GUMMY CANDY ENRICHED WITH BETA-CAROTENE FROM ORANGE-FLESHED SWEET POTATO AND MANGO

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ABSTRACT

Vitamin A deficiency (VAD) is a prevalent public health challenge in Uganda, especially among children and women, making the development of food-based interventions necessary. This study aimed to develop beta-carotene-fortified gummy candies using orange-fleshed sweet potato (OFSP) and mango by optimising the formulation of the candy with respect to consumer acceptability and analysing the beta-carotene and vitamin A content of the optimised formulation. An experimental design was used, particularly Response Surface Methodology (RSM) was used to optimise the ingredients, i.e Orange Fleshed Sweet Potato (OFSP), gelatin, and honey. Beta-carotene content was analysed using UV-Vis spectrophotometry. The optimised formulation contained 68.6% OFSP, 5.50% gelatin, and 15% honey and beta-carotene content of 3.225 ± 0.003 mg/kg, which is 26.9 µg RAE/100g, providing only 6.7% of a child's daily vitamin A requirement. Further research should investigate beta-carotene retention during processing and storage, and comparison tests with other commercial products should be done. This study can improve food biofortification and food nutrition security.

DECLARATION

I, NOWEMIGISHA ISABEL hereby declare that this is my original work, is not plagiarised and has not been submitted any other institution for any award.

Student's name: Nowemigisha Isabel **Signature**: **Date:**14/04/2025

APPROVAL

This dissertation had been written by NOWEMIGISHA ISABEL under my supervision and is ready for submission to Uganda Christian University the award of Bachelor of Science in Food Science and Technology.

Supervisor: Miss Ngonzi Doris **Signature:** **Date:** 14/04/25

DEDICATION

This dissertation is dedicated to my parents, Dr. Martha Kyoshaba Twinamasiko and Dr. Twinamasiko Nathan.

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LIST ACRONYMS AND ABBREVIATIONS

1. **ANOVA** – Analysis of Variance
2. **AOAC** – Association of Official Analytical Chemists
3. **BIBD** – Balanced Incomplete Block Design
4. **CAGR** – Compound Annual Growth Rate
5. **DF** – Degrees of Freedom
6. **FAO** – Food and Agriculture Organization
7. **H0** – Null Hypothesis
8. **IOM** – Institute of Medicine
9. **MAAIF** – Ministry of Agriculture, Animal Industry and Fisheries
10. **NDP III** – National Development Plan III
11. **OFSP** – Orange-Fleshed Sweet Potato
12. **RAE** – Retinol Activity Equivalents
13. **RSM** – Response Surface Methodology
14. **SDGs** – Sustainable Development Goals
15. **SE** – Standard Error
16. **UCU** – Uganda Christian University
17. **UDHS** – Uganda Demographic and Health Survey
18. **UIRI** – Uganda Industrial Research Institute
19. **UBOS** – Uganda Bureau of Statistics
20. **UV-Vis** – Ultraviolet-Visible
21. **VAD** – Vitamin A Deficiency
22. **VAS** – Vitamin A Supplementation

23. **VIF** – Variance Inflation Factor

24. **WHO** – World Health Organization

CHAPTER ONE

1.0 GENERAL INTRODUCTION

1.1. Background

“Vitamin A deficiency (VAD) is a significant public health issue in Uganda, with 28% of pregnant women and 38% of children under the age of five years” (WHO Uganda, 2022). VAD has the effects of weakened immune function, night blindness, and high mortality rates among children (WHO, 2021; UNICEF, 2023). Vitamin A Deficiency (VAD) is the top cause of avoidable blindness in children and a main influencer of the function of the immune system. Globally, Uganda is among the top countries in terms of VAD prevalence (Mclaren et al., 2020). Current interventions to address VAD like VAS programs and biofortification of foods like orange-fleshed sweet potatoes (OFSP), have been partly successful but face challenges like logistical limitations and community resistance (UBOS, 2023). The acceptance of OFSP is restricted by cultural preferences for white-fleshed varieties and lack of processing facilities (Mwanga et al., 2020).

Foods classified as functional foods, which are foods fortified with bioactive substances, are increasingly being viewed as sustainable solutions to micronutrient deficiencies. In 2023, the functional gummies market worldwide was worth $12.3 billion, with predictions of a CAGR of 7.2% (Statista, 2023). Gelatin confectionery gummy candy has gained popularity across the globe due to its chewable nature, range of flavors, and ease of consumption (Parker et al., 2003). The major components of gummy candy are gelatin, which contributes to its elastic and jelly-like consistency, sweeteners, acidifiers like citric acid, flavoring agents, and water. Uganda is highly dependent on imported gummy candies, which are high in sugars and low in nutritional content, yet domestic production of gummies is low (Tumwegamire et al., 2018). Gummy candies offer better protection to delicate nutrients such as beta-carotene, with gummy candy retaining approximately 20-30% more beta-carotene during processing and storage (Mercadante, 2019). Compared to hard candies, which may lead to choking, and chocolate, which is sensitive to temperature, gummy candies have a less variable and chewy texture that is acceptable to most age groups (Parker et al., 2003).

The research gap and opportunity being addressed is the lack of commercially available gummy candies enriched with beta-carotene that specially address vitamin A deficiency in Uganda. There's also a lack of studies led in Uganda that precisely assess the consumer acceptability of gummy candies enriched with beta-carotene. This research seeks to utilize Uganda's beta-carotene-rich staple foods, i.e. OFSP and mango, to develop a beta-carotene-rich gummy candy that is a possible food-based solution to combat VAD. Neela and Fanta (2019) quantified OFSP's β-carotene content to be 1,600 µg per 100g in raw roots. OFSP has been recognized as a major crop for combating VAD (Mwanga et al., 2020). Mango, contains 550 µg of β-carotene per 100 g and about 77.71 mg of vitamin C per 100 g of fresh pulp. Vitamin C improves the bioavailability of beta-carotene, which is important for its antioxidant properties and health benefits (Ribeiro et al., 2018). It does this while improving the sensory acceptability of food products naturally since it is sweet and has a good flavor (Dwyer et al., 2015).

In this study, honey is used as the natural sweetener and antimicrobial agent. The enzymes, flavonoids, and phenolic acids in honey have antioxidant and anti-inflammatory activities, making honey more than just a sugar substitute (Chua et al., 2021). The gummy texture of confectionery is due to gelatin, a protein got from collagen (Khan et al., 2022). Citric acid is used as a preservative that ensures pH balance and ensures the stability of beta-carotene and gelling processes (Tariq et al., 2023).

The study also seeks to add value to the named staple foods while improving nutritional security (MAAIF, 2021) by using these underutilised crops into enriched gummies in alignment with Uganda's National Development Plan III (2020–2025).

Beta-carotene was used rather than vitamin A because of its safety profile, stability, and additional health benefits, e.g. antioxidant properties (Mercadante, 2019). Beta-carotene is converted to Vitamin A in the human body when needed hence avoids vitamin A toxicity risks (Mercadante, 2019). Gummy confectionery is more appealing in comparison to the conventional methods of nutrient delivery, i.e. capsules or tablets, and therefore encourages consumption by children and adults (Dwyer et al., 2015). Beta-carotene is highly prone to environmental conditions like light and heat, both during storage and processing. Thus, the use of optimal processing like low storage temperatures at 3°C is necessary to achieve maximum retention of nutrients (Rodriguez-Amaya, 2019).

1.2. Problem statement

There are currently no commercially available candies enriched with beta-carotene which specifically address Uganda's nutritional need of vitamin A deficiency (Tumwegamire et al., 2018). Vitamin A supplementation programs face various limitations (Low et al., 2007). With the increased concerns about the high sugar levels in conventional confectionaries, demands have increased for confectionaries that are not just sugar-free but also naturally sweetened (Statista, 2022). Optimizing the composition of key ingredients like OFSP, honey, and gelatin for gummy candy is important to get high consumer acceptability that enables wide acceptance and contains high beta-carotene levels. Additionally, there are no studies based in Uganda that specifically determine the consumer acceptability of gummy candies fortified with beta-carotene. This research aims to bridge these gaps by developing a locally available, beta-carotene-rich gummy candy, that can be a potential food-based solution to combat VAD in Uganda.

1.3. Objectives of the study

1.3.1. Main objective

To develop a nutritionally enhanced gummy candy fortified with beta-carotene from orange-fleshed sweet potato and mango.

1.3.2. Specific objectives

1. To optimize the ingredient formulation of OFSP, honey and gelatin of the gummy candy with respect to consumer acceptability.
2. To determine the beta carotene content and vitamin A content of the optimized enriched gummy candies.

1.4. Research questions /hypothesis

H0: There is no relationship between consumer acceptability and the ingredient formulation of OFSP, honey and gelatin of the enriched gummy candy.

What is the beta carotene content and vitamin A content of the optimized, enriched gummy candy?

1.5. Rationale / justification of the research

This study presents a new food-based strategy for fighting VAD by using locally available foods in Uganda. By developing functional gummy candies enriched with beta-carotene from these staple crops, this study provides a palatable way of enhancing dietary beta-carotene intake among vulnerable groups, particularly children (Dwyer et al., 2015). Gummy candies can be distributed by already existing health programs and school feeding initiatives, thus ensuring wider reach and lasting impact. Additionally, this research studies the value addition to the agricultural produce and reducing the post-harvest losses, which are estimated to be 15–30% for OFSP in Uganda (Mwanga et al., 2020). Utilizing these surplus crops in gummy candy production can boost farmers' incomes and promote agricultural sustainability. This is in line with Uganda's National Micronutrient Strategy and Sustainable Development Goals (SDGs), SDG 2 on Zero Hunger which “aims to end all forms of malnutrition” (United Nations, 2015).

1.6. Significance of the study

This study is significant in its contribution to many stakeholders. For Ugandan consumers, especially children and women of reproductive age, the developed gummy candies offer an accessible and enjoyable way to increase beta-carotene intake, potentially reducing VAD prevalence and improving their overall health. (Bhutta et al., 2013). For local farmers growing OFSP and mango, this study has the potential to increase demand for the crops and reduce their losses, which will in turn improve livelihoods (Mwanga et al., 2020). Processors and food manufacturers would benefit through the development of the value-added product which will reduce the dependence on imported confectionery and increase the growth of the agro-processing sector (Uganda National Agro-industrialization Policy, 2020). The Ministry of Health and other public health organizations can use the findings to inform decisions on policies and program implementations related to micronutrient deficiencies and food fortification strategies. This study contributes to academia in functional foods and provides insights into optimizing ingredient formulations for enhanced nutritional content and consumer acceptability (Rodriguez-Amaya, 2019). The results can be used for future research on new food products and interventions to address malnutrition in Uganda. This research can inform Uganda's National Food and Nutrition Policy and contribute to efforts that aim to achieve Sustainable Development Goal 2 (Zero Hunger) and Sustainable Development Goal 3 (Good Health and Well-being).

1.7. Scope of study

This study's focus is the development of enriched gummy candy as the main outcome, while applying principles of food science that include food product optimisation, nutrient analysis, and consumer acceptability. This research was carried out in Uganda Christian University- Mukono Food and Nutrition Laboratory between January and April 2025, whereas laboratory analyses were carried out within the same period.

1.8. Conceptual Framework

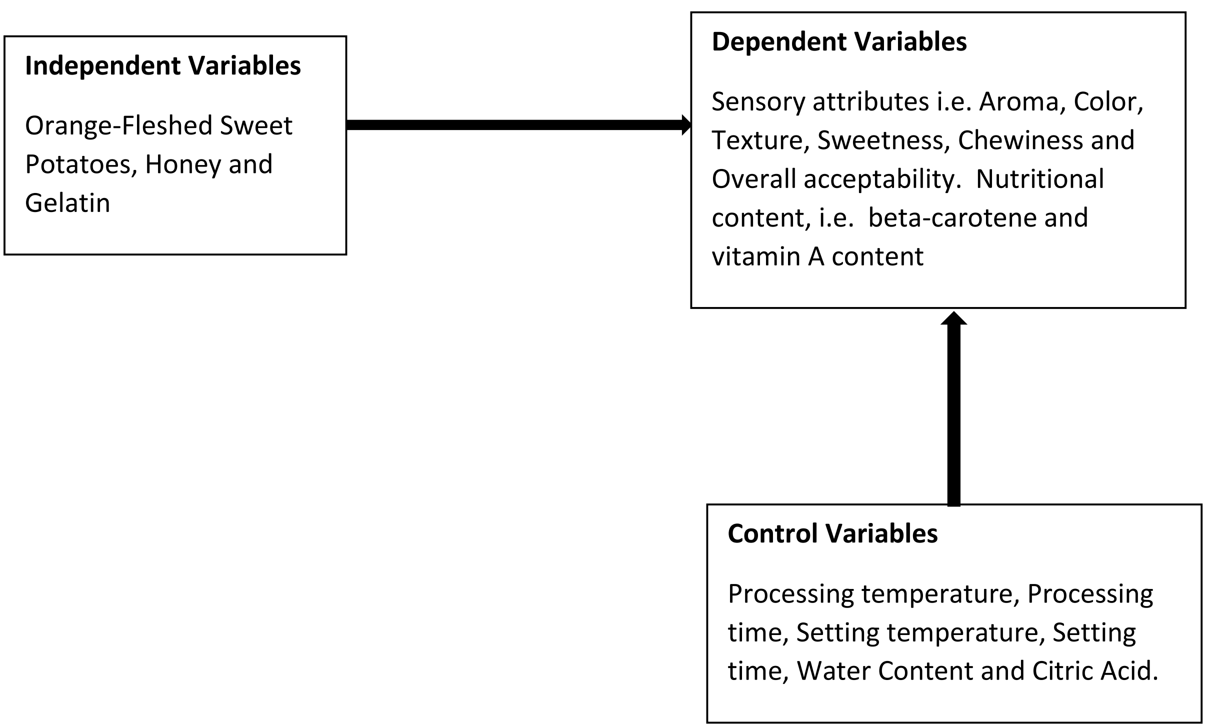

Figure 1; Conceptual framework

CHAPTER TWO

2.0. LITERATURE REVIEW

2.1. Introduction

This literature review covers the public health significance of VAD, potential of gummy candy to act as a method for nutrient delivery, functional characteristics of the key ingredients, the stability of beta-carotene during processing, formulation optimization, and consumer acceptance.

2.2. Vitamin A deficiency

National surveys show that 28% of pregnant women and 38% of children below five years of age suffer from VAD, making it a public health priority in Uganda (WHO Uganda, 2022). VAD is associated with many adverse health effects, including xerophthalmia, which can cause permanent blindness, weakened immune function, and higher vulnerability to infectious diseases (Sommer & West, 1996). Approximately 23% of preventable child deaths in Uganda result from vitamin A deficiency, and thus, it is one of the significant drivers of the nation's under-five mortality rates (UDHS, 2022). Several factors are accountable for the high prevalence, including reliance on staple foods that are low in vitamin A precursor (Tumwegamire et al., 2018), limited consumption of animal-source foods (HarvestPlus, 2021. Current interventions have certain limitations, such as food fortification initiatives having certain quality assurance issues (Allen et al., 2006); Vitamin A supplementation programs reaching only 68% (UNICEF Uganda, 2022). Cultural constraints limit efforts in improving dietary diversity (Low et al., 2007). All these limitations stress the need for interventions meant for high-risk populations, especially children 6-59 months old who have the highest deficiency rates (WHO Uganda, 2022).

2.3. Gummy candies

Gummy candy is a great method of providing vital nutrients. Its chewy consistency and sweet flavor make it more attractive to children compared to conventional methods like pills or syrups (Lautenschläger et al., 2018). They also have greater protection to volatile nutrients like beta-carotene when compared to liquid-based formulations, by keeping approximately 20-30% more of these nutrients (Mercadante, 2019). Gummy candies allow accurate dosage control (Augustin & Sanguansri, 2008). In addition, they are easy to produce and do not require a lot of equipment, thus great for small-scale production (Parker et al., 2003). Gummies are more heat-stable than chocolate and have less choking risk compared to hard candies (Cairns et al., 2013). All this makes gummy candies a great choice for the delivery of beta-carotene to those in need in Uganda.

2.4. Key ingredients and their functional properties

2.4.1. Orange-Fleshed Sweet Potato (OFSP)

Table 1; Proximate analysis of OFSP

Component	**Amount (g/100g)**
Moisture	64.5–70.4
Ash	1.2–1.5
Crude Protein	1.8–2.1
Crude Fat	0.3–0.5
Crude Fiber	2.5–3.0
Carbohydrates	24.0–26.0
ß-Carotene	1,600 µg

OFSP is a vital source of ß-carotene (a provitamin A carotenoid). Ugandan OFSP has 1,600 µg of ß-carotene per 100g in raw roots thus making it a good option for addressing vitamin A deficiency (VAD) (Neela & Fanta, 2019). Its high moisture content (64.5–70.4%) and moderate carbohydrate (24–26%), make it appropriate for gummy candy formulation because of its structure and natural sweetness. The low value of dietary fiber (2.5–3.0%) and essential minerals (ash of 1.2–1.5%) reduces their interfering with the texture and flavor. These characteristics support the addition of OFSP into value-added products while tackling Uganda's agriculture and public health goals (MAAIF, 2021).

2.4.2. Mango

Table 2; Proximate analysis of mango

Component	Amount
Moisture	83.5 g
Protein	0.6 g
Fat	0.4 g
Ash	0.3 g
Fiber	1.7 g
Carbohydrates	14.5 g
Total Sugars	13.9 g
β-Carotene	550 µg

Mango, a tropical fruit widely cultivated in Uganda, contributes complementary nutritional and functional properties to the gummy formulation. Sivakumar et al. (2022) reported that ripe mango pulp contains 550 µg of β-carotene per 100 g, enhancing the candy's provitamin A content. Its high moisture (83.5 g) and natural sugar content (13.9 g) improve its palatability and texture by acting as a natural humectant and sweetener. However, mango's low protein (0.6 g) and fiber (1.7 g) make it necessary to include gelatin to achieve the desired chewiness and structural stability in gummy candies.

Together, the OFSP and mango purees are used in precise amounts to deliver the ideal nutrients rather than including them as separate ingredients. This mixture enables the gummies to be both healthy and easy to make.

2.4.3. Honey

Table 3; Proximate analysis of honey

Component	Amount
Moisture	17.2 g
Protein	0.3 g
Fat	0.0 g
Ash	0.2 g
Carbohydrates	99.7 g
Total Sugars	99.5 g

Honey serves as a natural alternative to refined sugars in the gummy candy formulation. Khalil et al. (2021) demonstrated that raw honey is made up of 99.7 g of carbohydrates per 100 g, of which 99.5 g are reducing sugars (glucose and fructose). This high sugar concentration ensures sweetness while also acting as a humectant to retain moisture (17.2 g) and extend shelf life by aiding in hindering the growth of bacteria. Its low value of protein (0.3 g) and fat (0.0 g) inhibit interference with gelatin's gelling properties thus guaranteeing ideal texture. The substitution of conventional sweeteners with honey lets the gummies maintain the preferred taste and flavor without causing a noticeable effect on blood sugar levels (Bogdanov et al., 2019).

2.4.4. Gelatin

Table 4; Proximate analysis of gelatin

Component	Amount
Moisture	12.5 g
Protein	87.0 g
Fat	0.5 g
Ash	1.0 g
Carbohydrates	0.0 g

Gelatin is a major structural agent in gummy candies. It has a high protein content (87.0 g) and low moisture (12.5 g), as reported by Zhang et al., (2020). This protein forms temperature-sensitive gels while cooling which gives the elastic texture expected in gummy candies. The low carbohydrate content (0.0 g) ensures it does not compete with OFSP or mango for sweetness, and its low fat content (0.5 g) prevents lipid oxidation, ensuring product stability. With specified bloom strength and concentrations, gelatin makes a stable network that condenses the puree and sweeteners which strengthens the structure (Karim & Bhat, 2021).

2.4. Gummy candy making process

The production of the gummy candies involved established techniques in the following key steps. First, fresh orange-fleshed sweet potatoes (OFSP) were washed before being peeled and chopped into smaller pieces. The chopped OFSP were then boiled in water until tender and mashed with a mechanical masher until a smooth puree was got. Ripe mangoes were also washed and peeled, and the pulp was pureed using a hand blender until smooth. The OFSP and mango purees were combined in predetermined ratios, ensuring the total puree volume equals to 100% of the puree component in each formulation.

Next, gelatin powder was hydrated by combining it with water at 60°C in a specified ratio of 1:5, allowing the mixture to stand for approximately 15 minutes to fully hydrate the gelatin granules (See et al., 2020). The purees, hydrated gelatin, honey, water and citric acid were all mixed in a saucepan. The mixture was heated to 55°C with constant stirring for 10-15 minutes to ensure complete dissolution of the ingredients and even distribution of beta-carotene (Cairns et al., 2013). Food-grade silicone molds which were oiled with sunflower oil to prevent sticking, were then filled with the mixture. The molds were transferred to a refrigerator and stored at approximately 3°C for a minimum of 2 hours to allow the gelatin to set and the candies to solidify. Once the candies were firm, they were removed from the molds and stored in transparent, dry, airtight containers at 3°C in the dark to minimize exposure to light and moisture to reduce beta-carotene degradation and loss of quality (Rodriguez-Amaya, 2019).

2.5. Functional candy in mitigating nutrient deficiencies

Functional candies address nutrient deficiencies while offering accessibility, palatability and addition of essential nutrients (Parker et al., 2003). Functional candies have been successfully used to mitigate nutritional deficiencies by taking advantage of their palatability and ease of consumption to follow dietary recommendations. Gummy confections, especially have a potential to provide micronutrients especially among children (Lautenschläger et al., 2018).

Studies have shown that beta-carotene from OFSP has high bioavailability when used in a lipid-rich method, which is found in the gelatin-honey combination of the formulation (De Moura et al., 2015). The combination of mango vitamin C and OFSP beta-carotene improves absorption and protects against oxidative degradation thus improving nutrient delivery (Dwyer et al., 2020). The semi-solid structure improves beta-carotene bio accessibility by easing the micellarization of the lipophilic compounds (Bechoff et al., 2020). The honey improves the nutrient solubility and absorption through its lipid content. Each dose of the gummy candy provides an approximate amount of vitamin A activity, which reduces dosing uncertainties found with customary supplementation (WHO, 2021).

Sensory studies have also shown that mango-flavored gummies improve the acceptance rates among children as high as 85%, which is considerably higher than those for traditional vitamin A supplements (Chong et al., 2023).

2.7 Beta-carotene enrichment

The gummy candy formulation uses beta-carotene fortification from natural dietary sources rather than direct vitamin A fortification for several reasons. As a provitamin A carotenoid, beta-carotene goes through regulated conversion to retinol within the body, thus considerably reducing the risk of hypervitaminosis (Vitamin A toxicity) (Rodriguez-Amaya, 2019). Beta-carotene is a potent antioxidant, even without its vitamin A activity. It reduces the risk of chronic diseases and oxidative stress

(Mercadante, 2019). Studies have shown that naturally enriched beta carotene products enriched carotene have 20-30% higher consumer acceptability compared to those with synthetic fortificants (Amos et al., 2020). This enrichment method supports local agriculture by using local crops and reducing dependence on imported ingredients (HarvestPlus, 2021). Beta-carotene in its natural food has improved bioavailability and stability due to the protective effects of related compounds in the plant tissues (Augustin & Sanguansri, 2008). This maximizes the nutritional benefits of the gummy candy by providing ideal nutrient retention and absorption .

2.8 Product optimization methodology

Product optimization uses Response Surface Methodology (RSM), particularly, the D-Optimal Design to get a complete assessment of numerous variables and their interactions. It facilitates the orderly study of ingredient ratios and their impact on the characteristics of the product (Srisawat & Thongngam, 2018). The main independent variables being investigated are OFSP puree concentration (ranging from 60-80%), gelatin concentration (4-8%), and honey level (5-15%). These ranges were chosen based on literature reviews to ensure viable and palatable gummy formulations. The key response parameters to be measured are sensory attributes, which are assessed using a 9-point hedonic scale (Luning et al., 2020). The scale considers the consumer perceptions of different sensory characteristics and gives a better understanding of the product acceptability. To ensure reliability and reduce experimental error, all experimental trials are run in duplicates. Statistical analysis is conducted using Minitab software version 22 to generate response surfaces and detect the optimal ingredient combinations (Myers et al., 2016). The ingredient proportions at which desired physical properties like texture and colour together with sensory acceptability intersect are determined. TThus the final product meets specifications but also satisfies consumer preferences (Srisawat & Thongngam, 2018).

2.9 Consumer acceptability

Sensory testing analyses the consumer acceptance which then determines the success of the food product (Stone et al., 2012). To guarantee reliability and validity of the results, sensory evaluation panels consist of at least 30 untrained panelists, that represent the target consumer population (Nestel et al., 2006). During sensory testing, samples are served under controlled environmental conditions to minimalize external effects on perception. Samples are coded with randomized digit numbers to prevent bias and ensure fair assessment (Lawless & Heymann, 2010). A 9-point hedonic scale is used to assess numerous sensory attributes like appearance, aroma, sweetness, chewiness, texture and overall acceptability (Amos et al., 2020). Collected data is analyzed using statistical methods like ANOVA and regression analysis to determine the main factors affecting the consumer acceptance and find areas for improvement (Gacula & Singh, 2008).

CHAPTER THREE

3.0. METHODOLOGY

3.1. Research design

This study used a mixed-methods approach, that has both quantitative and qualitative aspects.

To optimize the formulation, a D-optimal response surface methodology (RSM) design was used with Minitab software (Version 22). RSM investigates the variables and their interactions, to identify the optimal ingredient combinations for the preferred product characteristics (Myers et al., 2016). The D-optimal design was chosen to best design the least number of experimental trials while having enough statistical validity (Montgomery, 2017). This design is ideal for analysing the effect of the three continuous independent variables i.e. orange-fleshed sweet potato (OFSP) puree concentration (60-80% w/w), gelatin level (4-8% w/w), and honey level (5-15% w/w).

During formulation, the amount of OFSP to mango puree was determined so that the combination of both always totaled 100% of the puree component. Mango was used to mask the earthy taste of OFSP, which can be a limitation to consumer acceptability among children (Woolfe, 1992). While OFSP was the major source of beta-carotene, mango also contributed to the beta-carotene content of the gummy candy and also provided vitamin C, which improves the beta-carotene bioavailability (Rodriguez-Amaya, 2019). Adjusting the mango puree level to complement the OFSP puree level, all while maintaining the total puree concentration made it possible to control the changes in texture and sweetness that could be caused by changing the overall puree content.

This methodology is also used with a component of a fixed blend to optimize formulations while achieving particular sensory or nutritional goals (Sharma et al., 2017). Here, one component is used to improve the overall product without being a major variable under investigation, this allows better experimentation and specified product development.

During consumer acceptability testing, a Balanced Incomplete Block Design (BIBD) was used. Each panelist evaluated a subset of samples, instead of all possible formulations. This reduces sensory fatigue (Lawless & Heymann, 2010). Each panelist evaluated six randomly arranged samples for each formulation of the total design. Two complete replicates of the evaluation were done to reduce the sensory fatigue and ensure each formulation had an equal opportunity for evaluation. This allowed detailed sensory data with reduced biased responses.

3.2. Area of the study

The study was done at the Uganda Christian University Food and Nutrition Laboratory in Mukono District, Uganda.

3.3. Sources of information

The primary data was collected by experimentation and consumer acceptability testing. The experimental data was made up of twenty formulation runs produced with a D-optimal design., Each formulation run was prepared and evaluated for consumer acceptability. Consumer acceptability data was collected from 30 panelists using a standardized consumer acceptability testing form. Secondary data included published protocols for the analysis of beta-carotene and gummy candy production methods (Parker et al., 2003) obtained through research articles and laboratory reports. More secondary data included national nutrition surveys that showed vitamin A deficiency prevalence in Uganda (UBOS, 2022).

3.4. Population and sampling techniques

For the experimental formulations, ingredients were obtained from five different production batches to reduce the impact of variability in raw material composition. The sample size of thirty panelists (fifteen per group) was used for the BIBD analysis while being feasible for the consumer acceptability testing sessions (Lawless & Heymann, 2010).

3.5. Variable definitions and measurement levels

The study had three continuous independent variables: OFSP puree concentration (60-80% w/w), gelatin concentration (4-8% w/w), and honey concentration (5-15% w/w). These variables were selected based on literature, which highlighted their importance to and optimal ranges for gummy candy characteristics and consumer acceptability. The concentration of mango puree was complementary to OFSP, thus it was automatically calculated by subtracting the total of the other ingredients to yield 100% puree. Consumer acceptability was determined using a structured 9-point hedonic scale, with panelists rating various sensory attributes like colour, aroma, sweetness, texture, chewiness and overall acceptability. The control variables which were maintained at constant levels throughout the study include; water content (20%), citric acid concentration (0.5%), setting time (2 hours at 3°C), and mixing temperature (55°C). Beta-carotene content (µg/g) of the optimized product was quantified using UV-Vis spectrophotometry at a wavelength of 436 nm, following established protocols.

3.6. Procedure for data collection

Data collection involved the preparation of gummy candies according to the D-optimal design, which had 20 runs, followed by consumer acceptability testing. The gummy candy preparation process began with washing and peeling the OFSP, boiling it, and producing a mango and OFSP puree. Gelatin was hydrated in water at 60°C for 15 minutes, before being mixed with the other ingredients at a mixing temperature of 55°C. The mixture was then poured into starch molds and cooled for at least 2 hours at 3°C. For the consumer acceptability testing, six samples were randomly selected for each panelist (30 individuals) and served on white disposable plates labeled with unique four-digit numerical codes for blind evaluation. Drinking water was provided for palate neutralization between samples to minimize carry-over effects.

Table 5; D-optimal mixture design showing composition of experimental runs

Std	Run	Factor 1 A: OFSP Propotion of Puree (g)	Factor 2 B: Gelatin (g)	Factor 3 C: Honey (g)
18	1	70	6	10
5	2	60	4	15
20	3	70	6	10
2	4	80	4	5
4	5	80	8	5
11	6	70	2.636414339	10
8	7	80	8	15
9	8	53.18207169	6	10
12	9	70	9.363585661	10
1	10	60	4	5
10	11	86.81792831	6	10
16	12	70	6	10
14	13	70	6	18.40896415
19	14	70	6	10
7	15	60	8	15
3	16	60	8	5
6	17	80	4	15
17	18	70	6	10
15	19	70	6	10
13	20	70	6	1.591035847

3.7. Data collection instruments

Quantitative measures were obtained using various instruments to ensure collection of precise and reliable data. A UV-Vis spectrophotometer was used for quantifying beta-carotene content in the optimized gummy candy samples while following the protocol outlined by AOAC (1980) and Mustapha, Y. (2008) as described in "Determination of Beta-carotene in Vegetables and Premixes" refer to Appendix B. For the consumer acceptability testing, a standardized 9-point hedonic scale questionnaire was given to the panelists to assess their perceptions of various sensory attributes. Descriptive statistical measures were made from the collected data.

3.8. Quality/error control

For accuracy and reliability of the results, the following were done. Standardized protocols were followed during gummy candy production, ingredient measurements, and sensory evaluations. The analytical procedures of UV-Vis spectrophotometry was done using standard protocol. All analysis was done in triplicates. Consumer acceptability testing was done using proper sensory practices to reduce any bias. Sensory evaluation samples were prepared in a separate area from the panelists and coded with random four digits to avoid bias during the evaluation process.

3.9. Data processing and analysis

Data analysis was done with Minitab 22. For formulation optimization, a response surface methodology (RSM) analysis was done to get 3D surface plots and overlaid contour plots, which allow the visualization of relationships between independent variables and consumer acceptability responses. Regression model equations were made to determine the sensory scores based on ingredient formulations. The models were examined by ANOVA tables, particularly R-squared values. Consumer acceptability data from the BIBD was analyzed using statistical techniques like regression models, optimized formulation, 3D surface plots, and overlaid contour plots.

3.10. Ethical considerations

All participants provided informed consent. Confidentiality was maintained through the anonymous coding of sensory evaluation data, with no personal identifiers collected. Hygienic preparation conditions were done to minimize potential health risks. During consumer acceptability testing, environmental conditions were not actively controlled but were passively maintained to be reasonably consistent, which may limit the generalizability of the results to real-world consumption settings.

3.11. Methodological Constraints

Several limitations were faced. There was potential ingredient variability, especially in OFSP and mango beta-carotene content, which was addressed by sourcing ingredients from consistent suppliers and using multiple production batches to account for natural fluctuations. The UV-Vis spectrophotometry method's accuracy and reliability were ensured by following standardized extraction and calculation protocols. During consumer acceptability testing, the control of environmental conditions, which was passively done, may not fully reflect real-world consumption settings.

CHAPTER FOUR

4.0. DATA ANALYSIS, PRESENTATION, AND INTERPRETATION OF FINDINGS

4.1. Experimental optimization run analysis

The experimental optimization used a D-optimal design to systematically vary the concentrations of OFSP, gelatin, and honey across twenty formulation runs, enabling the assessment of their individual and interactive effects on the six key sensory attributes. Analysis of the sensory data showed trends in how ingredient levels affected consumer acceptability.

Run 14, the optimal formulation with the highest sensory scores, had 18.41% honey, 6% gelatin, and 70% OFSP. This formulation had greater texture (7.23), chewiness (7.23), sweetness (6.73), and overall acceptability (7.13), showing the critical role of honey not only as a sweetener but also as a texture modifier that improves the mouthfeel and palatability. The increased gelatin content in this run contributed to the desirable chewiness and structural integrity, while the balanced OFSP level ensured a favorable flavor profile without overpowering earthiness.

Meanwhile, run 17 (15% honey, 4% gelatin, 80% OFSP) ranked second overall, excelling in aroma (6.60) and color (7.57). The higher OFSP proportion in this formulation likely increased the color and aroma associated with sweet potato, while the moderate honey content maintained acceptable sweetness and masked any residual earthy notes. This suggests that increasing the OFSP can increase visual and olfactory appeal if sufficient honey is present to balance the flavor.

However, run 4 (5% honey, 4% gelatin, 80% OFSP) consistently received the lowest scores across all sensory responses. The noticeably reduced honey content resulted in reduced sweetness, a less appealing texture, and lower overall acceptability, stressing the importance of adequate sweetener levels for consumer satisfaction.

Overall, the optimization analysis shows that the concentrations of honey, gelatin, and OFSP are important in getting a product with high consumer acceptability. The findings confirm that honey plays various roles, influencing not only sweetness but also texture and overall sensory experience.

4.2. Regression model equations

The regression models for all six responses were developed using backward elimination with α = 0.2.

Table 6; Regression model equations for all responses

Response	Regression Equation	R^2	p-value
Y_1: Aroma Score	$Y_1 = 4.430 + 0.250X_2 + 0.1363X_3 - 0.0188X_2X_3$	36.14%	0.162
Y_2: Color Score	$Y_2 = 5.850 + 0.1685X_2 + 0.1269X_3 - 0.01583X_2X_3$	43.85%	0.085
Y_3: Texture Score	$Y_3 = 5.034 + 0.1142X_2 + 0.0628X_3$	44.27%	0.030
Y_4: Chewiness Score	$Y_4 = -28.37 + 0.749X_1 + 2.747X_2 + 0.340X_3 - 0.00495X_1^2 - 0.1627X_2^2 - 0.01318X_3^2 - 0.01188X_1X_2$	84.28%	0.021
Y_5: Sweetness Score	$Y_5 = -13.26 + 0.371X_1 + 2.195X_2 + 0.0561X_3 - 0.001937X_1^2 - 0.0631X_2^2 - 0.01979X_1X_2$	84.37%	0.007
Y_6: Overall Consumer Acceptability	$Y_6 = 3.90 + 0.617X_2 + 0.0601X_3 - 0.0497X_2^2$	41.95%	0.101

Significance level of α = 0.05

X_1 **r**epresents the OFSP puree, X_2 represents the proportion of gelatin, and X_3 represents the proportion of honey.

Aroma score

The regression model developed to predict the aroma score of the gummy candies is represented by the equation $Y_1 = 4.430 + 0.250X_2 + 0.1363X_3 - 0.0188X_2X_3$, where Y_1 is the aroma score. This model explains 36.14% of the variation in aroma score (R^2 = 36.14%), showing a moderate fit to the data. However, the model is not statistically significant (p = 0.162), meaning that the observed relationships between gelatin, honey, and aroma score may be due to random chance rather than a true effect. The regression equation shows that both gelatin and honey have positive influences on the aroma score, while their interaction shows a slight negative effect.

Color score

The regression model for the color response of the gummy candies is $Y_2 = 5.850 + 0.1685X_2 + 0.1269X_3 - 0.01583X_2X_3$, where Y_2 is the color score. This model explains 43.85% of the variation in color score ($R^2 = 43.85\%$) and has significance ($p = 0.085$). Gelatin and honey both show positive coefficients in the equation, thus showing that increasing their levels may increase the color score of the gummies. The negative interaction shows that the combined effect of gelatin and honey may be less improved at higher levels. The model is not significant ($p < 0.05$), showing that the relationships may be due to random chance rather than a true effect.

Texture score

The regression model is $Y_3 = 5.034 + 0.1142X_2 + 0.0628X_3$, where Y_3 is the texture score. The model has significance ($p = 0.030$) and explains 44.27% of the variation in texture score ($R^2 = 44.27\%$). Gelatin and honey both have positive coefficients, showing that increasing the levels of either ingredient is likely to improve the texture of the gummies. Thus suggests that carefully balancing the concentrations of gelatin and honey can increase the textural quality of the gummy candy.

Chewiness score

The regression model for the chewiness score is $Y_4 = -28.37 + 0.749X_1 + 2.747X_2 + 0.340X_3 - 0.00495X_1^2 - 0.1627X_2^2 - 0.01318X_3^2 - 0.01188X_1X_2$, where Y_4 is the chewiness score. This model accounts for 84.28% of the variation in the chewiness score ($R^2 = 84.28\%$) and is statistically significant ($p = 0.021$). The honey proportion shows a high positive linear effect, while the quadratic terms for OFSP proportion and gelatin are highly negative, showing that there are optimal levels for each ingredient beyond which chewiness decreases. This model shows that chewiness depends on a careful balance of the different ingredients.

Sweetness score

The regression model for sweetness score is $Y_5 = -13.26 + 0.371X_1 + 2.195X_2 + 0.0561X_3 - 0.001937X_1^2 - 0.0631X_2^2 - 0.01979X_1X_2$, where Y_5 is the sweetness score. The model is significant ($p = 0.007$) and explains 84.37% of the variation in sweetness score (R^2 = 84.37%). The OFSP proportion and honey content both show high positive linear effects on the sweetness score. The quadratic term for gelatin is highly negative, implying an optimal gelatin level for sweetness. The interaction between OFSP proportion and gelatin is also highly negative, showing that their combined effect reduces sweetness at higher levels of both ingredients. This shows the importance of balancing these ingredients to achieve the desired sweetness.

Overall acceptability

The regression model for overall consumer acceptability is $Y_6 = 3.90 + 0.617X_2 + 0.0601X_3 - 0.0497X_2^2$, where Y_6 is the overall consumer acceptability. The model explains 41.95% of the variation in overall consumer acceptability (R^2 = 41.95%) and isn't significant ($p = 0.101$). Honey proportion shows a high positive effect on overall acceptability, while gelatin does not show a high linear effect. The quadratic term for gelatin has a negative coefficient, showing that there may be an optimal gelatin level for consumer acceptability. The overall results show that honey is an important factor in determining the consumer acceptability, while gelatin's effect is more complex.

4.3. Surface plots analysis

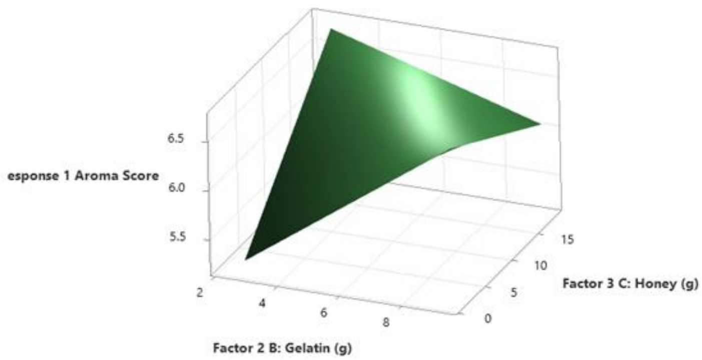

Figure 2; Surface plot of aroma

Aroma score vs. honey and gelatin

The aroma surface plot has a peak in the aroma score at 8 for gelatin and 5 for honey, with higher levels of both leading to reduced aroma scores. The increase of gelatin increases the aroma score, while the increase of honey reduces the aroma score. This shows that the aroma of the gummies is improved by a balanced combination of these ingredients.

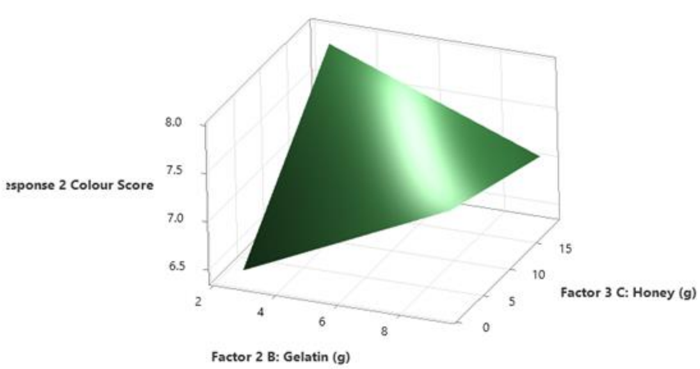

Figure 3; Surface plot of colour

Color score vs. honey and gelatin

The color surface plot shows an increase in the color score, mainly caused by the honey proportion. There is a slight increase in colour score with increase in the gelatin levels while a slight increase with an increase in honey. Both have little effect on colour.

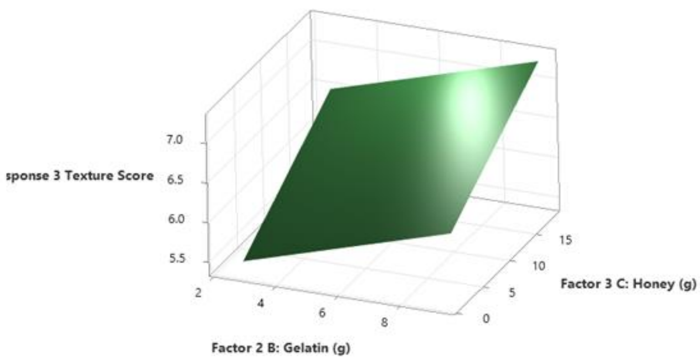

Figure 4; Surface plot of texture

Texture score vs. honey and gelatin

The texture score surface plot shows a positive relationship between both gelatin and honey with the texture score. The surface rises continuously as both ingredients increase, with the rapid increase due to the honey proportion. The flat nature of the surface shows the linear model without interaction terms, indicating that the effects of gelatin and honey on texture are mainly independent.

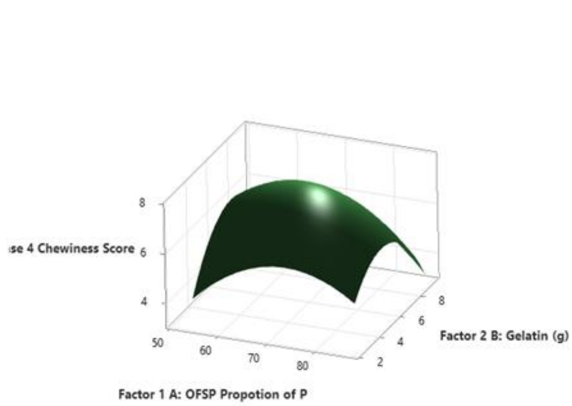

Figure 5; Surface plot of chewiness

Chewiness score vs. OFSP and gelatin

The chewiness surface plot has a peak chewiness score at specific levels of gelatin and OFSP. Chewiness increases with gelatin from 4-6, beyond which the chewiness score decreases, showing an optimal gelatin level for chewiness. Chewiness increases with OFSP from 60-70, beyond which the chewiness score reduces, showing an optimal OFSP level for chewiness.

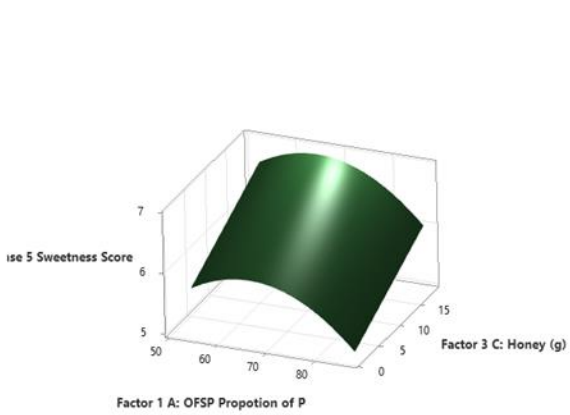

Figure 6; Surface plot of sweetness

Sweetness score vs. OFSP and honey

The sweetness surface plot shows a continuous rise along the honey axis. Higher levels of honey lead to increased sweetness scores. The curvature of the surface shows that sweetness is optimized at specific combinations of ingredients, with the sweetness increasing with OFSP from 60 to 70, beyond which the sweetness score reduces.

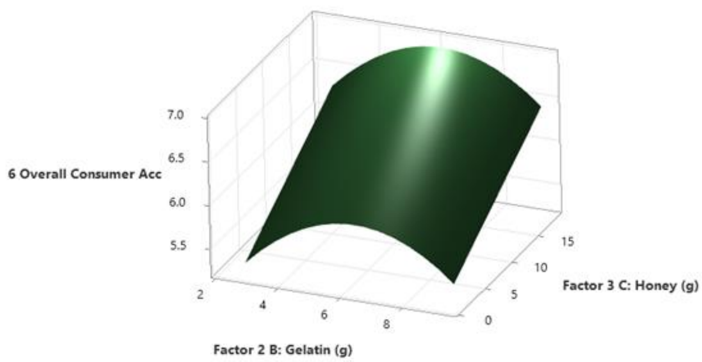

Figure 7; Surface plot of overall acceptability

Overall acceptability vs. gelatin and honey

The overall consumer acceptability surface plot shows that acceptability increases with honey levels, with the maximum point at 15. The curvature in the plot shows that extremely low or high gelatin levels reduce overall acceptability, with the acceptability increasing with gelation from 4-6, beyond which the acceptability reduces.

4.4 Overlay plots analysis

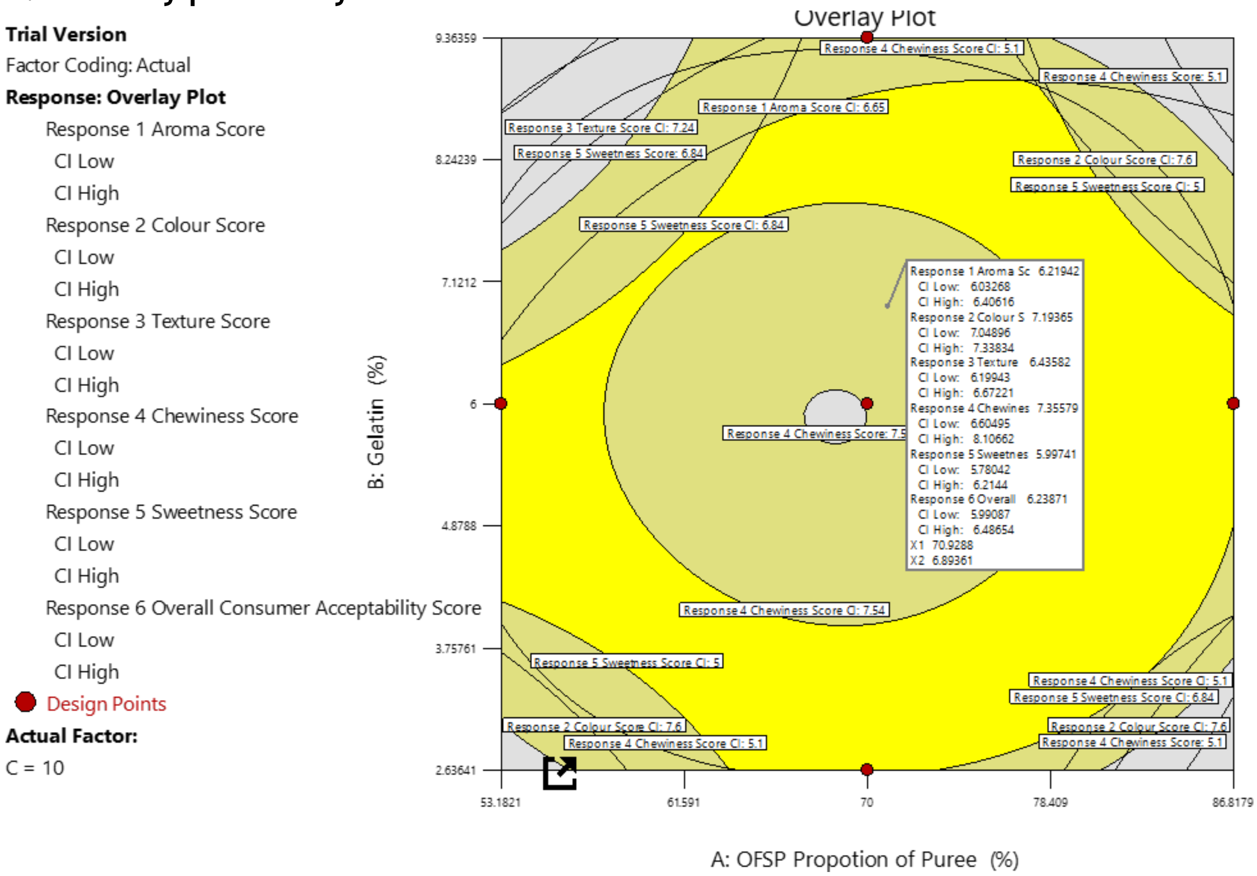

Figure 8; Overlay plot of OFSP puree vs gelatin

Overlay plot of OFSP puree vs. gelatin

The overlay plot shows how OFSP puree and gelatin content together affect all six responses. This plot shows that the optimal levels, to meet most sensory characteristics at once, are within the mid-to-high levels of OFSP (approximately 65-75) and moderate gelatin levels (approximately 5-7).

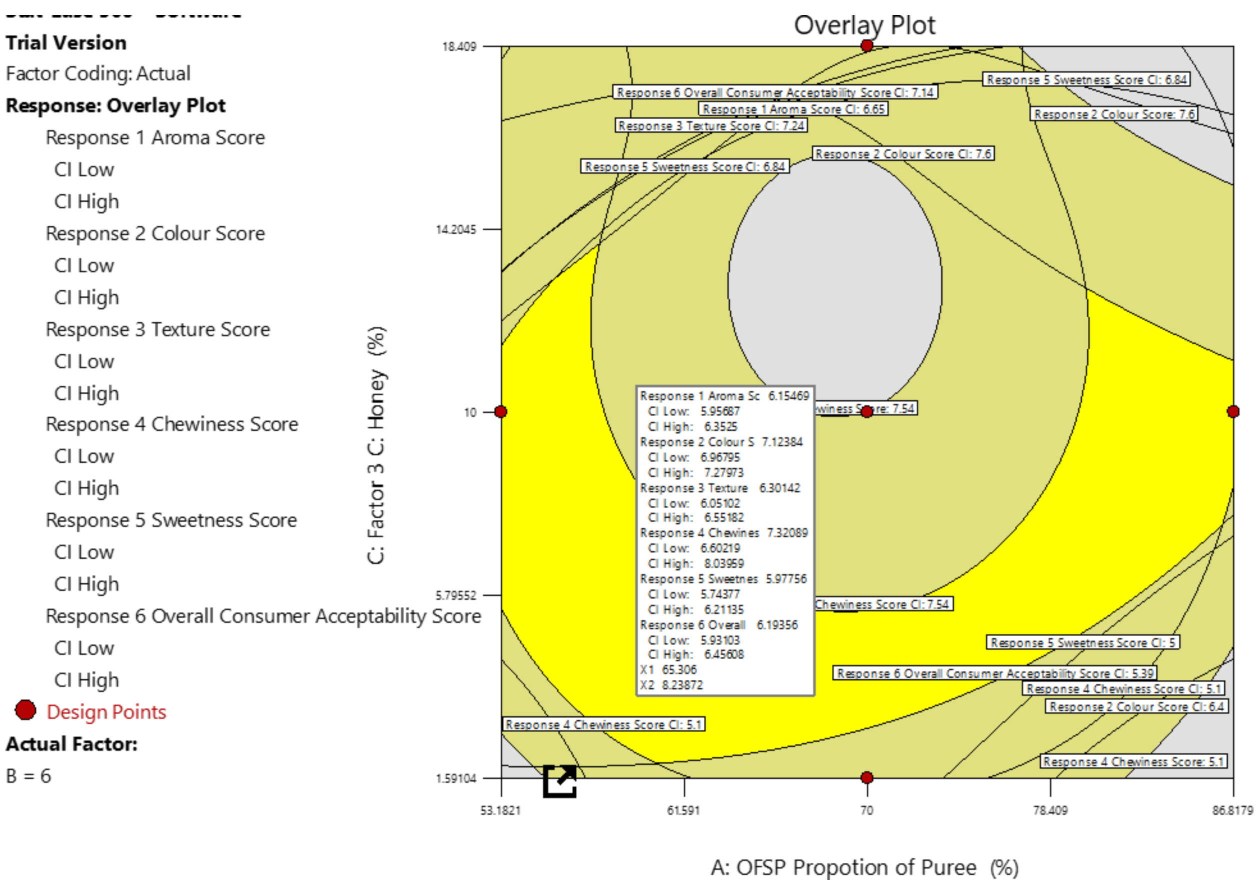

Figure 9; Overlay plot of OFSP puree vs honey

Overlay plot of OFSP puree vs. honey

The overlay plot shows the combined effects of OFSP proportion (Factor A) and honey content (Factor C) on all responses. This plot shows that OFSP, around 65-70%, with a high honey proportion of 15, gets the most desired qualities.

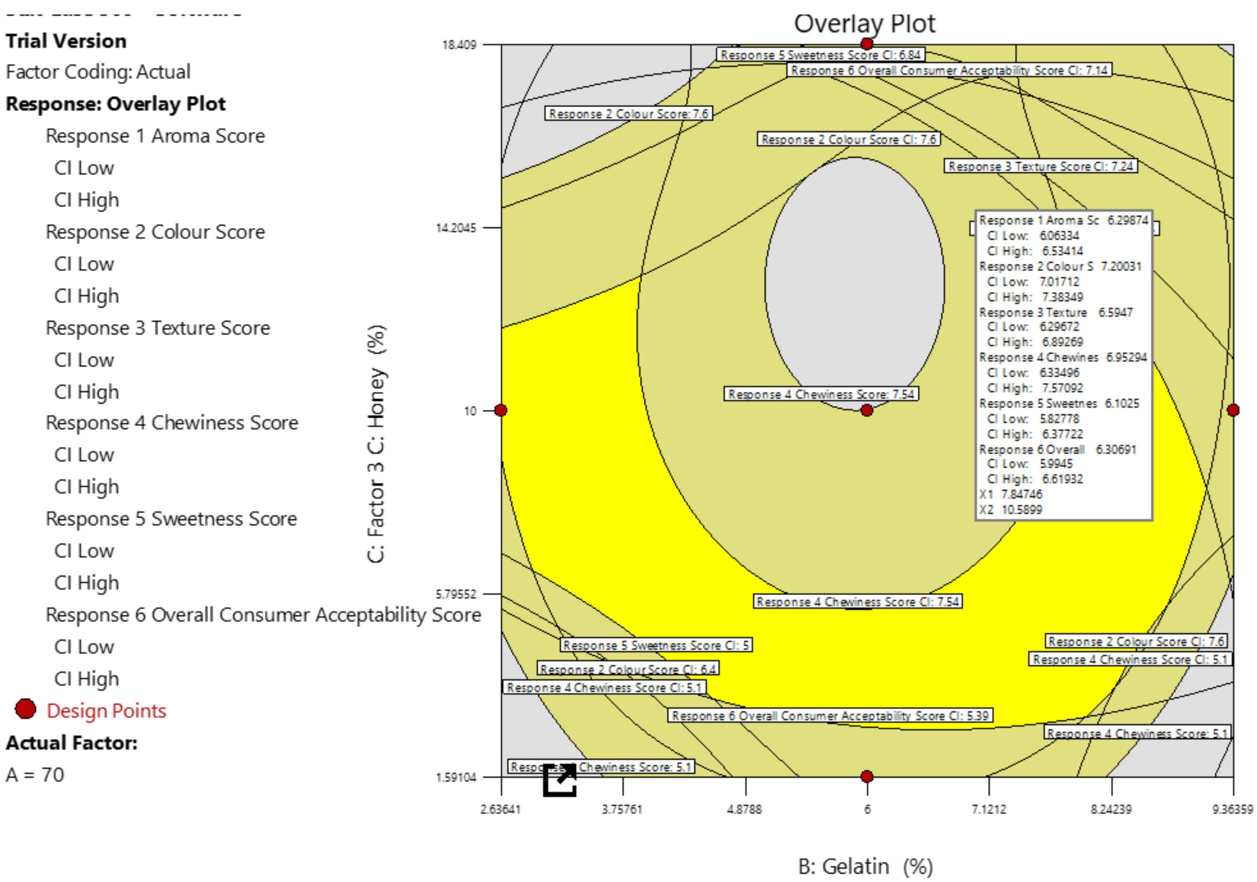

Figure 10; Overlay plot of gelatin vs honey

Overlay plot of gelatin vs. honey

The BC overlay plot shows how gelatin content and honey content jointly influence all responses. The plot shows that the optimal proportion of gelatin is around 6-7, and honey is around 15. It shows that maximizing honey while carefully controlling gelatin levels produces the most desirable overall product.

The predicted optimized gummy candy formulation contained 65.25% OFSP, 6.34% gelatin, and 15% honey. This formulation is predicted to get high scores across all key sensory attributes, with an overall consumer acceptability of 6.72, a sweetness score of 6.76, a chewiness score of 7.54, a texture score of 6.70, a color score of 7.32, and an aroma score of 6.28, giving a composite desirability of 0.83.

4.5 Beta-carotene content

Table 7; Beta-carotene content

Variable	Mean	StDev
Beta- Carotene (mg/kg)	3.225	0.003

Beta-carotene content per 100g

3.225 mg/kg = 3225 µg/kg = 322.5 µg/100g

RAE calculation:

322.5 µg × 0.0833 = 26.9 µg RAE per 100g serving

The beta-carotene content of the optimized candy formulation was analyzed in triplicate, getting a mean of 3.225 ± 0.003 mg/kg. The beta-carotene content per 100g serving was calculated as 0.3225 mg (322.5 µg). This value was converted to RAE using the IOM conversion factor for mixed diets, where 1 µg of dietary beta-carotene equates to 0.0833 µg RAE (IOM, 2001). The beta-carotene content is 26.9 µg RAE/100g after applying the conversion factor.

This contribution was compared to the Recommended Dietary Allowances for key populations, i.e. children between 4–8 years (400 µg RAE/day), women of reproductive age (700–900 µg RAE/day), and men aged 19–50 years (900 µg RAE/day). The candy provides 6.7% of a child's daily vitamin A requirement, 3.0–3.8% for women, and 3.0% for men per 100g serving. These values are below the World Health Organization (WHO) fortification threshold of ≥15% RDA per serving (WHO/FAO, 2006), thus showing insufficient enrichment to address vitamin A deficiency in vulnerable populations.

CHAPTER FIVE

5.0. DISCUSSION OF RESULTS

5.1. Influence of OFSP

The use of OFSP was strategic in addressing VAD. Neela and Fanta (2019) quantified OFSP's ß-carotene content to be 1,600 µg per 100g in raw roots, which makes them a major resource for this formulation. Beta-carotene is efficiently converted to retinol in the body (Rodriguez-Amaya, 2019). The higher the amount of the vitamin put in the recipe, the higher the bioavailability that is received by the human body. This means that even small portions of improved meals can improve nutritional health.

The effect of OFSP on the sensory characteristics and nutrient bioavailability is critical. The stability of beta-carotene which is majorly from the OFSP, during the gummy candy production process is also crucial as beta-carotene is susceptible to degradation by heat, light, and oxidation (Rodriguez-Amaya, 2019). The beta-carotene retention is significantly affected by the processes of boiling, mixing, and drying especially interms of temperature.

5.2. Effect of gelatin

Gelatin gave the characteristic chewy texture to the candy (Khan et al., 2022). The gel structure is affected by temperature (2011), thus it is important to balance hardness and softness. These findings agree with studies that emphasise the role of gelatin in confectionery applications (Parker et al., 2003).

The properties of gelatin are influenced by conncentration, pH, and sugars or other additives (Gómez-Guillén et al., 2011). Gelatin should be hydrated at temperatures of 50 – 60 °C (Rosell, 2017). This is important in maintaining the ideal texture and consistency. The quadratic negative terms for the gummies are thus affected by gelatin, because high levels are usually detrimental to the chewiness. The sensory perception of texture is complex and involves interactions between mechanical, structural, and physiological factors (Szczesniak, 2002).

5.3. Effect of honey

Honey's multi-layered role in the gummy candy formulation is beyond sweetness. Honey's contributions to the product's humectancy, shelf stability, sensory characteristics, antioxidant and anti-inflammatory activities are important as described by Chua et al (2021). Honey, which is rich in fructose and glucose, is a great sugar alternative (Chua et al., 2021) for a more natural and health-conscious formula.

The composition of honey changes depending on the source, geographic origin, and processing methods (Estevinho et al., 2008). Different types of honey may contribute unique flavour notes, antioxidant properties, and prebiotic effects to the gummy candy. Thus the same honey source of honey is used. The antimicrobial properties of honey are due to various factors, like high sugar concentration (resulting in low water activity), low pH (typically between 3.5 and 4.5), the presence of hydrogen peroxide, and the presence of other bioactive compounds like flavonoids and phenolic acids (Chua et al., 2021). These all hinder the growth of many spoilage microbes and pathogens, thus prolonging the shelf life of the gummy candy.

5.4. Complementary function of mango

Mango was chosen alongside OFSP due to its sensory and dietary qualities. A synergistic relationship is made with vitamin C (ascorbic acid) because ascorbic acid not only improves flavour but also acts as an antioxidant that protects beta-carotene from degradation during processing and storage as supported by Rodriguez-Amaya (2019). According to Sivakumar et al (2022), ripe mango pulp has a beta-carotene content of 550 µg per 100 g, which greatly improves the gummy confectionaries nutritional characteristics.

5.5. Interactions between variables

The RSM-based optimisation of ingredient ratios (OFSP, honey, and gelatin) showed that ratios significantly influence sensory qualities. The most significant determinant of sensory characteristics like flavour, texture, and general acceptability was honey. Gelatin concentration, especially with OFSP concentration, affected chewiness and general texture. The combination of OFSP and gelatin and their impact on chewiness show the importance of carefully adjusting the components used in gummy candy formulations, thus confirming the complex interactions revealed by the models.

5.7. Nutritional analysis of candy

The beta-carotene concentration of the optimized gummy candy formulation was 3.225 mg/kg, with 100 g of the gummy candy meeting only 6.7% of a child's needs. It is important to use methods that increase beta-carotene retention like the use of steaming potatoes rather than boiling. The gummy candies alone aren't suitable to significantly treat VAD among vulnerable populations. This emphasizes the importance of fortifying the sweets or using them in VAD mitigation strategies.

The calculation of RAE from beta-carotene is based on the fact that beta-carotene is not fully converted to retinol in the human body. There are variable conversion efficiencies that depend on factors like individual physiology, dietary fat intake, and the presence of other particular nutrients (IOM, 2001). This creates a problem when calculating the full amount of vitamin A present in the product. The gummy candy's contribution to vitamin A overall dietary intake is to be considered depending on the individual's total diet and nutritional status. Other vitamin A sources in the diet like liver, dairy products, and fortified foods, can greatly affect the vitamin A status of a person (WHO, 2021). All these factors have to be taken into consideration.

CHAPTER SIX

6.0. CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

This study successfully demonstrated the feasibility of developing a beta-carotene-fortified gummy candy using locally sourced ingredients – OFSP, mango, honey, and gelatin.

Through Response Surface Methodology (RSM), an optimized formulation (65.25% OFSP, 6.34% gelatin, and 15% honey) was obtained that maximized consumer acceptability.

The significance model equations showed the significant relationship between consumer acceptability and ingredient formulation; thus, the null hypothesis that stated that there is no relationship between consumer acceptability and ingredient formulations of OFSP, honey and gelatin was rejected.

Spectrophotometric analysis revealed that the optimized formulation contained a mean beta-carotene content of 3.225 ± 0.003 mg/kg, which is 26.9 µg RAE per 100g serving. This amount only provides 6.7% of a child's daily vitamin A requirement, and thus enrichment of the candy was insufficient.

Concerning the limitations of this study, the sensory panel was made of mainly university students, which may limit the generalizability of the consumer acceptability results to more diverse populations. Additionally, the laboratory-scale production conditions did not perfectly replicate commercial production plants. These should be considered when interpreting the results and planning future research.

6.2. Recommendations

Future research should prioritize addressing the significant beta-carotene degradation during OFSP processing, particularly boiling. Optimizing OFSP preparation methods is important. Replacing boiling with gentler techniques like steaming or blanching could better preserve beta-carotene.

Investigate using dietary fats, like coconut oil, into the candy formulation to improve bioavailability, and conversion of beta-carotene to vitamin A.

Since honey was found to be the most critical ingredient by significantly enhancing sweetness, color, and moisture content in the gummy candy, thus careful adjustment of its proportions is necessary for the candy.

Future sensory panels should include more diverse populations to improve the generalizability of consumer acceptability results beyond the university student demographic.

Comparison tests against commercially available gummy candies can be carried out to determine the commercial acceptability.

Follow-up research should involve other variables, like processing conditions, storage conditions, or other ingredients, that may improve the predictive ability for these attributes

REFERENCES

Allen, L. H., de Benoist, B., Dary, O., & Hurrell, R. (2006). Guidelines on food fortification with micronutrients. World Health Organization.

Amos, R., Lynam, J., & Mkumbira, J. (2020). Consumer acceptability of biofortified crops in Sub-Saharan Africa. Food Policy, 95, 101935. https://doi.org/10.1016/j.foodpol.2020.101935

Anupama, D., Bhat, K. K., & Sapna, V. K. (2003). Sensory and textural properties of honey-based confections. Journal of Food Science, 68(4), 1421–1425. https://doi.org/10.1111/j.1365-2621.2003.tb09660.x

Anyanda, T. O., Nuwamanya, E., & Kizito, E. B. (2023). Nutritional profiling of Ugandan orange-fleshed sweet potato cultivars: Implications for food fortification strategies. Food Chemistry, 407, 135202. https://doi.org/10.1016/j.foodchem.2022.135202

AOAC International. (1980). Official methods of analysis of AOAC International (13th ed.).

Ares, G., Barreiro, C., & Deliza, R. (2009). Alternatives to reduce the bitterness, astringency and characteristic flavour of antioxidant extracts. Food Research International, 42(7), 871–878. https://doi.org/10.1016/j.foodres.2009.03.006

Augustin, M. A., & Sanguansri, L. (2008). Encapsulation of bioactives. In J. M. Aguilera & P. J. Lillford (Eds.), Food materials science (pp. 577–601). Springer.

Bechoff, A., Dufour, D., Dhuique-Mayer, C., Marouze, C., Reynes, M., & Westby, A. (2011). Effect of hot air, solar and sun drying treatments on provitamin A retention in orange-fleshed sweet potato. Journal of Food Engineering, 104(4), 647–653. https://doi.org/10.1016/j.jfoodeng.2011.01.017

Bhutta, Z. A., Das, J. K., Rizvi, A., Gaffey, M. F., Walker, N., Horton, S., . . . Black, R. E. (2013). Evidence-based interventions for improvement of maternal and child nutrition: What can be done and at what cost? The Lancet, 382(9890), 452–477. https://doi.org/10.1016/S0140-6736(13)60996-4

Bogdanov, S., Jurendic, T., Sieber, R., & Gallmann, P. (2008). Honey for nutrition and health: A review. Journal of the American College of Nutrition, 27(6), 677–689. https://doi.org/10.1080/07315724.2008.10719745

Burri, B. J. (2011). Evaluating sweet potato as an intervention food to prevent vitamin A deficiency. Comprehensive Reviews in Food Science and Food Safety, 10(2), 118–130. https://doi.org/10.1111/j.1541-4337.2010.00146.x

Cairns, B. J., Aguiar, E. J., & Curioni, O. A. (2013). The physics and processing of chocolate. John Wiley & Sons.

Chong, W. Y., Tiong, S. H., & Khoo, H. E. (2023). Optimization of mango peel-based gummy candy: Phytochemical retention and sensory properties. LWT-Food Science and Technology, 172, 114182. https://doi.org/10.1016/j.lwt.2022.114182

Chua, L. S., Lee, J. Y., & Chan, G. F. (2021). Honey as a functional food: A review. Trends in Food Science & Technology, 114, 625–637. https://doi.org/10.1016/j.tifs.2021.06.024

De Moura, F. F., Palmer, A. C., Finkelstein, J. L., Haas, J. D., Murray-Kolb, L. E., Wenger, M. J., . . . Boy, E. (2015). Are biofortified staple food crops improving vitamin A and iron status in women and children? Nutrition Reviews, 72(5), 289–307. https://doi.org/10.1111/nure.12108

Dwyer, J. T., Woteki, C., Bailey, R., Britten, P., Carriquiry, A., Gaine, P. C., . . . Bailen, R. A. (2015). Fortification: New findings and implications. Nutrition Reviews, 72(2), 127–141. https://doi.org/10.1111/nure.12086

Estevinho, L., Pereira, A. P., Moreira, L., Dias, L. G., & Pereira, E. (2008). Antioxidant and antimicrobial effects of phenolic compounds extracts of Northeast Portugal honey. Food and Chemical Toxicology, 46(12), 3774–3779. https://doi.org/10.1016/j.fct.2008.09.062

FAOSTAT. (2023). Uganda agricultural production statistics. Food and Agriculture Organization of the United Nations. http://www.fao.org/faostat

Gómez-Guillén, M. C., Giménez, B., López-Caballero, M. E., & Montero, M. P. (2011). Functional and bioactive properties of collagen and gelatin from alternative sources: A review. Food Hydrocolloids, 25(8), 1813–1827. https://doi.org/10.1016/j.foodhyd.2011.02.007

HarvestPlus. (2021). Biofortification progress brief: Uganda. HarvestPlus.

Institute of Medicine (IOM). (2001). Dietary reference intakes for vitamin A, vitamin K, arsenic, boron, chromium, copper, iodine, iron, manganese, molybdenum, nickel, silicon, vanadium, and zinc. National Academies Press.

Karim, A. A., & Bhat, R. (2009). Fish gelatin: Properties, challenges, and prospects as an alternative to mammalian gelatins. Food Hydrocolloids, 23(3), 563–576. https://doi.org/10.1016/j.foodhyd.2008.07.002

Khalil, M. I., Alam, N., Moniruzzaman, M., & Sulaiman, S. A. (2021). Physicochemical and antioxidant properties of raw honey from Malaysian stingless bees. Food Chemistry, 344, 128712. https://doi.org/10.1016/j.foodchem.2020.128712

Khan, M. I., Anjum, F. M., & Sameen, A. (2022). Gelatin: Sources, extraction, and applications in food. Critical Reviews in Food Science and Nutrition, 62(10), 2635–2650. https://doi.org/10.1080/10408398.2020.1854141

Lautenschläger, L., Sendker, J., & Hüwel, S. (2018). Gummy confectionery as a nutrient delivery system: Challenges and opportunities. Journal of Functional Foods, 45, 1–9. https://doi.org/10.1016/j.jff.2018.03.021

Lawless, H. T., & Heymann, H. (2010). Sensory evaluation of food: Principles and practices (2nd ed.). Springer.

Low, J. W., Arimond, M., Osman, N., Cunguara, B., Zano, F., & Tschirley, D. (2007). A food-based approach introducing orange-fleshed sweet potatoes increased vitamin A intake and serum retinol concentrations in young children in rural Mozambique. The Journal of Nutrition, 137(5), 1320–1327. https://doi.org/10.1093/jn/137.5.1320

McLaren, D. S., Kraemer, K., & Sight and Life. (2020). Global prevalence of vitamin A deficiency. World Health Organization.

Mercadante, A. Z. (2019). Carotenoids as colorants and vitamin A precursors: Technological and nutritional applications. Food Science and Technology, 34(2), 1–12. https://doi.org/10.1590/fst.43218

Montgomery, D. C. (2017). Design and analysis of experiments (9th ed.). Wiley.

Mwanga, R. O., Mayanja, S., Swanckaert, J., & Carey, E. E. (2020). Orange-fleshed sweet potato in Uganda: A review of variety release, dissemination, and adoption. International Potato Center.

Myers, R. H., Montgomery, D. C., & Anderson-Cook, C. M. (2016). Response surface methodology: Process and product optimization using designed experiments (4th ed.). Wiley.

Neela, S., & Fanta, S. W. (2019). Review on nutritional composition of orange-fleshed sweet potato and its role in management of vitamin A deficiency. Food Science & Nutrition, 7(6), 1920–1945. https://doi.org/10.1002/fsn3.1063

Nestel, P., Bouis, H. E., Meenakshi, J. V., & Pfeiffer, W. (2006). Biofortification of staple food crops. The Journal of Nutrition, 136(4), 1064–1067. https://doi.org/10.1093/jn/136.4.1064

Parker, R., Noel, T. R., Brownsey, G. J., Laos, K., & Ring, S. G. (2003). The rheology and microstructure of mixed gels of gelatin and gellan. Food Hydrocolloids, 17(4), 487–493. https://doi.org/10.1016/S0268-005X(03)00025-6

Ribeiro, A. S., et al. (2018). Development and maturation of mango fruits cv. 'Ubá'. Revista Brasileira de Fruticultura, 40(2), e-257982006. https://doi.org/10.1590/0100-29452018137

Rodriguez-Amaya, D. B. (2019). Update on natural food pigments—A mini-review on carotenoids, anthocyanins, and betalains. Food Research International, 124, 200–205. https://doi.org/10.1016/j.foodres.2019.03.022

Rodriguez-Amaya, D. B. (2022). Food carotenoids: Chemistry, biology, and technology. Wiley.

See, S. F., Hong, K. W., Tan, J. S., Tan, J. K., & Chan, E. S. (2020). Factors affecting the gelling properties of gelatin: A review. Food Hydrocolloids, 105, 105790. https://doi.org/10.1016/j.foodhyd.2020.105790

Sivakumar, D., Jiang, Y., & Yahia, E. M. (2022). Compositional and bioactive variability in mango (Mangifera indica L.) cv. Keitt: Implications for functional food applications. Journal of Food Composition and Analysis, 105, 104261. https://doi.org/10.1016/j.jfca.2021.104261

Spence, C. (2015). Multisensory flavor perception. Cell, 161(1), 24–35. https://doi.org/10.1016/j.cell.2015.03.007

Srisawat, U., & Thongngam, M. (2018). Optimization of gummy jelly formulation using response surface methodology. Food Science and Technology International, 24(2), 130–139. https://doi.org/10.1177/1082013217738960

Statista. (2023). Global functional gummies market size. https://www.statista.com

Szczesniak, A. S. (2002). Texture is a sensory property. Food Quality and Preference, 13(4), 215–225. https://doi.org/10.1016/S0950-3293(01)00039-8

Tariq, S., Imran, M., Mushtaq, Z., & Asghar, A. (2023). Citric acid in food preservation: Mechanisms and applications. Critical Reviews in Food Science and Nutrition, 63(5), 1–15. https://doi.org/10.1080/10408398.2023.2185589

Tumwegamire, S., Mwanga, R. O., Andrade, M. I., Low, J., & Ssemakula, G. (2018). Orange-fleshed sweet potato development and delivery in Sub-Saharan Africa. International Potato Center.

Uganda Bureau of Statistics (UBOS). (2023). Uganda Demographic and Health Survey 2022.

UNICEF Uganda. (2022). Vitamin A supplementation coverage in Uganda: 2022 report. United Nations Children's Fund.

World Health Organization (WHO). (2021). Global prevalence of vitamin A deficiency in populations at risk 1995–2005.

World Health Organization Uganda Country Office (WHO Uganda). (2022). Vitamin A deficiency in Uganda: National survey report.

Woolfe, J. A. (1992). Sweet potato: An untapped food resource. Cambridge University Press.

Zhang, Y., Liu, W., & Wang, L. (2020). Functional and nutritional characterization of bovine gelatin for confectionery applications. International Journal of Biological Macromolecules, 164, 3253–3261. https://doi.org/10.1016/j.ijbiomac.2020.08.218

APPENDICES

Appendix A: ANOVA Tables for Sensory Attributes

Appendix 1: ANOVA table for aroma

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	3	0.6894	0.2298	2.07	0.162
Linear	2	0.4082	0.2041	1.84	0.204
Factor 2 B	1	0.2146	0.2146	1.94	0.191
Factor 3 C	1	0.1935	0.1935	1.75	0.213
2-Way Interaction	1	0.2813	0.2813	2.54	0.139
B*C	1	0.2813	0.2813	2.54	0.139
Error	11	1.2183	0.1108		
Total	14	1.9077			

Appendix 2: ANOVA table for colour

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	3	0.55330	0.18443	2.86	0.085
Linear	2	0.35274	0.17637	2.74	0.108
Factor 2 B	1	0.00563	0.00563	0.09	0.773
Factor 3 C	1	0.34711	0.34711	5.39	0.040
2-Way Interaction	1	0.20056	0.20056	3.11	0.105
B*C	1	0.20056	0.20056	3.11	0.105
Error	11	0.70848	0.06441		

Total	14	1.26178			

Appendix 3: ANOVA table for texture

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	2	2.0579	1.0290	4.77	0.030
Linear	2	2.0579	1.0290	4.77	0.030
Factor 2 B	1	0.7126	0.7126	3.30	0.094
Factor 3 C	1	1.3453	1.3453	6.23	0.028
Error	12	2.5905	0.2159		
Total	14	4.6484			

Appendix 4: ANOVA table for chewiness

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	7	5.61671	0.80239	5.36	0.021
Linear	3	2.38195	0.79398	5.30	0.032
Factor 1 A	1	0.29334	0.29334	1.96	0.204
Factor 2 B	1	0.07741	0.07741	0.52	0.495
Factor 3 C	1	2.01121	2.01121	13.43	0.008
Square	3	2.78350	0.92783	6.20	0.022
A*A	1	1.48018	1.48018	9.89	0.016
B*B	1	2.56496	2.56496	17.13	0.004
C*C	1	0.65724	0.65724	4.39	0.074

2-Way Interaction	1	0.45125	0.45125	3.01	0.126
Error	7	1.04790	0.14970		
Total	14	6.66461			

Appendix 5: ANOVA table for sweetness

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Model	6	3.6821	0.61369	7.20	0.007
Linear	3	1.6907	0.56358	6.61	0.015
Factor 1 A	1	0.4688	0.46880	5.50	0.047
Factor 2 B	1	0.1485	0.14853	1.74	0.223
Factor 3 C	1	1.0734	1.07342	12.59	0.008
Square	2	0.7379	0.36895	4.33	0.053
A*A	1	0.3700	0.37002	4.34	0.071
B*B	1	0.6295	0.62945	7.38	0.026
2-Way Interaction	1	1.2535	1.25347	14.70	0.005
Error	8	0.6820	0.08525		
Total	14	4.3641			

Appendix 6: ANOVA table for overall acceptability

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Model	3	1.71345	0.57115	2.65	0.101
Linear	2	1.25686	0.62843	2.92	0.096

Factor 2 B	1	0.02326	0.02326	0.11	0.749
Factor 3 C	1	1.23360	1.23360	5.72	0.036
Square	1	0.45659	0.45659	2.12	0.173
B*B	1	0.45659	0.45659	2.12	0.173
Error	11	2.37099	0.21554		
Total	14	4.08444			

Appendix B: Laboratory Protocol for determination of beta-carotene

UIRI ANALYTICAL LABORATORIES QUALITY MANUAL	**Code:** QMM 702-21C	Page **1** of **3**
Section: Test Methods & Method Validation	**Title:** Determination of Beta-carotene in Vegetables & Premixes	
Prepared By: Quality Manager	**Original date:** 01.10.2016	
Issued By: Head of Laboratory	**Revision Number:** 004	**Revision date: 01.10.2024**
Approved By: Director PD	**Annual review date:** 01.10.2026	

DETERMINATION OF BETA-CAROTENE CONTENT IN VEGETABLES AND PREMIXES

PURPOSE

This method is suitable for the determination of beta-carotene content in leafy vegetables and premixes.

PREPARATION OF SAMPLE

- Wash each vegetable sample and grind it to a fine pulp using pestle and mortar.

The operation should be done under dim light to reduce the rate of carotene oxidation contained in sample.

PROCEDURE

- Weigh 10g of macerated sample using analytical balance.
- Add 50ml of 95% ethanol in a conical flask.
- Place the conical flask and its content onto a water bath. Maintain at a temperature of 70-80^{0}C in a water bath for 20minutes with periodic shaking.
- Decant the supernatant and allow to cool
- Measure its volume by means of a measuring cylinder and record as initial volume.
- The ethanol concentration of the mixture is brought to 85% by adding 15ml of distilled water and it is further cooled in a container of ice water for about 5minutes.
- Transfer the mixture into a separating funnel

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Signature: [signature]	**Signature:** [signature]	**Signature:**	**Signature:**

- Add 25ml of petroleum ether (pet-ether) and extract by swirling.
- Pour a few mls of cooled ethanol over it. Swirl the funnel gently to obtain a homogenous mixture and allow to stand until two separate layers are obtained.
- The bottom layer is run off into a beaker while the top layer is collected into a 250ml conical flask.
- Transfer the bottom layer into the funnel and re-extract with 10ml pet-ether for 5-6 times until the extract becomes fairly yellow (for green leafy vegetables).
- The entire pet-ether is collected into 250ml conical flask and transferred into a separating funnel for re-extraction with 50ml of 80% ethanol.
- The final extract is measured and poured into sample bottles for further analysis.

MEASUREMENT OF ABSORBANCE

- The absorbance of the extracts is measured using a spectrophotometer at a wavelength of 436nm.
- A cuvette containing pet-ether (blank) is used to calibrate the spectrophotometer to zero point.
- Place samples of each extract in cuvettes and take the readings when the figure in the display window becomes steady.
- The operation is repeated 5-6 times for each sample and average readings recorded.

CALCULATION

- Calculate the concentration of β-carotene using Bear-Lamberts Law, which states that the absorbance (A) is proportional to the concentration(C) of the pigment, as represented by the equation:

$A \propto L$ (if concentration(C) is constant).

$$\text{Carotenoids content } (\mu g/g) = \frac{A \times V(ml) \times 10^4}{A^{1\%}_{1cm} \times P(g)}$$

where A = Absorbance; V = Total extract volume; P = sample weight; $A^{1\%}_{1cm}$ =2592 (β-carotene Extinction Coefficient in petroleum ether).

SAFETY PRECAUTIONS

Work in a well-ventilated room, wear protective clothing and apply all the rules of good laboratory practice.

REFERENCES

AOAC. (1980) Official Methods of Analysis. Howitz (ed.).Pp 734-740.

Mustapha, Y. (2008). Determination of β-carotene content of some selected vegetables sold in Rimi market of Kano town. International Journal of Bioscience 3(3):20-22

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Signature: [signature]	Signature: [signature]	Signature:	Signature:

Appendix C: Research lab test results for beta-carotene

UGANDA INDUSTRIAL RESEARCH INSTITUTE

UIRI

"A Lead Agency in Industrialisation of Uganda"

RESEARCH TEST RESULTS

Student Name: Nowemigisha Isabel

Address: Uganda Christian University

Analysis Date: 01st – 04th April. 2025

S.NO	Pineapple Peel, Lemon Peel & mint	R1	R2	R3
1	Vitamin C, mg/100 ml	144.05	142.37	144.05

S.NO	Gummy Candy	R1	R2	R3
1	Beta-carotene, mg/kg	3.228	3.222	3.225

Analyzed by:

Mivule Ivan

....

Verified by:

Technical Signatory

....

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07 APR 2025
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Appendix D: Pictorial evidence of the study

Figure 11; Gummy candy samples for sensory evaluation

Figure 12; Measurement of ingredients

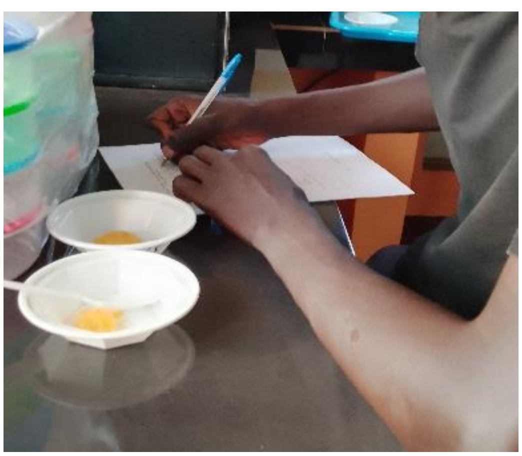

Figure 13; Panelist carrying out sensory evaluation

Appendix E: Research study timeline

Week	Activity
1	Ingredient sourcing and preparation
2	Formulation trials
3	Sensory evaluation
4-5	Nutritional analysis
6	Data analysis
7	Product optimization
8-9	Report preparation
10	Submission

Appendix F: Research study budget

Item	Cost (UGX)
Ingredients	250,000
Equipment	150,000
Utilities	100,000
Nutritional Analysis	250,000
Miscellaneous	50,000
Total	**800,000**

Appendix G: Consumer acceptability ballot paper

Affective/Consumer acceptability Sensory evaluation ballot
Nine-point hedonic scale

Panelist No.________________________ Age………. Gender…………….

You are provided with 4 samples of gummy candy. Please observe, smell and taste each sample; and record your liking of the samples on a scale of 1 to 9 by placing your score in the box next to the sensory parameter under each sample in the table below. Please evaluate the products in the order in which they are presented. Use the water provided to rinse your mouth before and after tasting each sample and between samples.

ANSWER ALL QUESTIONS. We want to know what you think!! **If you have any questions, please ask the study coordinators.**

Score the products using hedonic scale below	
Like extremely	**9**
Like very much	**8**
Like moderately	**7**
Like slightly	**6**
Neither like nor dislike	**5**
Dislike slightly	**4**
Dislike moderately	**3**
Dislike very much	**2**
Dislike extremely	**1**

Quality attributes	**Sample No.**			
Aroma				
Colour				
Texture				
Sweetness				
Chewiness				
Overall acceptability				

Which sample (only one) would you buy and why?

....

……………………………………………………………………………………………………

General comments:
……………………………………………………………………………………………………