

Application of a Cascade Refrigeration System for Storage of Hibiscus Tea (Zobo Drink) for Human Consumption

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ORIGINAL RESEARCH

Abstract- Since hibiscus tea is inexpensive, healthful, and has many nutritional benefits, individuals from various socioeconomic backgrounds frequently drink it. The main drawback of its large-scale manufacture is its short shelf life if not adequately chilled. In order to extend the shelf life of flavour-infused Zobo tea and conserve energy for mass production, the paper assesses the sensory properties of the tea in a cascade freezer and how much energy a convectional and cascade refrigeration system used. Within 120 minutes, a prepared hibiscus tea was frozen and kept at -15 °C for four days. After evaluation, the product's sensory quality was found to be suitable for ingestion. Over 72 hours, the natural flavour, colour, and taste of Zobo drinks did not change. The cascade freezer only required 3 kg of fuel for two hours of operation as opposed to 7.5 kg of gasoline for six hours of operation for the LG freezer. The quick deep-freezing process reduced fuel expenditures while preserving the product's short shelf life. The energy used by the cascade freezer was 1600 MJ at a cost of #24000 per month, as opposed to a total of 11200 MJ at a cost of #204000 per month. The cascade refrigerator saved 100.4 GJ of energy annually at a cost of #218600. The machine's effectiveness and energy efficiency were rated at 75%. The outcome has improved the cold storage supply chain for Zobo products for usage in emerging and developing nations on a commercial basis and saved energy.

Keywords- Cascade System, Zobo drinks, Shelf-life, Sensory, Energy consumption, Efficiency

1 INTRODUCTION

Making Zobo drink, a non-alcoholic beverage, involves boiling and sifting the dried petals of the hibiscus sabdariffa (Linn Roselle). After extracting the dried calyx of Hibiscus sabdariffa with hot water, (roselle) ginger, pine apples, and additional tastes are added as needed to make it into a non-alcoholic beverage. Popular among Nigerians, the Zobo drink is often requested for social gatherings and festivities, including weddings, birthdays, Thanksgivings, and naming ceremonies. Markets, school buildings, and parking lots all sell it.

Owing to the prohibitive cost of other readily available soft beverages, whose concentrates are expensive, hibiscus tea has become more popular among low-income countries, leading to a rise in sales and consumption. Due to its non-alcoholic nature, Zobo drink is extensively drunk across all socioeconomic levels (Ameh *et al.*, 2009). A source of oil, iced tea, food, and vegetables have all been made from the leaves, seeds, and calyces of the hibiscus plant (Omemu *et al.*, 2006). According to research, the calyces of the rosella plant are rich in nutrients and provide an optimal habitat for microbial development. They also include moisture, protein, lipids, ascorbic acid, calcium, riboflavin, niacin, and pigment (mainly anthocyanin) that give hibiscus tea its high nutritional value (Ezeigbo *et al.*, 2015).

Millions of individuals from all socioeconomic classes and backgrounds are now drinking the Zobo drink as a result of its increased popularity. The handling of the locally produced drink during manufacture remains a major source of worry, despite the fact that Zobo drink's popularity and usage are growing due to its nutritional and therapeutic advantages. Apart from production, packing, and storage conditions, there are additional sources of contamination that might lead to spoilage and low quality in the final product (Lund, 2009). Though the drink is more affordable than other bottle soft drinks and is frequently used for both financial and health-related reasons, its short shelf life, flavour loss, colour, and bacterial development after twenty-four hours after manufacture limit its acceptance (Braide *et al.*, 2012).

2 LITERATURE

2.1 IMPACT OF THE SPICE ADDITIVE ON HIBISCUS TEA

Spices are an excellent natural source of antiviral, anti-inflammatory, and immune-regulating chemicals. Like other herbs and vegetables, spices are rich in bioactive components called polyphenols, which can help control the immune system (Adeoye *et al.*, 2019). Phytochemicals, found in spices and vegetables but not regarded as essential nutrients, improve human health and aid in the prevention of disease (Oyewale *et al.*, 2020). Ginger (*Zingiber officinale*), alligator pepper, and "Atare" (*Aframomum danielli*) are among the natural and indigenous spices that are readily available in Nigeria. In the form of extract, paste, or dried powder, they are used to flavour a wide variety of foods, including soups, stews, juices, and drinks. Like agbo or aseje among the Yoruba, they are also utilized as medicine.

A freshly found local plant called alligator pepper is utilized temporarily to make COVID-19 medication (Egbuna and Ifemeje, 2015). Natural spices that have been

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added to the Zobo beverage increase its potential for immune support and health benefits. Thus, flavouring Zobo with spices creates a naturally refreshing drink free of any chemical additives, and regular intake could strengthen customers' immune systems to efficiently manage any sudden infections and diseases (Olarinde, 2022).

The short shelf life of the beverage (24 hours) if it is not refrigerated after preparation presents a problem for large-scale zobo manufacturing. Food-borne illnesses might proliferate in markets where zobo beverages are retailed and sold. Therefore, in order to ensure that zobo beverages sold in public areas have safe levels of zero organisms visible, it is imperative to develop efficient manufacturing procedures, post-production preservation methods, and packaging strategies (Builder *et al.*, 2010). The paper addresses the necessity for evaluating drinks in a cascade refrigeration system with extremely low temperature application, short deep-freezing duration, and simple chain of distribution mechanism at the doorstep of clients in large scale. The study evaluates a prepared sample at a fast freezing and storage-controlled temperature in a two-stage cascade refrigeration system using two environmentally friendly refrigerant combinations (R134a and R600a) in order to ensure sensory control and a secure cold supply chain for Zobo drinks management.

2.2 CASCADE REFRIGERATION SYSTEM FOR LOW TEMPERATURE APPLICATION

A multistage vapour compression refrigeration system (VCRS) with two stages is used in a cascade refrigeration cycle for ultra-low freezing applications. It is the most prevalent and effectively used technology for a wide range of daily activities, business, healthcare, and industrial production. Due to its numerous advantages in terms of human everyday requirements and scientific domains, this machine's uses have recently drawn interest from both academia and industry (Mouneer *et al.*, 2021). In order to lower and then maintain a temperature that is lower than the surrounding air, heat must first be removed from a body or enclosed space through the process of refrigeration. The single stage vapor-compression refrigeration cycles become unworkable for several food processing, storage, and preservation applications that demand moderately low temperatures with a sizably significant temperature and pressure differential (Shukla *et al.*, 2018).

Separating the refrigeration process into two or more phases is one way to handle such circumstances. Cascade refrigeration cycles are the term for these procedures. These processes are referred to as cascade refrigeration cycles. The heat released by the condenser in the lower system is extracted by the evaporator in the higher system through a cascade condenser that connects these two independent systems (Leonardo *et al.*, 2018).

The schematic diagram of a cascade refrigeration system is shown in figure 1 (Leonardo *et al.*, 2018). Exergetic Performance of a Household Refrigerator conducted a study on the energy analysis and optimization of R600a

as a replacement for R134a in a domestic refrigerator system using the Taguchi method and comparing R134a with R600a. In comparison to R134a, R600a performed better, and both refrigerants were environmentally friendly, according to the results (Joybari *et al.*, 2013).

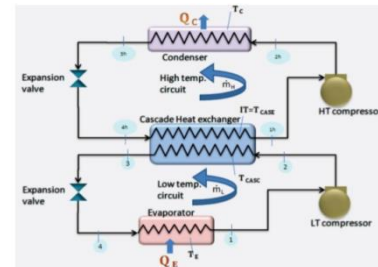


Fig. 1: Schematic diagram of a simple two stage cascade refrigeration system

2.3 REFRIGERANT SELECTION

The selection of eco-friendly R134a and R600a refrigerants in this study is purposely targeted rapid freezing and storing Zobo drink for shelf-life increase and high quality. The following factors were considered among others such as better mass flow rate, high refrigerating effect, high discharge pressure, short time for low-temperature attainment, zero Ozone Depletion Potential (ODP), affordability and availability. The physiochemical properties of the working fluid are shown in Table 1 (Akintunde, 2013).

Table 1. Physiochemical Properties of Selected Refrigerants

Properties	R134a	R600a
Chemical formula	CH ₂ FCF	C ₄ H ₁₀
Molecular weight (kg/m ³)	102.0	58.1
Melting point (°C)	-103.3	-159.6
Boiling point (°C)	-26.1	-11.7
Critical temperature(°C)	101.1	134.7
Critical pressure (bar)	40.6	3.7
Ozone Depletion Potential (ODP)	0	0
Latent heat of evaporation (kJ/kg)	215.9	386

3 MATERIALS AND METHODOLOGY

3.1 COLLECTION OF SAMPLES

The fresh ginger (*Zingiber officinale*) rhizomes, garlic bulbs, mature and dried alligator pepper (*Aframomum danielli*) pods, and dried red Hibiscus sabdariffa calyces were bought from the Ado market in Ekiti State, Nigeria. The samples had stones and other unwanted particles carefully removed. Following a thorough cleaning in sterile deionized water, the samples were left to air out at 40 °C in the sun.

3.2 PREPARATION OF GINGER, ALLEGATOR PEPPER AND GARLIC EXTRACTS

Using a clean, stainless-steel knife, 20 grams of alligator pepper, 100 grams of ginger, and 100 grams of garlic were separately diced into small bits. The chopped spices were then blended with 50 ml of deionized water in a blender

fitted with stainless steel blades to form smooth pastes. The pastes were further diluted with 100 ml of deionized water and then filtered through a clean Muslin cloth. The extracts were preserved in spotless plastic bottles and stored in a cascade refrigerator until they were needed for zobo production (Adesokan *et al.*, 2013).

3.3 PREPARATION OF ZOBO DRINKS AND STORAGE

After 10 minutes of boiling, the resultant extracts were allowed to stand for 15 minutes. Using a white muslin cloth, the heated, red-coloured aqueous extract was finely filtered into a plastic basin. After adding sugar and stirring until it dissolves, the result is a drink known as zobo. The beverages were allowed to cool to ambient temperature before being placed in sterile bottles and swiftly chilled in a two-stage cascade refrigerator utilizing R134a and R600a at -15 °C as shown in Figure 2. The products were then kept in a temperature-controlled environment for 96 hours until further analysis on sensory characterization was completed (Adeniji, 2017).



Fig. 2: Two-Stage Cascade Refrigeration System

Equation 1 was utilized to calculate the energy usage of the systems, analyse the financial effects, and display the findings (Oginni *et al.*, 2017).

$$\text{Energy Consumed} = \text{Heating value} \times \text{Fuel mass} \quad (1)$$

The overall cascade system performance was determined by equation 2.

$$COP_{cas} = \frac{\text{Refrigerating effect}}{\text{Compressor work input}} \quad (2)$$

4 RESULTS AND DISCUSSION

The composition detailed of the materials used in kilograms and centilitres relative to the rate of refrigerating effect with time were shown in Table 2. The freezing temperature of -15 °C was attained at different loads. It took the cascade refrigerator 85 minutes to freeze 1 kg of Zobo bottle to -15 °C whereas 12 kg (1200 cl, 16 bottles at 50 cl each) was frozen at -15 °C for two hours. The freezing time is directly proportional to load. However, the increase in time of freezing is lower compared with convectional freezers.

Table 2. Mass of Zobo and Time of Freezing at -15 °C

Mass (kg)	Zobo (cl)	Bottle	Time (Min)
1	100	2	85
4	400	8	90
8	800	16	100
12	1200	24	120

Table 3 presents the sensory characteristic of spiced hibiscus tea in terms of taste, colour, flavour and overall acceptability for the tea. Refrigerating flavoured zobo tea is likely to be acceptable by the general population if well preserved. The popular choice of refrigerated product is commonly utilized in most Nigeria households. On comparison, the sensory of raw zobo drinks (6.20, 6.50, 6.60 and 5.30) was lower than freezing responses (6.60, 6.80, 7.30 and 7.40) respectively. The cascade freezer retained the sensory hibiscus tea qualities for 72 hours.

Table 3. Sensory Features of Flavoured Raw and Frozen Hibiscus Tea

Parameter	Before freezing	Storage assessment after freezing (Days)			
		Raw	1	2	3
Taste	6.20	6.60	6.60	6.56	5.20
Colour	6.50	6.80	6.80	6.78	5.30
Flavour	6.60	7.30	7.30	7.26	6.80
Acceptability	5.30	7.40	7.40	7.40	7.00

The energy consumption of a convectional and cascade refrigeration system was compared in order to evaluate the system's efficiency as presented in Table 4. In contrast to the LG Thermocool freezer, which required 7.5 kilograms of gasoline to run for six hours, the cascade freezer only required 3 kg of fuel and a 3 KVA generator. Fuel for the convectional freezer cost #2,480, while the cascade freezer had ten days in a month at freezing energy retention of 1600 MJ. On the other hand, to keep the Zobo product at the necessary ultra-low temperature, the LG freezer used 11200 MJ of energy throughout a thirty-day period of daily operation. It is evident from Table 2 that the LG freezer costs #204000 to run for 30 days, but the cascade refrigerator costs #24000. This is a better application in developing nations where the power supply is epileptic. Operating the cascade system costs #301000, an annual difference from the #2464300 overall cost of the LG freezer. The typical refrigerator used 120 GJ of electricity, but the cascade only used 18 GJ. Throughout the trial period, the cascade freezer conserved 100.4 GJ of energy per year.

Table 4. Analysis of Fuel Cost and Energy Consumption

Freezer	MF (kg)	RT (hr)	FC (k#)	RT /D	RT /M	TEC (GJ)	TC (k#)
Trad.	7.5	6	6.82	1	30	11.2	204
Casc.	3	2	2.48	3	10	1.6	24

Where; Trad. = traditional, Cas. = Cascade, MF = mass of fuel, RT = Running time, FC = fuel cost, D = day, M = month, TEC = total energy consumption, TC =total cost, k = kilo (1000), G = giga, hr = hour

The results of the proximate analysis of prepared Zobo drinks before freezing is shown in Figure 3. The raw content of water, ash, fat, protein and carbohydrate were 88.3 %, 0.67 %, 0.76 %, 1.78 % and 8.47 % respectively. Water has the highest value of 88.3 %, followed by carbohydrate with (8.47 %), protein (1.78 %), fats (0.76 %), ash (0.67 %) in that order.



Fig. 3: Results of Proximate Analysis of Prepared Zobo before Freezing

Figure 4 showed the results of proximate analysis of prepared Zobo drinks after freezing at 72 hours storage. The content of water, ash, fat, protein and carbohydrate were 88.3 %, 0.67 %, 0.76 %, 1.78 % and 8.47 % respectively. Water has the highest value of 88.3 %, followed by carbohydrate with (8.47 %), protein (1.78 %), fats (0.76 %), ash (0.67 %) in that order.

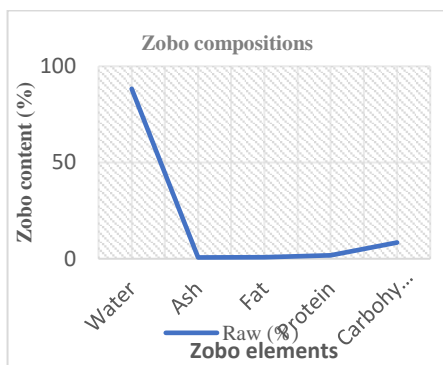


Fig. 4: Results of Proximate Analysis of Prepared Zobo at Frozen Storage

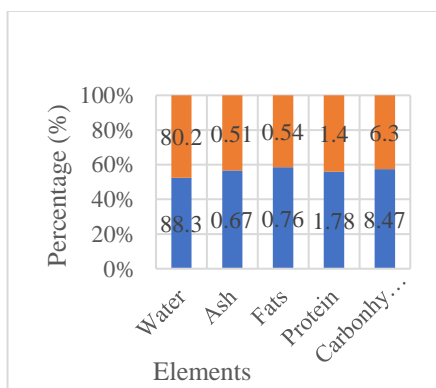


Fig. 5: Product Assessment in Day 3 and Day 4 of Storage

Figure 5 presents the comparison of refrigerated flavoured hibiscus tea between 72 hours and 96 hours of controlled-storage using cascade freezer. A fall in water content (88.3 to 80.2 %) was noted. Other elements have similar denaturization in values as ash (0.67 to 0.51 %), fats (0.76 to 0.54 %), protein (1.78 to 1.4 %) and carbohydrate (8.47 to 6.3 %) respectively. This implies

that, when stored at a regulated temperature, the cascade system would effectively retain the product content for 72 hours by extending its short shelf life. A refreezing process is required after three days.

5 CONCLUSION

The cascade refrigeration system was used to freeze prepared Zobo drinks at -15 °C for two hours and stored at temperature-controlled. The system extended the short shelf-life of the fresh Zobo drinks and retained its qualities over three days. The findings of this study showed that, in addition to flavour, taste, and colour, natural spices, quick freezing and temperature-controlled storage improve the well-known health benefits of Zobo. In terms of temperature control, the product's storage prolongs its limited shelf life with no energy. The taste, colour, and flavour boosts while continuous freezing application stopped. The temperature-regulated storage improved zobo beverages for acceptability.

The machine's effectiveness and energy efficiency were rated at 75%. The study's remarkable feat of refreezing after two hours a day and keeping the proper freezing temperature for three days without the need for electricity was impressive for mass production. While the LG freezer needed 7.5 kg of gasoline to run for six hours, the cascade freezer only needed 3 kg for two hours of operation. The product's limited shelf life was preserved while fuel costs were decreased by the rapid deep-freezing technique. Compared to a total of 11200 MJ at a cost of #204000 per month, the energy utilized by the cascade freezer was 1600 MJ at a cost of #24000 per month. At a cost of \$218600, the cascade refrigerator produced an annual energy savings of 100.4 GJ. The outcome has improved the cold storage supply chain for Zobo products for usage in emerging and developing nations on a commercial basis and saved energy.

One remarkable aspect of this study was its capacity to refreeze after 72 hours and to keep the temperature below freezing for days in the absence of an electrical supply. This would greatly improve the cold storage supply chain for Zobo products for usage in emerging and developing nations on a commercial basis and save energy. Hibiscus sabdariffa is a spice crop bred for economic sustainability and job creation at low-cost.

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