.114286	6			

Correlation Coefficient = -0.97828

R-squared = 95.7031 percent

R-squared (adjusted for d.f.) = 94.8438 percent

Standard Error of Est. = 0.0313392

Mean absolute error = 0.0212245

Durbin-Watson statistic = 1.65709 (P=0.1298)

Lag 1 residual autocorrelation = 0.0824935

The StatAdvisor

The output shows the results of fitting a linear model to describe the relationship between pH and Days. The equation of the fitted model is

pH = 3.87893 - 0.015625*Days

Since the P-value in the ANOVA table is less than 0.05, there is a statistically significant relationship between pH and Days at the 95.0% confidence level.

The R-Squared statistic indicates that the model as fitted explains 95.7031% of the variability in pH. The correlation coefficient equals -0.97828, indicating a relatively strong relationship between the variables. The standard error of the estimate shows the standard deviation of the residuals to be 0.0313392. This value can be used to construct prediction limits for new observations by selecting the Forecasts option from the text menu.

The mean absolute error (MAE) of 0.0212245 is the average value of the residuals. The Durbin-Watson (DW) statistic tests the residuals to determine if there is any significant correlation based on the order in which they occur in your data file. Since the P-value is greater than 0.05, there is no indication of serial autocorrelation in the residuals at the

95.0% confidence level.

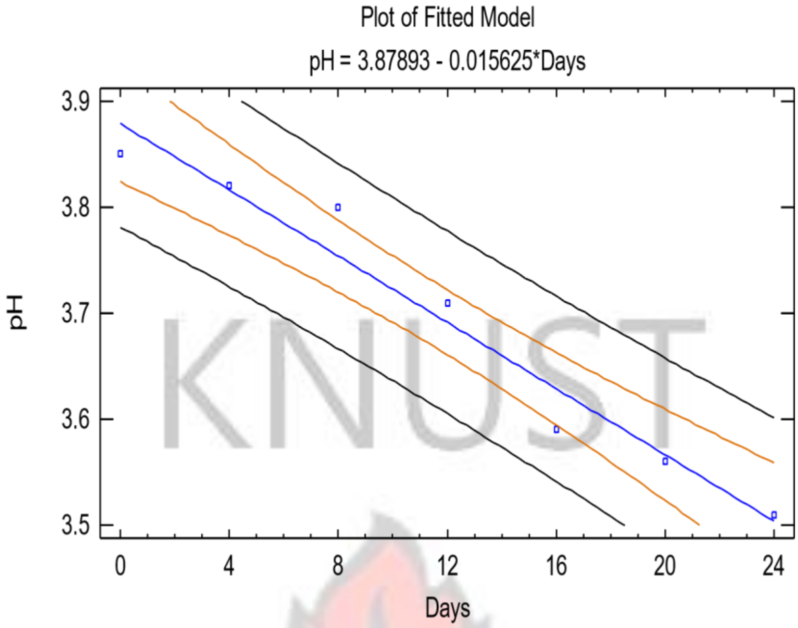
Comparison of Alternative Models

Model	*Correlation*	*R-Squared*
Squared-Y	-0.9787	95.78%
Linear	-0.9783	95.70%
Square root-Y	-0.9781	95.66%
Exponential	-0.9778	95.62%
Reciprocal-Y	0.9773	95.52%
Reciprocal-Y squared-X	0.9631	92.76%
Logarithmic-Y squaredX	-0.9609	92.34%
Square root-Y squaredX	-0.9598	92.13%
Squared-X	-0.9587	91.91%
Double squared	-0.9564	91.47%
Squared-Y square rootX	-0.9033	81.59%
Square root-X	-0.9007	81.12%
Double square root	-0.8993	80.88%
Logarithmic-Y square root-X	-0.8980	80.64%
Reciprocal-Y square root-X	0.8953	80.16%

Logarithmic-X	<no fit>	
Square root-Y logarithmic-X	<no fit>	
Multiplicative	<no fit>	
Reciprocal-Y logarithmic-X	<no fit>	
Squared-Y logarithmicX	<no fit>	
Reciprocal-X	<no fit>	
Square root-Y reciprocal-X	<no fit>	
S-curve model	<no fit>	
Double reciprocal	<no fit>	
Squared-Y reciprocal-X	<no fit>	
Logistic	<no fit>	
Log probit	<no fit>	

The StatAdvisor

This table shows the results of fitting several curvilinear models to the data. Of the models fitted, the squared-Y model yields the highest R-Squared value with 95.7764%. This is 0.0732349% higher than the currently selected linear model. To change models, select the Analysis Options dialog box.


Plot of Fitted Model
pH = 3.87893 - 0.015625*Days
3.9
3.8
3.7
3.6
3.5
pH
0
4
8
12
16
20
24
Days