UTILIZATION OF WASTE FOR VARIOUS PRODUCTS FROM PINEAPPLE cv. GIANT KEW

Thesis

submitted to

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of

Doctor of Philosophy

in

Horticulture (Fruit Science)

by

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Dedicated to my beloved family

DECLARATION

I, Sentinaro Walling, hereby declare that the subject matter of this thesis is the record of work done by me, that the contents of this thesis did not form the basis of the award of any previous degree to me or to the best of my knowledge to anybody else, and that the thesis had not been submitted by me for any research degree in any other university/institute.

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This is to certify that the thesis entitled "**Utilization of Waste for various products from pineapple cv. Giant Kew**" submitted to Nagaland University in partial fulfillment of the requirements for the award of degree of Doctor of Philosophy in Horticulture (Fruit Science) is the record of research work carried out by Ms. Sentinaro walling, Registration No. PhD./HOR/00149 under my personal supervision and guidance.

The results of the investigation reported in the thesis have not been submitted for any other degree or diploma. The assistance of all kinds received by the student has been duly acknowledged.

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This is to certify that the thesis entitled "**Utilization of Waste for various products from pineapple cv. Giant Kew**" submitted by Ms. Sentinaro Walling Admission No. 228/17, Registration No. PhD./HOR/00149 to the NAGALAND UNIVERSITY in partial fulfillment of the requirements for the award of degree of Doctor of Philosophy in Horticulture (Fruit Science) has been examined by the Advisory Board and External examiner on ……………….............

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LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
AOAC	Association of Official Analytical Chemist
cN/tex	centi Newton /tex
cv.	Cultivar
BIS	Bureau of Indian Standards
ERMA	Electronic Recording Machine Accounting
et al.	And others
etc.	etcetera
Fig.	Figure
g	Gram
ha	Hectare
HCl	Hydrochloric acid
ICAR	Indian Council of Agricultural Research
i.e.	That is
MSL	Mean Sea Level
NHB	National Horticulture Board
NS	Non-Significant
NU	Nagaland University
PALF	Pineapple leaf fibre
pH	Negative logarithm of hydrogen ion activity of a soil
R.H.	Relative Humidity
S	Significant
S X A	Cropping season x Age of crop
SAS	School of Agricultural Sciences
SEm±	Standard Error Mean

TSS	Total soluble solids
Var.	Variety
viz.	Videlist (namely)
°B	Degree Brix
°C	Degree Celsius
TSS	Total soluble solids
/	Per
%	Percent

ABSTRACT

A study was conducted at Department of Horticulture, School of Agricultural Sciences, Nagaland University during the year 2018-2021 for effective utilization of waste of pineapple cv. Giant Kew. A total of three experiments were carried out to study the quality of fibre extracted from pineapple leaf, to evaluate the qualitative parameters of vinegar produced from pineapple waste (peel, core and pomace) and to examine the preparation of candy from pineapple core.

The first experiment comprised of twelve treatments with three replications using a split-plot design. Pineapple sucker and crown, harvested at different ages (main crop, first ratoon and second ratoon crop) and cropping seasons (winter and summer) were procured from established pineapple fields in Molvom village. In pineapple sucker, fibres extracted from first ratoon crop during summer season exhibited the highest fineness (2.27 tex), tensile strength (36.13 cN/tex), modulus of elasticity (1548.33 cN/tex), elongation at break point (2.70%) and cellulose content (70%). In crown, fibres from second ratoon crop during summer season had the highest fineness (2.16 tex), tensile strength (30.15 cN/tex), modulus of elasticity (1275.73 cN/tex), elongation at break point (2.54%) and cellulose content (60.53%). Based on the findings, fibre from sucker obtained from the first ratoon crop during summer season exhibited superior physical, mechanical and bio-chemical properties, while crown fibres showed better attributes in the second ratoon crop during summer season.

The second experiment conducted in a completely randomized design (CRD) with three treatments and five replications, studied the quality of vinegar from pineapple waste (peel, core, and pomace). Two stage fermentation *viz.,* alcoholic and acetous fermentation were carried out with commercial wine yeast (Lalvin EC-1118) and *Acetobacter aceti* (MTCC- 3246). Vinegar prepared from peel exhibited the highest acetic acid content (4.75%), lowest pH (2.6), superior colour intensity (4.05) and density (2.99). Sensory evaluation also showed that peel vinegar scored the highest in colour (7.65), flavour (6.96), sourness (8.02) and overall acceptability (7.76), with pomace vinegar scoring the lowest. Pineapple peel vinegar was adjudged the best and most acceptable, highlighting the substantial impact of various pineapple waste components on vinegar quality, with peel emerging as the most favourable for production.

The third experiment was laid out in completely randomized design with five treatments *viz*., T_1 (40% sugar), T_2 (50% sugar), T_3 (60% sugar), T_4 (70% sugar), T_5 (No sugar) and replicated thrice. The prepared candies were packed in air-tight glass containers and stored for a period of six months. The observations in respect of physico-chemical and sensory characteristics were recorded from freshly prepared core candy and thereafter periodically at one month interval. With the progress of storage period, an increasing trend was observed in total sugar (41.42% to 44.73%) and reducing sugar (18% to 20.76%), while a decreasing trend was recorded for moisture content (22.24% to 19.96%), titratable acidity (0.45% to 0.35%) and ascorbic acid (5.93 to 4.64 mg/100g). Sensory evaluation indicated that sugar level had a significant impact on colour, flavour, taste, texture and overall acceptability. Candy with 70% sugar consistently received the highest scores, while treatment with no sugar had the lowest ratings. Although all the sensory attributes declined over six months of storage, candy with 70% sugar maintained the highest rating throughout the period.

Keywords: Pineapple *cv.* Giant Kew, waste utilization, pineapple fibre, vinegar, candy.

CHAPTER I

INTRODUCTION

INTRODUCTION

In recent years, there has been a growing emphasis on sustainable development, driving initiatives to enhance the efficiency of raw material utilization while minimizing waste generation in agriculture. By-products or residues are waste materials that have exceeded its utility or economic value and usually originate from human activities like forestry, farming, processing and animal husbandry (Routray and Orsat, 2017). The by-products from agro-industries are mainly generated from the food chain during harvest operations, storage, shipment, commercial processing, packaging, wholesale sectors, home consumption, and other processes (Zhu *et al*., 2020). Many agro-industrial wastes are not properly disposed or reused, leading to a detrimental impact on the health of humans and animals (Zihare *et al*., 2018). Utilizing agro industrial by-products minimizes environmental impact and reduces the expense associated with waste management. Additionally, it supports businesses financially by enhancing the value of wastes and by-products. In this context, the 'circular economy' refers to a system of resource utilization where production system components focus on reduction (minimizing the use of raw materials), reuse (maximizing the recycling of products and components), and recycling (high-quality reuse of raw materials) (Leder *et al*., 2019). When a product reaches the end of its intended use, its materials are retained within the economy and reused productively, thereby creating additional value. Also, according to the international agenda for 2030, the Sustainable Development Goals aims to minimize food losses in production and supply chains, including post-harvest losses and reducing per capita food waste at the retail and consumer levels (Holmberg and Erdemir, 2019).

The challenge of waste utilization in the fruit and vegetable processing industries has emerged as a globally significant task. Ensuring a complete utilization of horticultural produce is not only a requirement but also a demand for countries aspiring to implement low-waste technology in their agribusiness (Rudra *et al*., 2015). Horticultural waste refers to indigestible parts that are discarded at different stages such as collection, handling, shipping and processing. Wastes are generated at different stages from farm to consumer, encompassing both pre and post-consumer stages of the food supply chain (Panda *et al*., 2016). However, horticultural by-products contain valuable phenolic compounds, pigments, sugar derivatives, dietary fibers, organic acids, and minerals. Many of these bioactive compounds offer beneficial health attributes (Dilas *et al*., 2009; Yahia, 2017). Subtropical and tropical fruits exhibit significantly higher by-product ratios compared to temperate fruits (Schieber *et al*., 2001).

Pineapple [*Ananas comosus* (L.)] belongs to the family Bromeliaceae and originated in South America. It is a monocotyledonous, xerophytic, perennial plant with tough and spiny-tipped leaves which includes fragile dusty bloom on the underside as well as the waxy upper surface (Bartholomew *et al*., 2003; Smith, 2003). The plant can grow up to a height of 75-150 cm with a spread of 90-120 cm. The plant develops to a cone-shaped juicy and fleshy fruit with crown at the top (Morton, 1987). It is the only species that is grown commercially as a fruit crop and is greatly appreciated for its nutritional content. Pineapple is commonly consumed as fresh fruit, juice, RTS, fruit powder and concentrate. It is an excellent source of ascorbic acid, fairly rich in vitamin A, B, K, protein, fibre, essential nutrients and minerals (calcium, magnesium, potassium, phosphorus, sodium, manganese, iron) and antioxidants namely flavonoids (Hossain *et al*., 2015). Also bromelain, a proteolytic enzyme present in pineapple, has wide applications in pharmaceutical and food uses (Hebbar *et al.,* 2008). Pineapple ranks as the third most important tropical fruit after banana and citrus, contributing over 20% in tropical fruit production of the world (UNCTAD, 2016). The total production in India was reported to be 1.71 million tonnes, constituting approximately 6.07% of the global production of 28.17 million tonnes (FAO, 2019).

In pineapple cultivation, a significant amount of leaves are generated alongside the fruits, and as such two types of waste can be termed from pineapple production: pineapple on farm waste (POFW), typically encompassing leaves, roots, and stem remnants at the farm, and pineapple processing waste (PPW) which generates huge amount of waste during pulping and juicing (Banerjee *et al.,* 2018).The industrial processing of pineapples contributes to a notable portion of fruit biowastes, primarily consisting of peel (30%), pomace (50%), core (7%), and crown (13%), accounting for approximately 25–35% of the overall fruit (Banerjee *et al*., 2018). Food valorization has been advocated as an innovative method to preserve the beneficial and economical qualities of food waste and undesirable by-products. (Garcia-oliveira *et al*., 2022). Currently waste management methods include land filling, incineration, pyrolysis, gasification, composting and anaerobic digestion. However, these approaches often involve considerable capital costs for waste disposal, and the use of land contributes to greenhouse gas emissions. In addition, pineapple by-products present vast market opportunities due to their versatile applications in food, textile and pharmaceutical industries (Scheiber *et al*., 2001). Hence, adopting efficient and cost-effective technology is crucial for recovering valuable by-products, which will also stabilize the economy.

Pineapple leaves, which constitute a substantial portion of the plant, are largely unused and require significant attention for commercial exploitation. After harvesting pineapple fruits, these leaves are typically discarded, either through burning or natural decomposition (Wan and Zainuddin, 2013). Pineapple leaves contain long fibres suitable for various textile and non-textile applications. Utilizing these leaves would significantly reduce waste, thereby mitigating environmental impact. Plant waste fibres or agro-wastes, are lignocellulosic materials composed of lignin, cellulose, and hemicelluloses.

Compared to synthetic fibres, natural fibres are abundant, sustainable, biodegradable, renewable, cost-effective and environmentally friendly, making them suitable for diverse applications, including textiles, composites and paper and pulp manufacturing (Reddy and Yang, 2005). Pineapple cultivation in India involves over 25,000 plants per hectare, with each mature leaf weighing around 65 to 70 grams, contributing to an annual production of over 100,000 tons of pineapple leaf fibre (PALF), valued at approximately $200 million internationally with an average yield of 2-2.5% (Hazarika *et al*., 2016).These fibres can be used to reinforce polymer composites and serve as alternatives to synthetic fibres (Pandit *et al*., 2020). Pineapple leaf fibres (PALF) are noted for their softer texture compared to other vegetable fibres, while also exhibiting high strength and a smooth surface (Jose *et al*., 2016). Considering agricultural waste, PALF demonstrate high specific strength, rigidity, and flexural and torsional rigidity, comparable to jute fibres. They are classified as high-grade commercial fibres, positioned between jute and cotton or jute and ramie, and possess all necessary textile properties. PALF can be blended effectively with jute, cotton, ramie and some synthetic fibres (Ghosh *et al*., 1979). However, the quality of natural fibres is influenced by factors such as plant age, growing environment, species, harvesting methods and temperature (Velde and Kiekens, 2001).

Wastes generated during pineapple processing are valuable raw materials primarily composed of dietary fibre, pectin, protein, phenolic compounds, vitamins, proteolytic enzyme, bromelain and minerals (Diaz-Vela *et al*., 2013). Pineapple waste are rich in sugars, which serves as an ideal substrate for fermentation, enabling production of vinegar and various fermented beverages (Tropea *et al*., 2014). These residues also contain bioactive compounds, suggesting a potential for developing higher-value specialty vinegars. Vinegar production can enable the processing industries for utilization of excess, substandard fruit and processed by-products without jeopardizing the quality of the finished product. The pineapple processing industries produces mainly canned pineapple and pineapple juices, generating high amounts of by-products such as peels (29–42%), core (10–20%) and minor amounts of crown and stem (Pardo *et al*., 2014). Vinegar has been a staple in human diets for ages, serving as a condiment, aromatizer, preservative, nutritious beverage, and a widely used in ancient medicine due to its therapeutic qualities (Solieri *et al*., 2009). Vinegar can be made from any non-toxic material that has sugar juice or can be made with sugar juice (Omojasola *et al*., 2008). Vinegar is also recognized as a functional food, serving as a food preservative, medicine, and antioxidant (Budak *et al*., 2014; Shizuma *et al*., 2011). The production of vinegar is an economical food fermentation process that can be carried out at minimal costs using fruit waste (Solieri and Giudici, 2009). The vinegar production involves two biotechnological processes: alcoholic fermentation by Saccharomyces yeasts which converts sugars to ethanol, followed by ethanol oxidation to acetic acid by acetic acid bacteria (Raspor and Goranovic, 2008). Fruit vinegar is a nutritious product with functional properties that has recently piqued consumer interest because of its antimicrobial, anti-inflammatory, antidiabetic, antioxidant and antihyperlipidemic effects (Yagnik *et al*., 2021).

Pineapple core is a significant by-product in the canning industry, constituting 15% of the total pineapple processing waste (PPW). It is a rich source of the bromelain enzyme (Tochi *et al*., 2008). Instead of being discarded, the pineapple core can be utilized for candy making. Candy is a confectionery made by impregnating fruits or vegetables with sugar syrup, draining the excess syrup, and drying the resultant product to a shelf-stable state for storage. Various fruits and vegetables, such as citrus peels, apples, ginger, mangoes, guava, and carrots, have been used to make candy (Sharma *et al*. 1998; Ribeiro and Sabaa 1999; Chandu and Prasad, 2006). White sugar, containing 99.7% sucrose, is typically used as the sweetening agent in candy preparation (Durrani *et al*., 2011).

Northeast region is one of the major pineapple growing areas of India, with Nagaland occupying an area of 9 thousand ha with a total production of 142.5 thousand tonnes/annum (NHB, 2019). Considering the importance of pineapple crop in this region and with the increasing production, wastes are also proportionally increasing. Therefore, utilization of these residues has a promising prospect not only in terms of minimizing environmental impact but also for obtaining an added income for pineapple growers. Despite being an important crop of this region and the high value-added products that can be obtained from its waste, study on waste utilization and qualitative analysis on recovery of by-products has not been studied in depth. Keeping in view of the aforesaid points and considering the potential of pineapple waste, the present study was undertaken with the following objectives:

i. To study the quality of fibre extracted from pineapple leaf.
ii. To study the qualitative parameters of vinegar produced from pineapple waste.
iii. To study the preparation of candy from pineapple core

CHAPTER II

REVIEW OF LITERATURE

REVIEW OF LITERATURE

2.1. To study the quality of fibre extracted from pineapple leaf

Natural fibres are commonly classified by their botanical origin. Mcdougall *et al*. (1993) categorized them into several types: bast fibres (jute, flax, cannabis, ramie, and kenaf), leaf fibres (banana, sisal, agave and pineapple) seed fibres (coir, cotton and kapok), grass and reed fibres (wheat, maize and rice).

In general, natural fibres are known for is low energy consumption, low density, non-abrasive nature, affordability, renewability, biodegradability, easy availability and widespread abundance (Sanadi *et al*., 1995).

Yfoulis and Fasoulas (1998) reported that lower temperature and environmental stress reduces plant vigour and alter fibre properties by decreasing cellulose within secondary walls.

The mechanical properties of plant fibres are influenced by their physical, chemical and morphological characteristics. Attributes such as fibre shape, size, crystallite content, orientation and wall thickness significantly affect the properties of individual fibres (Bledzki and Gassan, 1999).

Furthermore, the proportion of cell wall molecules, including cellulose, hemicelluloses, lignin and structural proteins is expected to control the variability in the mechanical properties of the fibre cells (Palit *et al.*, 2004).

Pettigrew (2001) reported that cotton fibre formed at high temperatures was 3% stronger than that formed under ambient conditions, and that poor quality fibre is produced in conditions with less sunlight.

Gominho *et al.* (2000) investigated the potential of *Cynara cardunculus* for pulp production by studying the chemical composition and pulping potential

of the stalks. They reported that the whole stalks contained 7.7% ash, 14.6%extractives, 17.0% lignin and 53.0% polysaccharides, primarily cellulose and xylans.

Shatalov and Pereira (2002) conducted a comparative study on the pulping ability of *Arundo donax*, focusing on the main morphological parts of the stem, including nodes and internodes. The study revealed differences in chemical composition between these parts, which affected their pulping characteristics. In particular, internodes contained ash (6.14%), extractives (11.16%), lignin (21.31%), hemicellulose (28.48%) and alpha-cellulose (32.93%), while nodes had ash (4.77%), extractives (13.04%), lignin (20.92%), hemicelluloses (32.03%) and alpha-cellulose (29.18%.

Mazumdar *et al.* (2005) investigated on Chinese kenaf (*Hibiscus cannabinus* L.) variety Sekko-ichi, which was planted and harvested at various stages: 76, 116, 152, 185, and 226 days after planting. The bast fibres were separated manually by hand and analyzed for lignin content. Using pyrolysis-gas chromatography, the study revealed that the ratio of syringyl to guaiacyl products (S/G) increased from 1.86 to 3.16 with maturity and remained at a constant after 152 days.

Uma *et al*. (2007) evaluated Indian culinary bananas for their suitability in fibre extraction, comparing manual and mechanical methods to determine fibre yield. Fibre yields from mechanical extraction ranged from 0.24% to 1.15%, with the highest yield in the Enna Benian variety (1.15%) and the lowest in the Birbutia variety (0.25%). In contrast, manual extraction produced fibre yields between 0.13% and 0.78%, with Enna Benian again recording the highest (0.78%) and Kallu Monthan the lowest (0.13%).

Mohammed *et al*. (2009) evaluated pineapple leaf fibre from three popular cultivars (Josapine, Sarawak and Moris Gajah), characterizing them physically and mechanically to identify the most suitable cultivar for fibre production. The tensile strengths and Young moduli of the pineapple leaf fibre (PALF) from these cultivars were generally higher than some reported values, while elongations at break were lower. The 'Josapine' PALF exhibited the highest tensile strength, Young's modulus and elongation at break. For all the cultivars, tensile strength and Young's modulus decreased with increasing diameter, while elongation at break remained unaffected. The fibre quantity, fineness, mechanical properties, and thermal stability, josapine was the most favourable cultivar, followed by sarawak and moris.

Shen *et al.* (2009) aimed to establish baseline data on cell wall development in different sections of developing internodes in switch grass (Alamo variety). Their findings revealed that the stem had the highest lignin content compared to other parts.

Banik *et al.* (2011) reported that pineapple leaf fibres extracted with a conventional decorticator had a fineness of 2.8 tex, a tensile strength of 26.1 g/tex, and an extension at break of 3.0% and chemical composition of Cellulose 69.5% and lignin 4.4%.

Mortazavi and Moghaddam (2010) conducted a study on leafiran fibres to assess their tensile properties using hot alkali treatment. They found that leafiran fibre had a tenacity of 25-40 cN/tex and a linear density of 4 tex. Their results also indicated that higher lignin content enhances the extension ability of natural fibres, with leafiran fibres (26% lignin) demonstrating greater elongation compared to kenaf (17% lignin), jute (9% lignin) and pineapple (8.3% lignin) fibres.

Nadirah *et al.* (2012) investigated the chemical and thermal properties of cultivated pineapple leaf fibres (PALF). Their study reported that the fibres contained 74.33% of cellulose, 10.41 % of lignin, 4.73% of ash and 6.68% of other extractives.

Sengupta and Debnath (2012) studied on jute-based ternary blended yarns and analyzed the fibre properties of jute before blending it into yarn where tensile strength of 23 cN/tex was obtained in jute fibre.

Belkhir *et al.* (2013) investigated on seasonal variations in chemical composition of esparto leaves. They found that cellulose content was 43.3% in winter season and 44.5% in summer season, while ash content was lower during winter season (2.4%) as compared to summer season (3.4%).

Zainuddin *et al.* (2014) examined the physicochemical properties of pineapple fibres extracted from leaves and stems of different varieties (MD2, Josapine, and Moris). The study reported a crude fibre content ranging from 30.93% to 31.04% in leaves and 37.63% to 41.75% in stems. Total nitrogen content varied between 0.37% and 0.64%o, with highest levels in the Moris variety (1.13%), followed by MD2 (0.93%) and Josapine (0.91%). Among the stems, Josapine had the highest nitrogen content (0.64%), while MD2 had the lowest (0.37%). Ash content was relatively consistent in leaves- MD2 (2.35%), Josapine (2.11%), and Moris (2.08%) but was notably higher in stems, with the Josapine cultivar showing the greatest value. The study also highlighted significant variability in lignocellulosic content across different parts of the pineapple plant.

Braga *et al.* (2015) analyzed the chemical composition of pineapple crown leaf biomass to evaluate its energy potential for use in energy conversion. The study revealed the following chemical composition: hemicellulose

(35.49%), cellulose (12.93%), lignin (26.40%), extractives (25.18%), moisture (8.96%), and ash (5.22%)

Divya *et al.* (2016) evaluated the fibre extraction and quality of different genomic groups of bananas (*Musa paradisica* L.) using four cultivars: Grand Naine (AAA), Karpura Chekkarakeli (AAB), Kovvur Bontha (ABB) and FHIA-3 (AABB). Their study found that machine extraction yielded the highest fibre recovery percentage (1.172%), followed by 0.5% NaOH treatment (0.466), while 0.75% NAOH had the lowest recovery (0.328%). Among the cultivars, Kovvur Bontha achieved the highest fibre recovery percentage (1.66%), followed by Karpura Chekkarakeli with 1.260%, and FHIA-3 had the lowest recovery (0.663%).

Gebino *et al.* (2018) reported an elongation at break of 2.45% and a tensile strength of 228.3 MPa for Ethiopian pineapple leaf fibre.

Jose *et al.* (2018) investigated the potentiality of Indian pineapple leaf fibre for apparel use from the Queen Variety. The fibres were collected and extracted using a decorticator after a two-year growth period from a plantation in Assam. The study reported a tensile strength of 2 1.1 cN/tex for the decorticated pineapple leaf fibres and 22.5 cN/tex for the retted fibres. The initial modulus was 1038 cN/tex for the decorticated fibres and 1009 cN/tex for the retted fibres.

Jalil *et al.* (2019) conducted a comprehensive study on the characterization and spinning performance of pineapple leaf fibres, highlighting their economic and sustainable potential for the textile industry in Bangladesh. The study revealed that pineapple leaf fibres have a relatively high linear density of 3.20 tex and a breaking elongation ranging from 2.5% to 4.0%.

Vijay *et al.* (2019) studied the characterization of raw and alkali-treated natural cellulosic fibres from *Tridax procumbens*. Their findings revealed that alkali treatment increased the cellulose content while reducing hemicellulose, lignin and wax. It also enhanced the fibres thermal stability, tensile strength, crystallinity and surface roughness.

Faria *et al.* (2020) studied pineapple crown fibre for nanocellulose production and reported the chemical composition of unbleached fibre, which included lignin (12.2%), alpha cellulose (51.4%) and hemicellulose (13.4%). The fibre also had a moisture content of 12.7%, ash content of 6.73% and extractives at 3.62%.

Soraisham *et al.* (2021) investigated on the potential of fibres extracted from banana (*Musa domestica* var. balbisiana) for textile use. They optimized the retting period to 28 days in water, and the extracted fibres exhibited a tensile strength of 34.86 cN/tex , elongation of 2.4% and an initial modulus of 1727.7 cN/tex.

Alam *et al.* (2022) investigated the physio-mechanical properties of pineapple leaf fibres extracted using a decorticator machine to separate the cambium and fibre. Their study reported fibre strength of 28.56 g/tex, linear density of 2.22 tex, a breaking extension of 1.21% and a textile modulus of 29.26 N/tex.

Saikia *et al.* (2023) evaluated on physical properties of mechanically extracted *Musa acuminata* fibres. The extracted fibres underwent process of degumming (1:30 liquor ratio) and bleaching (5% hydrogen peroxide). Their findings showed that untreated *Musa acuminata* fibres had the highest tensile strength (22.00 g/tex), while bleached fibres exhibited a lower tensile strength (18.65 g/tex), indicating their suitability for applications requiring strength and durability.

Johny *et al.* (2023) studied on the extraction and physico-chemical characterization of pineapple crown leaf fibres. Their findings confirmed that

PCLF fibres are substantially similar to pineapple leaf fibres, reporting a tensile strength of 24.3 MPa and a strain at maximum strength of 2.19%. They also reported the chemical composition of pineapple crown leaf fibre, which comprised of cellulose (67.3%), hemicellulose (16.9%), lignin (7.4%), wax (3.8%), pectin (1.3%), and ash (0.8%).

Jalil *et al.* (2024) reported a fineness of 3.4 tex, a tensile strength at break of 23 cN/tex, and an elongation at break of 3.95% in bleached pineapple leaf fibres.

2.2. To study the qualitative parameters of vinegar produced from pineapple waste

2.2.1. Vinegar

The word vinegar is derived from the French 'vin', meaning wine and 'aigre' which means sour (Allgeier, 1974). Vinegar is a sour and sharp liquid used as a condiment and for food preservation. There are primarily two types of vinegar- synthetic and brewed. Brewed vinegar is produced through alcoholic fermentation followed by acetous fermentation of any sugary or starchy material (Okafor, 1987). Whereas synthetic vinegar is made from only acetic acid and water having 4 per cent minimum acetic acid (Beheshit maal *et al*., 2010)

Vinegar, a traditional fermented product can be made from a variety of raw materials, each imparting a unique taste and flavour. This traditional acidic condiment is widely produced from various agricultural materials such as rice, malt, apples, wine, molasses, dates, sorghum, pears, grapes, berries, melons, coconut, honey, , malt grains and whey (Frazier and Westhoff, 1998).

Acetic acid, the main acid in vinegar, provides its characteristic strong aroma and sour taste. Consequently, vinegar is extensively used as a food preservative and seasoning (Ho *et al*., 2017).

2.2.2. Official Standards for vinegar

According to the Food and Agriculture Organization (FAO) of Rome, vinegar is defined as a liquid fit for human consumption, produced from substances containing starch and/or sugar through alcoholic and acetous fermentation. The residual ethanol content in vinegar must be less than 0.5% for wine vinegar and 1% for other types of vinegar (Joint FAO/WHO Food Standards Program, 1998). The Food and Drug Administration (FDA), vinegar must contain a minimum of 4% acetic acid (Food and Drug Administration, 2006).

2.2.3. Vinegar production

Vinegar is produced through two distinct biochemical stages. Initially, yeasts typically Saccharomyces species, ferments raw sugary and starchy materials into ethanol. Subsequently, acetic acid bacteria (AAB) oxidize the ethanol into acetic acid in an aerobic process. AAB are well known for their ability to spoil wines because they can produce large amounts of acetic acid from ethanol and other compounds present in wines (Joyeux *et al.,* 1984).

2.2.4. Microorganism involved in vinegar production

The microorganisms involved in vinegar production are primarily yeasts and acetic acid bacteria. Yeasts are responsible for alcoholic fermentation, while acetic acid bacteria are essential for acetification or acetic acid fermentation.

2.2.4.1. Alcoholic fermentation

Yeasts are defined as unicellular ascomycetous or basidiomycetous fungi, with vegetative growth primarily occurring through budding or fusion. They do not form their sexual states within or upon a fruiting body (Kurtzman and Fell, 1998)

Yeasts from the family Saccharomycetaceae within the phylum Ascomycota are crucial for alcoholic fermentation. Jay *et al.* (2005) highlighted that these yeasts are particularly favoured for the fermentation of juices due to their high tolerance to acidity. Their robustness under acidic conditions makes them the microorganism of choice in various fermentation processes, contributing significantly to the production of alcoholic beverages.

Bai *et al.* (2008) reported that the substrates for yeast metabolism were mainly mannose, fructose, glucose, and sucrose, which were metabolized to two molecules of pyruvate and acetaldehyde. These were further converted into ethanol and carbon dioxide by the action of the enzymes pyruvate decarboxylase and alcohol dehydrogenase. The yeast *Saccharomyces cerevisiae* had the ability to dominate the fermentation process, even in natural fermentations, which led to the production of vinegar in ancient times.

2.2.4.2. Acetic acid fermentation

Acetic acid bacteria (AAB) are Gram-negative, typically ellipsoidal to rod-shaped microorganisms that are aerobic and use oxygen as the terminal electron acceptor. Initially, AAB were classified into two primary genera, *Acetobacter* and *Gluconobacter*. However, the classification has expanded to include twelve additional genera which are now recognized within the family Acetobacteraceae (Sengun and Karabiyikli, 2011).

Acetobacter aceti are Gram-negative bacteria, motile due to the presence of flagella, which can be either peritrichous or polar. They are catalase positive and oxidase negative (Holt *et al*., 1994).

De Ory *et al*. (1999) observed that optimum temperature to maximize the specific growth rate of Acetobacter aceti was 30.9˚C.

2.2.5. Production methods of vinegar

There are three different methods for vinegar production ranging from traditional methods employing wooden casks (Orleans Process) and surface culture (Generator Process) to submerged fermentation (Bhat *et al*., 2014).

2.2.5.1. The Orleans Process

The oldest and well known method for vinegar production is an Orleans slow process method. It is a slow, continuous process, which originated in France. The vinegar produced by Orleans process was high in quality characteristics due to the slow process that stimulates the development of flavor and aroma (Cruess, 1958).

Raspor and Goranovic (2008) reported that vinegar produced using the Orleans process achieved high quality due to the extended fermentation period, which enhances flavor and aroma development. Their findings indicated it ensured a steady supply of finished vinegar. However, a significant drawback of this method is the lengthy production time that leads to elevated costs per unit volume, despite relatively low equipment and operational expenses.

2.2.5.2. Generator process

This method, also called the fast process or German process became the primary industrial production method in the nineteen and twentieth centuries, emphasizing the use of a generator system. In the generator or quick process, the fermenter is a large container filled with sawdust or similar material that provides a large surface area for acetic bacteria to thrive. Wine is circulated through the generator while air is injected in the opposite direction (Peppler and Beaman, 1967).

2.2.5.3. Submerged process

The submerged process of vinegar production is notably more efficient and cost-effective than other methods, making it particularly well-suited for industrial applications. This fermenter suspends bacteria in the medium, distinguishing them from the traditional process (De Ory *et al*., 1999).

In the submerged process, bacteria are substrate-free, and air is introduced into the medium via a bottom stirrer in the tank. The fermentor includes features such as air outflow, cooling coils, a thermometer, and a foam control system (Mazza and Murooka, 2009).

2.2.6. Physico-chemical properties of vinegar

Kocher *et al*. (2006) studied the conversion of sugarcane juice to ethanol by *Saccharomyces cerevisiae*. The ethanol obtained was used for vinegar production using adsorbed (bagasse, corn cobs and wood shavings) and entrapped (calcium alginate) cells of *Acetobacter aceti*. All the three adsorbed carrier materials were statistically similar for acetic acid production and produced acidity from 5.9 to 6.7% after 28 days of submerged fermentation.

Sossou *et al.* (2009) investigated the processing of pineapple peelings into vinegar using biotechnological methods. They isolated two microorganisms from pineapple juice: *Saccharomyces cerevisiae* (LASO1) and *Acetobacter* sp. (ASVO3). The study involved successive fermentations, with pineapple juice initially containing a sugar concentration of 20° Brix. The juice was inoculated with 10° cells of *Saccharomyces cerevisiae* for alcoholic fermentation over 4 days, followed by inoculation with 10° cells of *Acetobacter sp.* This process produced vinegar with 4.5 acetic degrees, a Brix value of 5.3% and a pH of 2.8 over a period of 23-25 days. The study also highlighted that the glucose tolerance of *Acetobacter sp.* was crucial for the growth of acetic bacteria in high-sugar environments, and ethanol concentration did not affect the growth of the acetic bacteria.

Raji *et al.* (2012) investigated the production of vinegar from pineapple peel using a two-stage fermentation process. Initially, the pineapple peel was fermented for 48 hours with baker's yeast (*Saccharomyces cerevisiae*) to convert sugars into ethanol. Following this, a secondary fermentation stage employed acetic acid bacteria (*Acetobacter aceti*) with continuous aeration over nine days to convert ethanol into vinegar. Parameters such as pH, refractive index, viscosity, and percentage of acetic acid were evaluated and recorded as 2.80, 1.08 g/ml, 1.390 and 0.94 cp, respectively. The study concluded that pineapple peel was effective in producing vinegar with optimal yield.

Byarugaba-Bazirake *et al.* (2014) utilized banana peels, which still contained adequate starch to produce vinegar. The process involved separating the extract from the peels, boiling it to gelatinize the starch, filtering it through muslin cheese cloth and then fermenting it with wine yeast. The study demonstrated that matooke peels are a suitable substrate for producing high-quality vinegar. The fermentation process took 28 days, resulting in vinegar with 6.0% (v/v) acetic acid, 5.0°Brix and a pH of 2.9, which falls within the standard ranges for brewed vinegar

Minh (2014) conducted a study on fermentation of star fruit juice into vinegar using the yeast *Saccharomyces cerevisiae* and *Acetobacter aceti* bacteria. The study found that acetic acid production was highest at an ethanol concentration of 10% and an optimal pH of 3.5.

Praveena *et al.* (2014) carried out a study on phytochemical screening and antioxidant capacities of vinegar made from peel and fruit of pineapple. Light yellow coloured vinegar was obtained from the pineapple fruit mixture, while light brown vinegar was derived from pineapple peel mixture, both exhibited mild fruity, acetic aroma through simultaneous fermentation by *Saccharomyces boulardii* and *Acetobacter*. The results further indicated presence of carbohydrates, saponins, flavonoids, tannins, quinines, terpenoids and coumarins in pineapple peel and fruit vinegar. Additionally, the antioxidant content was found to be higher in peel vinegar (2077 mg acetate equivalence/100 ml).

Umaru *et al.* (2015) investigated the production of vinegar from pineapple wine. In their study, pineapple peel juice was fermented using *Saccharomyces cerevisiae*, followed by oxidation to vinegar (acetic acid) with *Acetobacter* species. The resulting wine had a total alcohol content of 10.8%. The vinegar produced had a pH value of 3.6, titratable acidity of 0.24 g/ml (lactic acid) and 0.16 g/ml (acetic acid), with a total acidity of 3% (acetic acid).

Dias *et al.* (2016) studied the production of jabuticaba vinegar using a mixed culture of immobilized cells. The acetic acid fermentation was performed with a mixed culture of immobilized *Acetobacter aceti* CCT 0190 and *Gluconobacter oxydans* CCMA 0350 cells. The vinegar exhibited particularly high concentrations of citric acid (6.67 g/L), malic acid (7.02 g/L), and succinic acid (5.60 g/L).

Raichurkar and Dadagkhair (2017) studied on preparation of vinegar from custard apple and analyzed its physicochemical properties. The vinegar production process lasted 30 days and yielded custard apple vinegar with a specific gravity of 1.019, 5.39% (v/v) acetic acid, 2.0 °Brix and a pH of 2.8, all within the standard ranges for brewed vinegar after complete fermentation. Sensory evaluation by ten panel members rated the market vinegar samples as ‘like extremely’ on a nine-point hedonic scale, while the custard apple vinegar was rated as ‘like very much.

Roda *et al.* (2017) used physical and enzymatic treatments for saccharification of pineapple waste, followed by fermentation with

Saccharomyces cerevisiae for 7-10 days under aerobic conditions at 25°C. This process yielded approximately 7% alcohol. The resulting alcoholic medium was then used as a seed broth for acetic fermentation with *Acetobacter aceti* as the inoculum, conducted for about 30 days at 32°C, resulting in 5% acetic acid.

Beegum *et al.* (2018) conducted a comparative evaluation of natural vinegar produced from mature coconut water and partially fermented coconut inflorescence sap. The study aimed to assess the fermentation behavior and quality of vinegar derived from these substrates. Initially, alcoholic fermentation was predominant in the mature coconut water. However, in the later stages of fermentation, acetic acid production in the sap was accelerated, resulting in a higher acetic acid concentration in the sap-based vinegar (5.87%) compared to the vinegar from mature coconut water (4.20%). The findings indicated that the higher alcohol content in the coconut sap was associated with increased acetic acid production. Furthermore, as alcohol concentration decreased, there was a corresponding gradual increase in acetic acid concentration.

Chalchisa and Dereje (2021) investigated the effects of fermentation time and bacterial strains on acetic acid production from pineapple peels. The study aimed to produce vinegar using three strains of acetic acid bacteria- *Propionicbacterium acidipropionici*, *Pantoea agglomerans*, and *Pantoea dispersa*. A factorial experimental design was used, considering fermentation times of 24, 48 and 72 hours with the three bacterial strains. The fermentation was carried out in 500 mL Erlenmeyer flasks with 200 mL of medium at 28°C, with aeration rate, temperature, and carbon source held constant. The study reported pH values ranging from 3.5 to 4.31, total soluble solids between 1.3 and 2.31 °Brix, total residual reducing sugar from 0.50% to 2.47% and titratable acidity from 3.13 to 6.15 mg/100g. Significant differences ($P<0.05$) were observed in these parameters. The study reported that both bacterial strain and fermentation time significantly influence vinegar production, with the highest acetic acid yield of 6.15 g/L achieved after 72 hours of fermentation using *Propionicbacterium acidipropionici.*

Constance *et al.* (2021) investigated the vinegar production capabilities of *Garcinia kola* (bitter kola) and *Artocarpus heterophyllus* (jackfruit). The study employed both added inoculants and naturally occurring indigenous inoculants for fermentation. The process involved seven days of alcoholic fermentation at 30°C, followed by 28 days of acetic fermentation. The results revealed that the pH of the vinegar ranged from 2.6 to 2.9 for bitter kola, 3.20 to 3.73 for jackfruit with peel, and 3.20 to 3.40 for jackfruit without peel. Acetic acid yields varied from 0.80% to 2.30% for bitter kola, 0.80% to 1.92% for jackfruit with peel, and 0.98% to 1.92% for jackfruit without peel. The alcohol content ranged from 0% to 0.5%, and the specific gravity ranged from 1.001 to 1.083.

Bertan *et al.* (2022) investigated on utilizing pineapple solid waste from processing pineapples to obtain value-added products (vinegar). Pineapple pulp and peel wines were fermented into vinegar using wild strains of acetic bacteria via traditional Orleans method, followed by enrichment with leaf extract from Red-Jambo (*Syzygium malaccense*). The study reported the following vinegar parameters: pH values were 3.64 for pulp, 3.65 for peel, 3.45 for pulp with extract and 3.48 for peel with extract; total acidity (g/100 mL) was 5.50 for pulp, 4.50 for peel, 5.58 for pulp with extract, and 4.73 for peel with extract. Further, peel wines exhibited higher luminosity (L*) and saturation index (C*) compared to pulp wines, with a color leaning more towards yellow. Acetification reduced the saturation index (C*) and intensified the hue angle in the peel vinegar.

2.3. To study the preparation of candy from pineapple core

Kakaidi *et al.* (2006) conducted a study on the preparation and shelf life of ber candy. The candies were stored in polyethylene bags and plastic boxes and analyzed at 30-day intervals over a 6-month period. The findings revealed that ascorbic acid and moisture content gradually decreased over time, while total sugar and reducing sugar content increased with storage period. In addition, the mean score for organoleptic properties such as taste, color, texture, and overall acceptability, also decreased as the storage period increased. These results indicate that the chemical constituents and organoleptic properties of ber candy stored in plastic boxes or polyethylene bags can be maintained for up to 180 days without any adverse effects on quality.

Verma *et al.* (2006) studied the effect of method of preparation and storage on the chemical characteristics of peel candy of darunj (*Citrus medica*). Candy was prepared by utilizing peel of darunj following slow and fast methods of preparation. The prepared product was wrapped in wax paper and stored at room temperature for 18 weeks. From the results of the study it was inferred that both the method of preparation as well as storage intervals had a significant effect on the chemical parameters like moisture, acidity, sugars, ascorbic acid and energy values.

Kumar and Sagar (2009) investigated on optimal osmotic concentration and temperature for dehydrating mango, guava slices, and aonla segments. The study found that acidity decreased with higher sugar concentrations due to acid leaching into the hypertonic solution, while ascorbic acid and sugar content increased. Higher temperatures reduced ascorbic acid retention. Sensory evaluations showed that 60 °Brix sugar concentration at 60 °C yielded the best results.

Durrani *et al.* (2011) studied on development and quality evaluation of honey based carrot candy with different combinations of honey. Sensory evaluation was performed to establish the most preferred candy and the preferred treatment of candy was further assessed for overall quality during storage at room temperature over a period of 6 months. The results indicated a decrease in sensory quality scores from an initial score of 8.3 to 6.8 over the storage period.

Nayak *et al.* (2012) evaluated aonla candies made from different cultivars (Krishna, NA-7, NA-10, and Chakkaiya) and flavoured with ginger and cardamom. The fruits were blanched in boiling water with 2% alum for 8 to 10 minutes, then cooled in tap water and cut into segments. These segments were soaked for 24 hours in sugar syrups with concentrations ranging from 50^0 to 70 ^{0}Brix, flavoured with ginger and cardamom in 70 °Brix syrup for three days, then dried in a cabinet drier and stored under ambient conditions. During storage period of nine months, the moisture and ascorbic acid decreased, while total soluble solids, acidity and browning increased and non-reducing sugar decreased. Based on organoleptic evaluation, candy made from Krishna cultivar and flavoured with cardamom powder was rated the best.

Gupta and Kaul (2013) conducted a comprehensive study to evaluate the effect of sugar concentration and time interval on the quality and storability of ber chuhara (*Zizyphus mauritiana*). An osmo-air drying process was optimized, with pretreatment involving dipping fruits in 5% NaOH for 5 minutes, rinsing with 5% citric acid, and soaking in a 4000 ppm KMS solution for 12 hours to enhance osmosis. Fruits were then steeped in sugar solutions (40, 50, 60, and 70°Brix) for 24, 48, and 72 hours before air-drying at 52 ± 2°C. During storage, moisture, ascorbic acid and tannin content decreased, while total sugars increased. Based on quantitative and sensory evaluations, ber chuhara prepared with 60°Brix steeping for 72 hours was rated the best, followed by those made with 70°Brix and 50°Brix sugar syrups.

Sharma *et al*. (2013) conducted a study to standardize the preparation protocol for wild apricot fruit bars. During six months of storage, moisture content increased, while total sugars and vitamin C decreased, accompanied by slight reductions in titratable acidity and sensory quality.

Shamrez *et al.* (2013) studied on preparation of candy from citron peel with treatments T_0 (control), T_1 (sliced citron peel + 30% sugar + potassium metabisulphite), T_2 (sliced citron peel + 40% sugar + potassium metabisulphite) and T_3 (sliced citron peel + 50% sugar + potassium metabisulphite). The candies were stored for six months and evaluated every 30 days using a 9-point hedonic scale. Results showed significant decrease in flavour, texture and overall acceptability scores, from 8.25 to 4.92, 9.00 to 5.25 and 8.70 to 5.00, respectively. Among the combinations, T_2 was the most preferred and remained stable for six months at room temperature.

Divya *et al.* (2014) investigated the effect of storage on nutritional attributes of sapota candy. They observed that as storage time increased, sapota candy stored in different packaging experienced a decrease in titratable acidity and ascorbic acid content. In contrast, the levels of reducing sugar and total sugar showed an upward trend with prolonged storage.

Jothi *et al.* (2014) assessed the prospect in marketability and storage life of pineapple preserve and candy. Pineapple slices were treated with 2% solution of common salt to prevent browning, then cut into cubes and treated with 1% calcium chloride and 0.25% potassium metabisulphite solution and finally processed. The preserves were processed with 60°, 65° and 70° Brix sugar syrup and candies were processed with 65°, 70° and 75° Brix sugar syrup. The results through sensory evaluation indicated that the preserve processed from 65° Brix sugar syrup and the candy processed from 70° Brix sugar syrup were the favourite sample with the highest overall acceptability. Further, the shelf-life of candy (6 months) packed in high-density polyethylene bag is higher than preserve (4 months) packed in glass bottle when stored at ambient temperature (27C to 30°C).

Khanom *et al.* (2015) developed pineapple candy using fresh pineapple slices dipped in 40%, 50% and 60% sugar solutions, and then dried in a solar drier. The slices, cut to 0.5 cm and 1.0 cm thicknesses were soaked overnight, with the thinner slices drying faster. Sensory attributes such as colour, flavour, texture and overall acceptability were evaluated using ANOVA followed by DMRT. The candy prepared from 0.5 cm slices osmosed in a 60% sugar solution was the most preferred.

Mondal *et al.* (2017) conducted an investigation to determine the optimal sugar concentration for preparing aonla candy. Candies were prepared with sucrose syrup concentrations of 40%, 50%, 60%, 70% and 80%, with fresh aonla candy used as a control. The shelf-life stability of the candy was assessed over a period of 120 days at ambient temperature. The findings indicated significant decrease in moisture and ascorbic acid content with increasing storage duration, while reducing and total sugar levels increased significantly. Sensory evaluations revealed that although most samples maintained good colour, flavour, texture, taste and overall acceptability, these attributes gradually declined over time. The study concluded that varying sugar syrup concentrations significantly influenced the quality parameters of aonla candy.

Dwivedi and Pandey (2017) carried out an experiment for development of protocol for preparation and preservation of ginger flavoured aonla candy. Their findings underscored significant alterations in the candy attributes during storage. Initially, the candy registered a moisture content of around 18%, which gradually diminished to approximately 13% over the storage period. Over the course of four months, there was a gradual increase in total sugar content 68.62-73.36 %, while the levels of ascorbic acid exhibited a declining trend 132.80 to 56.48 mg/100g. Through sensory evaluation and biochemical analysis, aonla candy treated with a 2% ginger extract emerged as the most suitable option.

Rajeshbhai *et al.* (2018) studied the preparation of carrot candy using different levels of sugar/syrup treatments, storing the processed candy at room temperature for periodical evaluation at 0, 2, 4 and 6 months to study qualitative changes. The findings revealed that, over six months of storage, the carrot candy showed a decrease in acidity and moisture content and an increase in reducing and total sugar content.

Mahato *et al*. (2020) investigated the preparation and evaluation of fruit candy from unripe mango using eight treatments with different blanching methods and sweetening agents. Hot water blanching with 40°Brix sugar syrup (T_3) resulted in high TSS, total sugar and reducing sugar, while hot water blanching with 40°Brix honey syrup (T_7) showed better biochemical retention. The highest overall acceptability score (8.77) was recorded for T_3. The study demonstrated that unripe mango slices can be effectively processed into candy, which remains stable for up to six months when stored in polyethylene pouches under ambient conditions. Further, total sugar and reducing sugar content increased, while acidity, ascorbic acid and organoleptic scores declined with the progression of the storage period across all treatments in unripe mango candy.

Bansode *et al.* (2021) investigated the effect of different storage periods (0, 30, 60 and 90 days) on the chemical and sensory characteristics of ginger candy. Ginger was soaked using seven different treatments and the candy was prepared using two methods through cold syruping and vacuum syruping. The blanched ginger candy prepared using the vacuum syruping method demonstrated the best chemical and sensory characteristics, achieving the highest sensory scores compared to the cold syruping. During the 90 days storage period, moisture content decreased from 11.29% to 7.09%, acidity reduced from 1.98% to 1.05% while TSS increased from 68.27°Brix to 72.04°Brix.

Gupta *et al.* (2020) studied on preparation of osmo-dried galgal peel sticks using different concentration of sugar and jaggery solution of 30^0, 40^0 and 50 ^{0}Brix. The prepared galgal sticks were stored at ambient temperature to evaluate changes in chemical and organoleptic quality at monthly intervals for three months. A decreasing trend in titratable acidity (0.57% to 0.53%), moisture

(14.85% to 13.34%) and ascorbic acid (123.83 to 113.5 mg/100 g) was observed. Treatment with 50^0 brix sugar demonstrated the highest overall acceptability throughout storage, making it the most preferred candy even after three months.

Kaur and Singh (2021) investigated the methods for preparing kinnow peel candies, testing nine treatments to reduce bitterness through various boiling, soaking and brining techniques. Treatment T_2 (multiple boiling for 8 to 10 minutes, followed by cooking and steeping in 75° Brix sugar syrup) achieved the highest quality in terms of acceptability, taste, flavour, total soluble solids (TSS) and ascorbic acid. Treatment T_1 (single boiling for 15 minutes) also yielded favourable results but was less effective than T_2. The study observed a significant increase in total sugar content and a decrease in ascorbic acid and titratable acidity. Flavour also notably declined, with mean score for overall acceptability dropping from 7.86 to 6.2 during the storage of kinnow candies.

Kour *et al.* (2020) investigated on utilization of eureka lemon peel for the development of value-added product. The process involved washing and blanching the peels for 5 minutes, followed by soaking in sugar and jaggery syrup for 24 hours. After draining, the peels were dried at 60°C for 4–5 hours, then packed in LDPE bags and stored at room temperature for three months. The study reported that osmo-dried peel flakes prepared with 75°Brix sugar syrup were superior in overall acceptability compared to other treatments. During the storage period, ascorbic acid content decreased from 10.60 to 4.10 mg/100 g, while total sugar content increased significantly from 50.20% to 52.58%. Overall acceptability declined from 8.11 to 7.93 over three months. The study confirmed that osmo-dried Eureka lemon peel flakes which are typically considered waste can be effectively transformed into a desirable product.

Kour *et al.* (2021) investigated on enhancing the shelf life of ripe Santa Rosa plums by subjecting them to osmotic treatment using sugar and honey solutions ranging from 40% to 70%. Following dehydration, the osmo-dried plums were packed in low-density polypropylene and stored at ambient temperature for three months. During storage, increasing trends were observed in reducing sugars and total sugar, while titratable acidity declined. Among the osmotic agents tested, osmo-dried plums treated with 70° Brix honey syrup were rated highest in overall acceptability, followed by those treated with 60° Brix honey syrup.

Verma *et al.* (2023) investigated on osmotic dehydration of karonda using sugar and jaggery solutions at concentrations of 50^0, 60^0 and 70 ^{0}Brix. The karonda was soaked for 24 hours before being dehydrated in a cabinet dryer and packaged in low-density polyethylene pouches in ambient storage for three months. The study found that the mean values of total sugar content in osmo-dried karonda increased significantly from 38.84% to 41.54% and reducing sugar content increased from 32.99% to 35.68% during storage, while ascorbic acid content decreased from 10.08 to 3.92 mg/100g. in terms of sensory attributes, treatment with 70 ° Brix sugar syrup treatment was superior scoring 7.90, 7.92, 7.95 and 7.92 for colour, texture, taste and overall acceptability respectively, without adversely affecting physico-chemical and sensory characteristics, and exhibited a good shelf life with no microbial spoilage for over 90 days.

Shrivastava *et al.* (2023) investigated the preparation and storage stability of papaya candy. The papaya candy was stored for three months, with observations recorded every 30 days. Sensory tests evaluated colour and appearance, texture, flavor, taste and overall acceptability. The study found a decreasing trend in all sensory attributes over the storage period. Treatment T_7 (1 kg papaya slices, sugar syrup at 75° Brix, and ginger extract at 5%) was identified as the most effective recipe, offering the best quality, storage stability, and maximum benefit-cost ratio.

CHAPTER III

MATERIALS AND METHODS

MATERIALS AND METHODS

The present investigation entitled "**Utilization of waste for various products from pineapple cv. Giant kew**" was undertaken at Department of horticulture, School of agricultural sciences, Nagaland University, Medziphema Campus during the year 2018-2021. The details of materials used and methodology employed during the course of investigation have been discussed below.

3.1. General information

3.1.1. Location

The pineapple leaf samples for fibre study and fruits were collected from the farmers fields at molvom village, Medziphema under Chümoukedima district, Nagaland. The geographical coordinates of Molvom village is 20^0 45'45''N latitude and 93^0 53'04'' E longitudes at an elevation of 360 meters above mean sea level (msl) and is bounded by Assam on its North and West, Kohima on the East and Peren District in the South.

3.1.2. Climatic condition

The farmer's field lies in humid sub-tropical zone having annual rainfall about 2000-2500 mm per annum. The mean temperature ranges from 21 ^{0}C to 32 ^{0}C in summer and 8 to 12 ^{0}C in winter.

3.2. Experimental materials

The pineapple leaf and crown were harvested from established pineapple fields in the same area at molvom village. Pineapple fruits were procured from the farmer's field at molvom village. Commercial wine yeast *Saccharomyces cerevisiae* Lalvin (EC-1118) was obtained from Brew mart India and the bacterial culture *Acetobacter aceti* (MTCC 3347) from CSIR-Institute of

Microbial Technology, Chandigarh. The lyophilized culture was maintained on Yeast extract peptone mannitol medium and recultured on regular intervals

3.3. Experiment-I: To study the quality of fibre extracted from pineapple leaf

The pineapple sucker and crown based on different ages (main crop, first ratoon and second ratoon crop) were harvested from established pineapple fields around the same area at Molvom village. The samples were brought directly to the laboratory and separated for fibre extraction and proximate analysis. A total of 150 leaves for each replication were taken for fibre extraction. For proximate analysis, the leaf and crown samples were chopped and dried for further analysis. The samples for fibre extraction were collected for two consecutive years.

3.3.1. Technical details:

Experimental design	Split-Plot design
Replications	3(Three)
Factor	2 (two)
Period of investigation	2 years (2019-20 and 2020-21)
	Main plot factor

Season

S_1 : Summer crop

S_2 : Winter crop

Sub-plot factor:

Age

A_1 : Main crop

A_2 : 1st ratoon crop

A_3 : 2nd ratoon crop

Type of leaf at harvest

T_1 : Leaf /sucker

T_2 : Crown

Treatment randomization:

R_1	R_2	R_3
$S_1 A_1 T_1$	$S_1 A_1 T_1$	$S_1 A_1 T_1$
$S_1 A_2 T_1$	$S_1 A_2 T_1$	$S_1 A_2 T_1$
$S_1 A_3 T_1$	$S_1 A_3 T_1$	$S_1 A_3 T_1$
$S_2 A_1 T_1$	$S_2 A_1 T_1$	$S_2 A_1 T_1$
$S_2 A_2 T_1$	$S_2 A_2 T_1$	$S_2 A_2 T_1$
$S_2 A_3 T_1$	$S_2 A_3 T_1$	$S_2 A_3 T_1$
$S_1 A_1 T_2$	$S_1 A_1 T_2$	$S_1 A_1 T_2$
$S_1 A_2 T_2$	$S_1 A_2 T_2$	$S_1 A_2 T_2$
$S_1 A_3 T_2$	$S_1 A_3 T_2$	$S_1 A_3 T_2$
$S_2 A_1 T_2$	$S_2 A_1 T_2$	$S_2 A_1 T_2$
$S_2 A_2 T_2$	$S_2 A_2 T_2$	$S_2 A_2 T_2$

Plate 1: Pineapple wastes

3.3.2. Extraction of fibre

The sucker and crown samples were collected immediately after the fruits were harvested in the summer and winter seasons for two consecutive years. The fibres were extracted mechanically using a respodar extraction machine. The leaf samples were fed into a feed roller where they were crushed, stripped and then pulled back. After extraction, the fibres were washed two to three times using clean tap water to remove any attached debris and sun-dried for a period of two days. The dried fibres were then further cleaned manually by hand to remove any remaining residues. After cleaning, the extracted fibres were properly packed and stored for further investigation. The principle of mechanical extraction method is to subject the stem to a succession of blows to break up the woody core (Jarman *et al.*, 1978). The flow diagram for extraction of pineapple fibre is given in Figure. 3.1.

3.3.3. Physical parameters

3.3.3.1. Fibre yield (%)

For fibre yield, weight of pineapple leaf before extraction and the final dried weight of extracted fibre were recorded. The fibre yield percentage was obtained using the equation given below:

$$\text{Fibre yield (\%)} = \frac{weight\ of\ dried\ pineapple\ leaf\ fibre\ (g)}{weight\ of\ fresh\ pineapple\ leaves(g)} \times 100$$

Collection of leaves and cleaning

↓

Leaf samples fed in feed roller and pulled back

↓

Washed thoroughly in clean tap water 2-3 times

↓

Drying of extracted fibres

↓

Cleaning of dried fibres

↓

Storage

Fig. 3.1. Flow sheet for extraction of pineapple fibre

Plate 2: Extraction of pineapple fibre

Pineapple crown fibre

Fibre from pineapple sucker

Plate 3: Extracted fibre of Pineapple crown and sucker

3.3.3.2. Fineness

The fineness or linear density of the extracted fibre was determined using gravimetric method by measuring the total length of fibres and weighing them on an analytical balance with least count balance of 0.0001 g scale (Varma *et al.*, 1984). The linear density was calculated on the basis of weight of 100 single fibres randomly selected and length of each single fibre was recorded in centimeter using a measuring scale. The fineness was determined using the formula:

Linear density/ Fineness (tex) = W/L

Where,

W is the weight of 100 randomly selected fibres and

L is the total length of 100 fibres.

3.3.4. Mechanical properties

For conducting the test, all the fibre samples were pre-conditioned for 24 h at 27 ± 2°C at 65 ± 2% RH (relative humidity) before any test following BIS standard IS 6359–1977. For tensile properties, a total of 100 tests were conducted for each sample. The fibres were randomly selected and tested on the tensile tester (INSTRON, 5567) following the Indian standards (BIS 235; 1991). The fibre was subjected to a load that increases at a constant rate such that the average time to break falls within the specified limit of 20 ± 3 s. The preconditioned fibre sample was fixed between two jaws and was subjected to a load that increases at a constant rate. The gauge length was maintained at 20 mm. The average tenacity, elongation at break and initial modulus were reported on the histogram. A total of randomly selected 100 fibres were tested for each sample.

3.3.5. Bio-chemical properties

For biochemical properties, extracted fibres were used to analyze for cellulose hemicellulose and lignin. For analysis of ash, moisture, crude fibre and total nitrogen the dried leaf and crown samples were prepared as per the procedure followed by Zainuddin *et al*. (2014).

3.3.5.4. Crude fibre (%)

Two gram of sample was weighed and transferred into a spoutless beaker of 1L capacity. After transferring into the beaker, 200 ml of sulphuric acid was added and boiled for 30 minutes on a hot plate. The beaker was then sealed with the help of a round bottom flask filled with cold water to act as a condenser for maintaining the volume of the contents of the beaker. It was then filtered through a muslin cloth and hot water washing was repeated several times to make it completely acid free. After proper washing, the residue was placed into the beaker again and boiled in alkali (NaOH) for 30 minutes. Hot water washing is done repeatedly to make it alkali free and contents of the beaker are filtered. Finally, the residue is transferred to a clean silica basin and dried in a hot air oven to a constant weight. The residue weight after cooling is then noted along with the silica basin. The silica basin is then placed inside the muffle furnace for ashing the dried residues at 550-600 °C for 1-2 hours and its final weight was taken after cooling (Thimmaiah,1999). Crude fibre was calculated out by using this following formula:

$$\text{Crude fibre (\%)} = \frac{(a-b)}{w} \times 100$$

Plate 4: Measurement of individual fibre length to determine fineness and Universal Testing Machine for assessing tensile properties

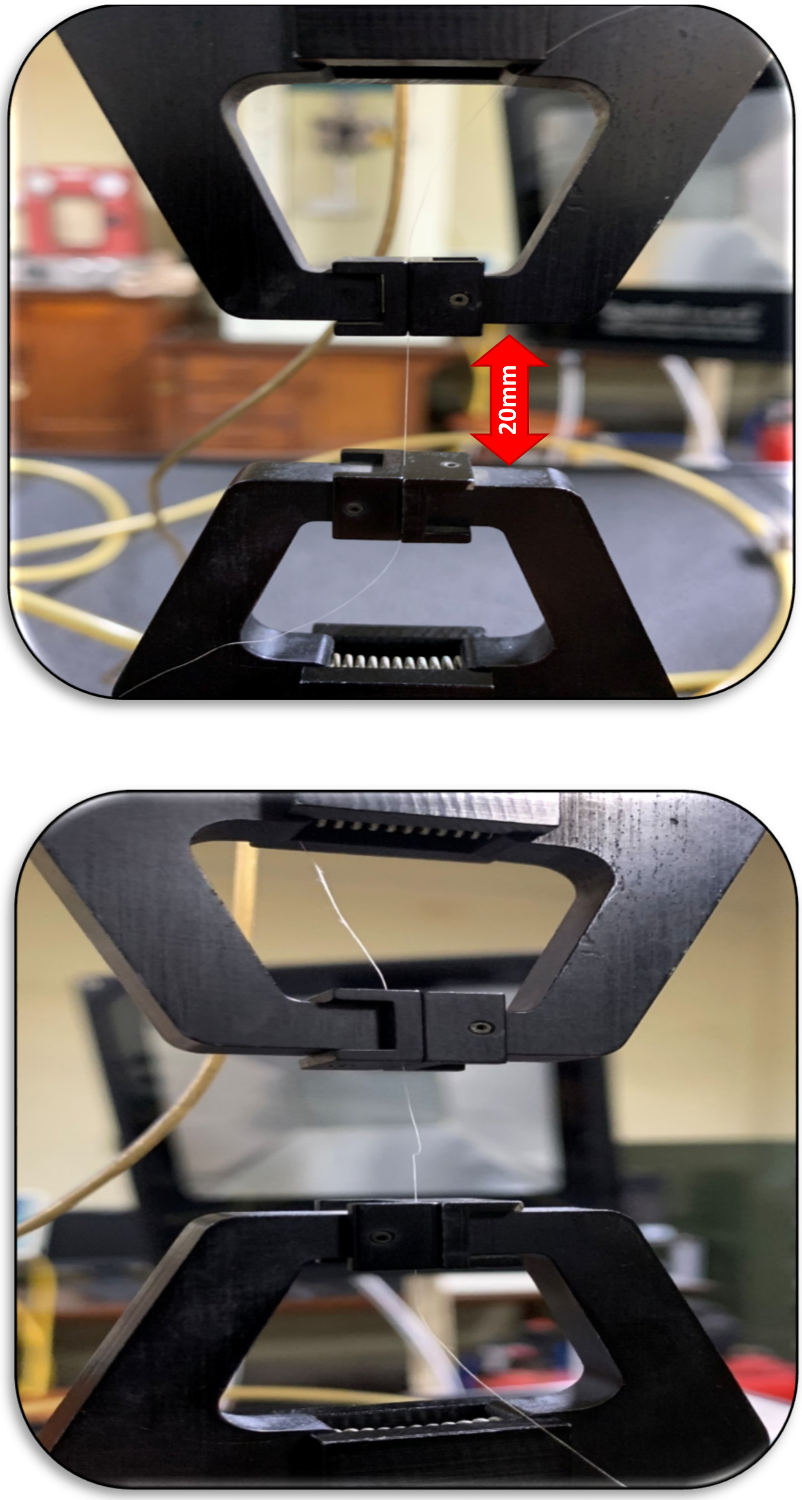


Plate 5: Testing for tensile properties at gauge length of 20 mm

Where, a = weight (g) of silica basin plus oven dried residues left after acid and alkali digestion

b = weight (g) of silica basin plus ash

c = weight (g) of oven dried sample

3.3.5.5. Total nitrogen (%)

The nitrogen content was determined by kjeldahl method (Bhargava and Raghupati, 1993) and the results were expressed in percentage.

$$\% \text{ nitrogen} = \frac{14 \text{ x TV x } 0.1\text{N x } 100}{\text{sample weight} \times 1000}$$

3.4. Experiment- II: To study the qualitative parameters of vinegar produced from pineapple waste.

Ripened pineapple fruits were procured directly from the farmer's field at Molvom village. Pineapple waste comprising of peels, core and pomace were utilized for vinegar production and to assess its qualitative parameters**.** For vinegar production, commercial wine yeast *Saccharomyces cerevisiae* Lalvin (EC-1118) procured from Brew mart India was used for alcoholic fermentation and pure bacterial culture *Acetobacter aceti mtcc* 3246 was obtained from CSIR-Institute of Microbial Technology, Chandigarh for acetic acid fermentation. The Lyophilized bacterial culture was revived right after arrival on Yeast extract peptone mannitol (YPM) medium (Table 3.1), sub-culturing at bimonthly intervals as and when required with the following composition. All chemicals and solvents used in this study were of analytical grade and used as supplied.

Table 3.1: Composition of Yeast Extract Peptone Mannitol (YPM) medium

Ingredients	Amount (Gms/litre)
Yeast extract	5.0
Peptone	3
Mannitol	25
Agar	15

pH of YPM= 5-6.5*

3.4.1. Technical details

Experimental design: Completely randomized design (CRD)

No. of treatments: 3 (three)

Replications: 5 (five)

Treatment details:

Pineapple waste (T):

T_1 - Peel

T_2 - Core

T_3 - Pomace

3.4.2. Processing of vinegar

3.4.2.1. Preparation of yeast and Bacteria for fermentation

For alcoholic fermentation, commercial wine yeast *Saccharomyces cerevisiae* Lalvin (EC-1118) was rehydrated in lukewarm water. While, the inoculum preparation for acetous fermentation was done by transferring a loopful of *Acetobacter* aceti into conical flask containing sterile glucose yeast extract broth with 7% (v/v) ethanol and incubated in a rotary incubator at 30^0 C until an optical cell mass density of 0.5 (equivalent to 1 x 10^6 cfu/mL) was obtained (Molelekoa *et al*., 2018). The broth for the inoculum was prepared with the following composition (Table 3.2).

Table.3.2: Composition of medium for inoculum preparation

Constituent	Amount (g/L)
Glucose	10
Yeast extract powder	10
Ethanol	60
Magnesium sulphate $MgSO_4$	0.5
Potassium dihydrogen phosphate KH_2PO_4	0.5

3.4.2.1. Alcoholic and acetic fermentation for vinegar

Ripened pineapple fruits were acquired from farmers field at molvom and brought directly to the laboratory for processing. The fruit was subjected to a thorough washing in clean tap water to remove any dirt particles. Following that, the fruit cores were removed using a core remover and the peels were carefully sliced with knife. The pulp obtained after peeling and core removal was ground in a mixer, sieved through a muslin cloth and manually pressed by hand to obtain the pomace for vinegar production. The residual peels and cores were finely chopped and subjected to maceration. For alcoholic fermentation, pineapple waste viz., peel, core and pomace were then ameliorated by adding sugar to obtain 15^0 brix. The must of different waste materials was inoculated with wine yeast (2.5g/ litre). Must was allowed to ferment in glass containers in anaerobic condition at 28°C for a duration of seven days and stopped once it reached stable total soluble solids (TSS). After the completion of fermentation, wine was clarified two-three times by siphoning and stored in sterilized glass jars for further processing of vinegar.

In second stage fermentation, wine was poured in sterilized glass bottles with a wide mouth opening and inoculated with bacterial culture at a rate of ten percent (v/v) in an incubator at 30 °C. After this, the glass bottles were carefully covered with muslin cloth and a headspace was provided so as to promote aerobic fermentation. In the initial 3-4 days of fermentation occasional stirring of jars were performed for speeding up the fermentation. The samples for analysis were drawn carefully not to disturb the bacterial film (mother vinegar) by sterilized pipette for investigation of qualitative parameters (Sossou *et al*., 2009). Samples were analysed at 3 days intervals for 25 days. The flow diagram for processing of pineapple waste vinegar is given in Figure.3.2.

3.4.3. Physico-chemical parameters

3.4.3.1. pH

The pH was recorded using a pH meter and prior to its measurement, standard buffer solutions were used for calibration. The pH of the samples was noted directly after it.

3.4.3.2. Total Soluble Solids (ºBrix)

Total soluble solids were measured with the help of ERMA Hand Refractrometer (0 to 32° B) calibrated at 20 °C. The readings were further corrected as per international correction table and the results represented as °Brix as per A.O.A.C. (1984).

Alcoholic fermentation of different pineapple waste

Wine derived from pineapple waste

Plate 6: Fermentation process of pineapple wine

Sorting and washing of pineapple fruit

↓

Removal of peel, core and pomace

↓

Addition of sugar and yeast

↓

Incubated at 28 °C for 7 days for alcoholic fermentation

↓

Clarification and storage

↓

Clarified wine were poured in sterile glass bottles

↓ Aerobic fermentation

Addition of 10 % inoculum of broth containing *Acetobacter aceti*

↓

Covering the bottles with sterile muslin cloth and incubated at 28 °C

↓

Bottles were periodically stirred for first 4-5 days

↓

Acidity of vinegar was taken till a constant value was obtained

Fig.3.2. Flow sheet on preparation of pineapple waste vinegar

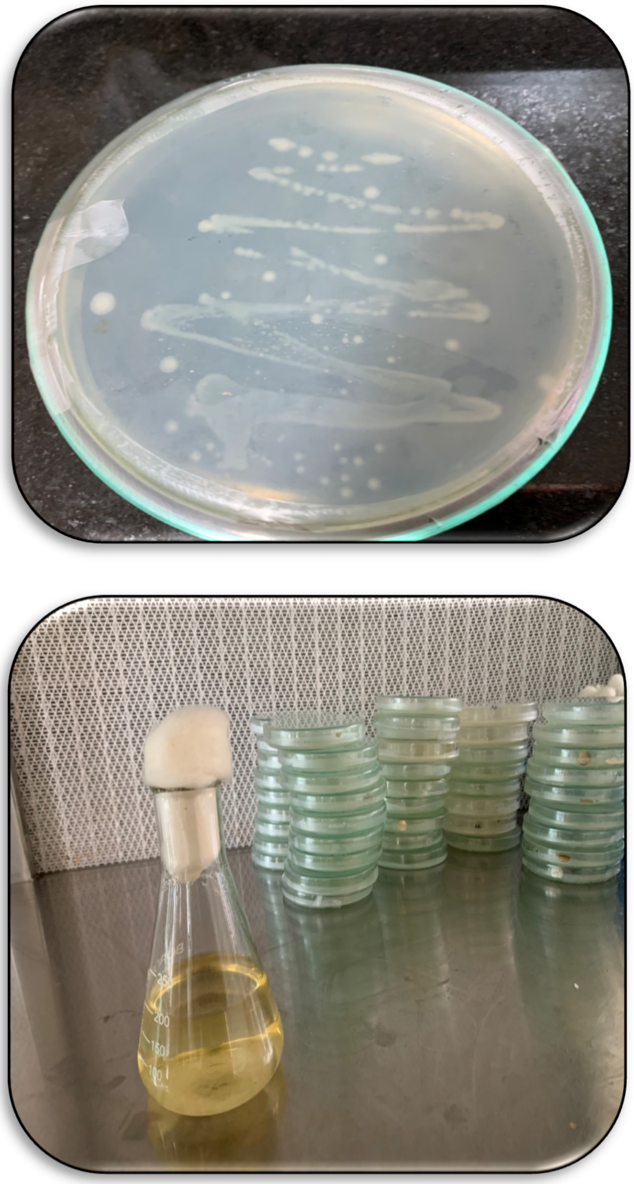


Plate 7: Preparation of broth culture for acetic fermentatio

3.4.3.3. Specific Gravity

Pycnometer bottle was washed, oven dried, cooled and weighed using a weighing balance. The sample was then filled into bottle and weighed (AOAC, 1984). The specific gravity (SG) was calculated as

$$SG = \frac{weight\ of\ sample}{weight\ of\ water}$$

3.4.3.4. Acetic acid (%)

Acetic acid was estimated by titrating the known aliquot of sample against 0.1 N NaOH solution using Phenolpthalein as an indicator. It was calculated and expressed as per cent acetic acid (A.O.A.C., 1984).

$$\%\ \text{Acetic acid} = \frac{\text{Titre value x 0.1x60x10}}{\text{Aliquot of sample taken for determination x 10}}$$

3.4.3.5. Titratable acidity (%)

Titratable acidity was estimated by titrating the known aliquot of sample against 0.1 N NaOH solution using Phenolpthalein as an indicator. The total titratable acidity was calculated and expressed as per cent citric acid (Ranganna, 2001).

$$\%\ \text{Titratable acidity (citric acid)} = \frac{\text{Titre value x 0.1x64x10}}{\text{Aliquot of sample taken for determination x 10}}$$

3.4.3.6. Alcohol content (%)

Specific gravity of the fermenting must and specific gravity of wine were determined separately. The alcohol content of wine was calculated by the following formula (Berry, 2000)

Alcohol by volume (ABV) %

$$= \frac{original\ specific\ gravity - final\ specific\ gravity}{7.36} \times 1000$$

3.4.3.5. Colour measurements

The colour of the produced samples was analyzed using a UV-VIS spectrometer and readings were taken at different wavelengths A_{420nm}, A_{520nm}, A_{620nm} for determining Color intensity (CI), colour density, colour tone following the procedure described by Yildirim (2006). Colour intensity ($A_{420m} + A_{520m} + A_{620m}$), colour density ($A_{420nm} + A_{520nm}$), shade or tint ($A_{420nm} / A_{520nm}$) were used to calculate the colour of vinegar. Also, proportions of yellow (Y %), red (%R) and blue (%B) were determined as A_{420nm}x 100/colour intensity, A_{520nm}x 100/colour intensity and A_{620nm}x 100/colour intensity respectively.

3.4.4. Sensory evaluations

The sensory evaluation for the developed vinegars was evaluated on the basis of colour, odour, sourness and overall acceptability by a panel of 10 semi-trained judges using a 9-point hedonic scale (Amerine *et al*., 1965). Samples were coded and placed in a random manner prior to testing. The coded samples were put in a transparent disposable cup and a glass of water was kept for rinsing the mouth after testing the given sample. It was rated based on the scale given below:

Grade	Score
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

Plate 8: Acetous fermentation of wine samples

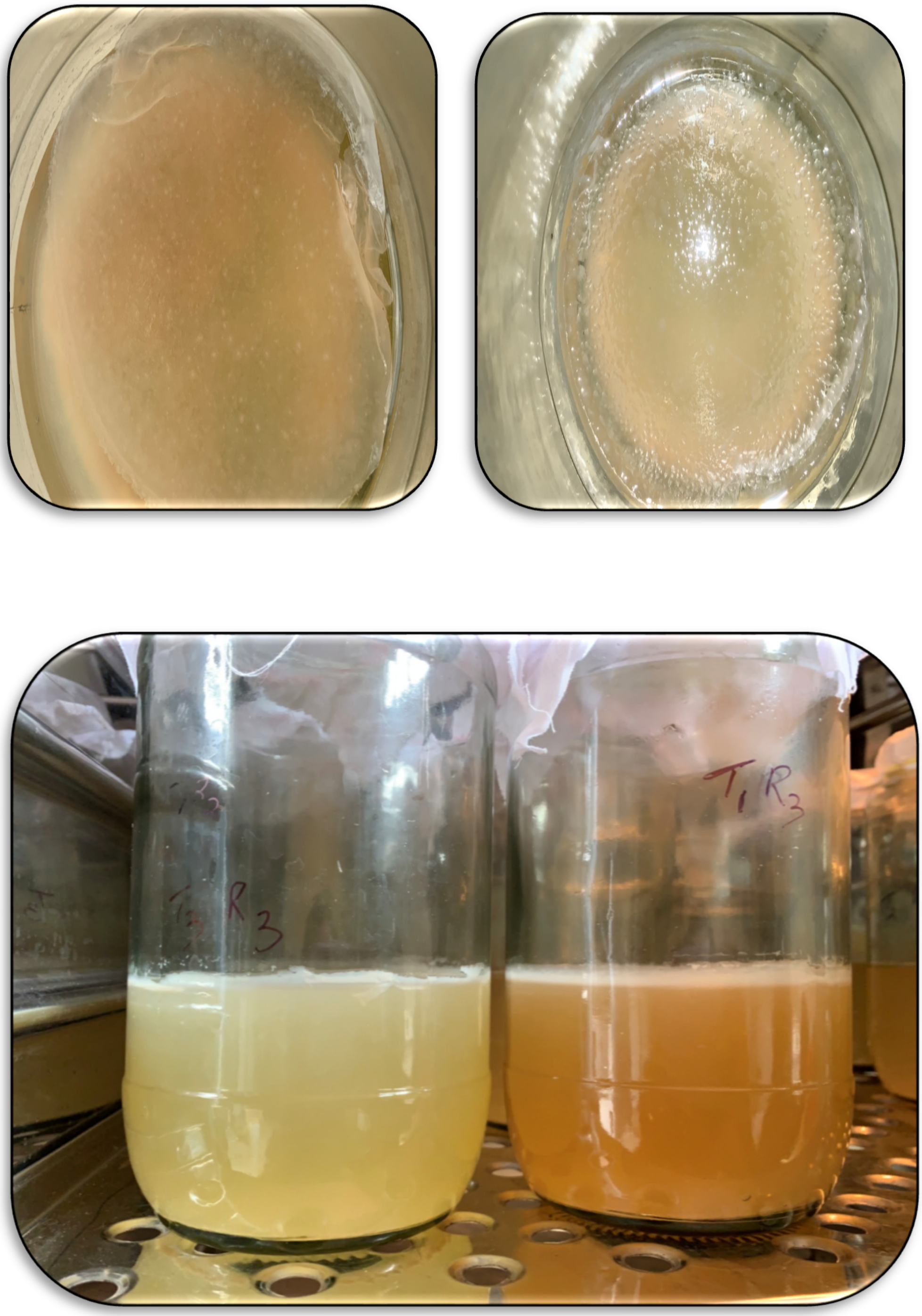
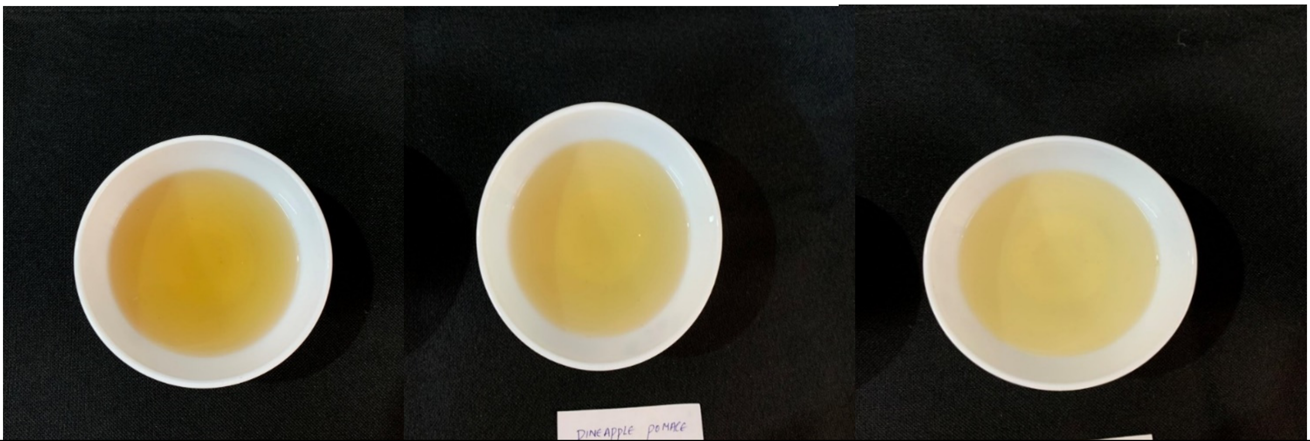


Plate 9: Appearance of mother film in vinegar



Peel vinegar	Pomace vinegar	Core vinegar

Plate 10: Vinegar prepared from different pineapple waste

3.5. Experiment-III: To study the preparation of candy from pineapple core

The fruits were procured from the farmer's field and brought immediately to the laboratory. The pineapple core used for candy preparation was extracted with the help of a core remover. The prepared candies were stored in pre-sterilized 200 ml glass jars for further analysis. Initial observations were recorded immediately after preparation prior to storage, followed by evaluations at 30, 60, 90, 120 and 180 days to assess both physico-chemical and organoleptic parameters.

3.5.1. Technical details:

Experimental design: Completely randomized design (CRD)

Replications: 3 (Three)

No. of treatments: 5 (Five)

Period of investigation: 2 years (2019 & 2020)

Treatments details:

- T_1- 40 % sugar
- T_2 - 50 % sugar
- T_3 - 60 % sugar
- T_4 - 70 % sugar
- T_5- No sugar

3.5.2. Processing of pineapple core candy

Pineapple core were cut into uniform sizes of 0.5 cm thickness with the help of a knife. The chopped cores were washed thoroughly in water and were subjected to boiling for 5 minutes to soften the core and dipped in cold water immediately after blanching to prevent overcooking. After blanching, the cores were pricked with the help of a toothpick and steeped in sugar syrup as per the treatments, core pieces with no sugar treatment were used as control. The pricked and blanched pieces were steeped in separate containers with varying sugar concentrations (40° brix, 50° brix, 60° brix, and 70° brix) in a 1:1 proportion for 24 hours. Next day, core pieces were removed and separated from the sugar solution and boiled. Thereafter, the core pieces were then steeped into the boiled sugar syrup for an additional period of 2 days. Finally, the core piece were separated by straining the sugar syrup and subjected to drying with the help of hot air oven at 50 °C for 12 hours (Khanom *et al*., 2015). Lastly, the prepared candies were packaged in pre-sterilized glass jars and stored under ambient conditions for further investigation. The flow sheet for processing of pineapple core candy is given below in Fig.3.3.

3.5.3. Physico-chemical parameters of core candy

3.5.3.1. Moisture content (%)

The moisture content was determined using the oven dry method at 100ºC, following the procedure of A.O.A.C. (1984). Samples from each replication across all treatments were initially weighed and then subjected to oven drying until a constant weight was achieved. The moisture percentage was subsequently calculated using the formula:

$$\text{Moisture (\%)} = \frac{Initial\ weight - Final\ weight}{initial\ weight} \times 100$$

Collection, Selection and washing of fruit

↓

Removal of core and cut into uniform sizes of 0.5 cm thickness

↓

Core pieces were pricked and blanched for 5 minutes
(addition 0f 0.1% citric acid)

↓

Steeping of core pieces for 24 hours in different concentration of sugar solution (40^0, 50^0, 60^0 ,70^0 brix)

↓

Separation of core pieces from syrup and boiling of sugar solution

↓

Core pieces were again steeped into the boiled sugar syrup for an additional period of 2 days

↓

Straining of syrup and drying of the segments in hot air oven for 12 hrs

↓

Packing in air-tight glass containers

↓

Storage

Fig.3.3. Flow sheet of pineapple core candy preparation

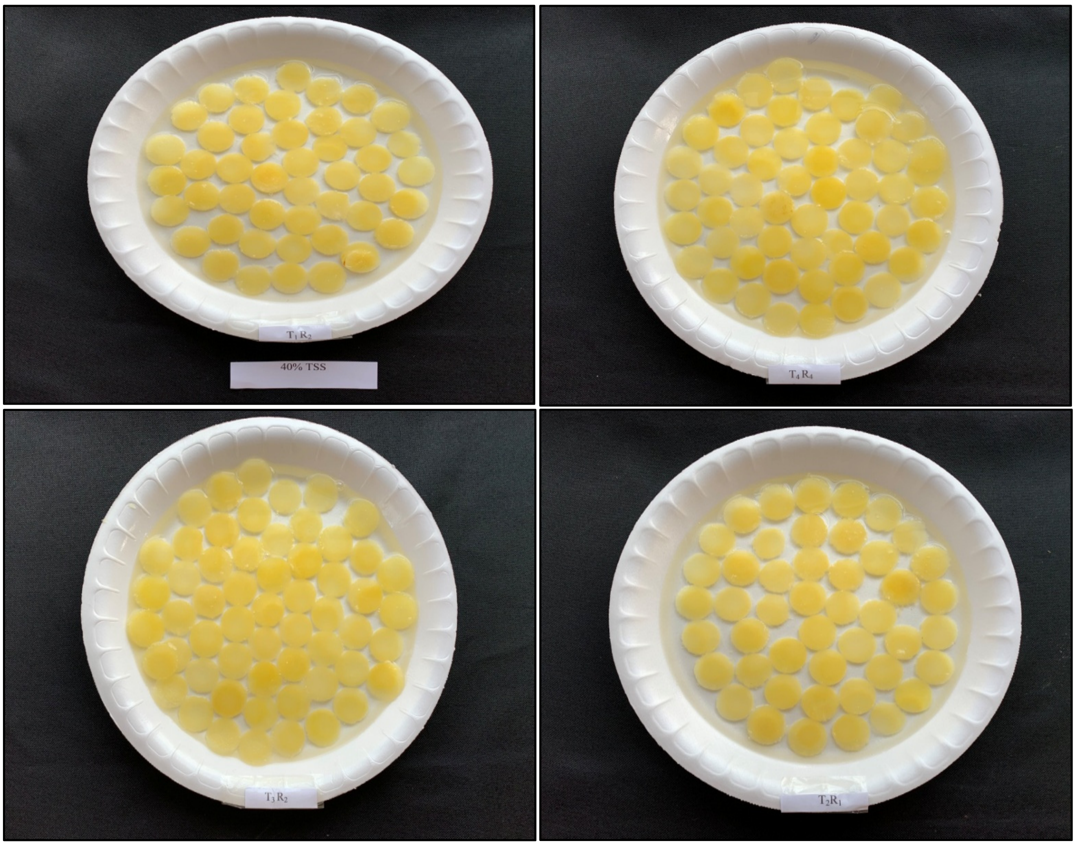


Plate 11: Steeping of pineapple core in different concentration of sugar

3.5.3.2. Ascorbic acid (mg/100gm)

Ascorbic acid content was determined using the titration method with 2,6-dichlorophenol indophenol dye, as suggested by Ranganna (2001). The titrated value was recorded and calculated as follows:

Vitamin C (mg/100g) =

$$\frac{Titre\ value\ x\ dye\ factor\ xVol.make\ up\ (25ml)}{Aliquot\ of\ sample\ taken\ for\ determination\ (5ml)x\ vol.of\ sample\ for\ estimation\ (2.5ml)} \times 100$$

3.5.3.3. Total Sugar (%)

For total sugar estimation, 10 ml of the extract was taken in a conical flask, to which 8-10 drops of concentrated HCl and 15-20 ml of distilled water were added. The mixture was boiled for 8-10 minutes until the hydrolyzed juice reached its endpoint, determined by pH paper (5.5-7.0) turning blue when dipped in the solution. The solution was then transferred to a volumetric flask and brought to volume with distilled water. Total sugar content was determined by titrating the liquid against Fehling 'A' and Fehling 'B' reagents using methylene blue as an indicator (A.O.A.C. 1984). The data obtained were presented as percentage (%).

Total sugar (%) = $(a \times v \times 100)/(T \times 100 \times W)$

Where, a = factor (0.052)

V = volume made up in the volumetric flask (100 ml)

T = titrated value

W = volume of juice initially taken for determination (10 ml)

3.5.3.4. Reducing Sugar (%)

Reducing sugar was estimated by titrating with Fehling A and Fehling B reagents using methylene blue as an indicator. The end point was indicated by the precipitation of a deep brick-red color in the solution. The titratable value was then used to calculate the reducing sugar content, which was expressed in percentage (%) (A.O.A.C. 1984).

Reducing Sugar (%)= $(a \times v \times 100)/(T \times 100 \times W)$

Where, a = factor (0.052)

V = volume made up in the volumetric flask (100 ml)

T = titrated value

W = volume of juice initially taken for determination (10 ml)

3.5.3.4. Titratable acidity (%)

Titratable acidity was estimated by titrating the known aliquot of sample against 0.1 N NaOH solution using Phenolpthalein as an indicator. The total titratable acidity was calculated and expressed as per cent citric acid (Ranganna, 2001).

% Titratable acidity (citric acid) $= (\text{Titre value x } 0.1\text{x}64\text{x}10)/(\text{Aliquot of sample taken for determination x } 10)$

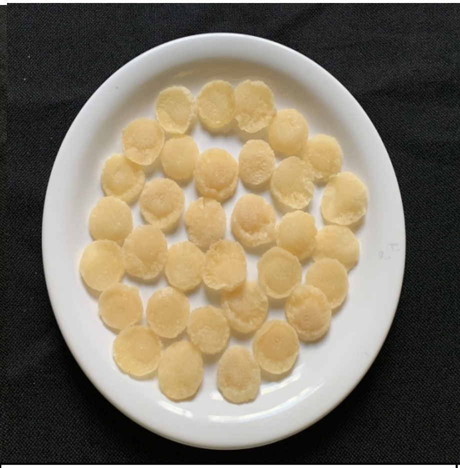
3.5.4. Sensory evaluations

The sensory evaluation was carried out using 9 point hedonic scale as described by Amerine *et al*. (1965). The samples were determined for colour, appearance, flavour, texture, taste and overall acceptability by 10 semi- trained panelists. Pineapple core candies were evaluated at initial stage prior to packaging and thereafter at an interval of 30 days up to 180 days (6 months). Organoleptic quality determines the storage stability of the product.

3.6. Statistical analysis

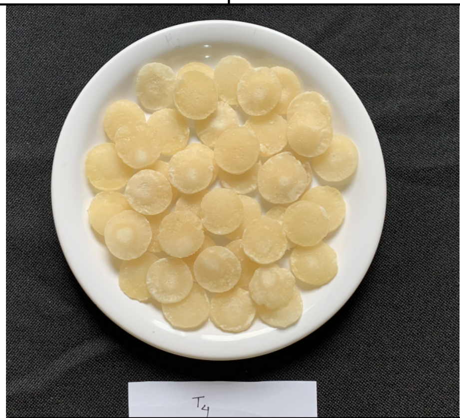
The data collected were subjected to two-way analysis of variance (ANOVA) by split plot design in experiment-I while experiment-II & III were evaluated by one-way analysis of variance (ANOVA) by completely randomized design in accordance with procedure outlined by Gomez and Gomez (1984). Fisher Shedecor ‘F’ test was used to determine the significance and non-significance of the variance due to different treatments at 5% level of significance.

T_1 (40% sugar)



T_2 (50% sugar)

T_3 (60% sugar)



T_4 (70% sugar)

T_5 (No sugar)

Plate 12: Pineapple core candy prepared with different treatments

CHAPTER IV

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

The results of the present investigation are presented and discussed in this chapter, alongside relevant works of other researchers, under the following headings.

4.1. To study the quality of fibre extracted from pineapple leaf

4.1.1. Physical parameters

4.1.1.1. Fibre yield (%)

4.1.1.1. a. Fibre yield in pineapple sucker

From the analysis of data shown in Table 4.1, it was observed that cropping season and crop age had significant influence on fibre yield of suckers in both the years as well as in pooled data.

From the pooled data, the highest fibre yield was recorded in summer season (1.57%), while the lowest yield was exhibited in winter season (1.51%).

With regards to crop age, the highest fibre yield was recorded from second ratoon (1.60%) followed by first ratoon (1.55 %) and the lowest was observed in main crop (1.45%).

The interaction between the cropping season and age of crop showed no significant difference on the fibre yield of pineapple suckers. However, the highest level of fibre yield was recorded from S_2A_3 (summer season + 2nd ratoon crop) with 1.61%, which was at par with S_2A_3 (winter season + 2nd ratoon crop) with 1.60 % and the lowest fibre yield was recorded in S_2A_1 (winter season + main crop) with 1.40%.

4.1.1.1. b. Fibre yield in pineapple crown

Data presented in Table 4.2 illustrates the influence of cropping season, age and their interaction on the fibre yield of pineapple crowns. From the pooled data, cropping season showed significant effect on the fibre yield of pineapple crown. The highest fibre yield (1.42%) was recorded in summer season and the lowest was noted in winter season (1.33%).

Age of crop also exhibited significant effect on fibre yield of pineapple crown in both individual years and in pooled data. The fibre yield of crown also showed a similar trend like suckers, with the highest recorded in second ratoon (1.43%) and lowest in main crop (1.34%) which was statistically at par with first ratoon (1.35%).

The interaction between cropping season and crop age showed no significant difference. However, the highest level of fibre yield was observed in S_1A_3 (1.49 %), followed by S_1A_2 (1.39%) and the lowest was found in S_2A_1 (winter season + main crop) with 1.30 %.

In this study, the fibre yield from pineapple suckers varied between 1.40% and 1.61%, while for crowns, it ranged from 1.30% to 1.49%. The results align with findings from Banik *et al.* (2011), who reported pineapple leaf fibre yields of 2.5% to 3.5% and Pandit *et al.* (2020), who similarly reported yields ranging from 1.55% to 2.5% from pineapple leaves. The slight variability in fibre yield from the present result in comparison with previous studies could be attributed to the differences in extraction methods and plant varieties. Divya *et al.* (2016) documented a fibre yield of 0.633% to 1.663% from bananas through mechanical extraction, while Uma *et al.* (2006) reported that depending on variety and the extraction method employed fresh banana plants yield about 0.6% to 0.96% fibre. This highlights that fibre yield

Table 4.1: Effect of cropping season, age of crop and their interaction on the fibre yield (%) of pineapple sucker

Particulars	Year		
	2019-20	2020-2021	Pooled
Cropping season (S)			
S_1 - Summer	1.53	1.61	1.57
S_2 - Winter	1.44	1.57	1.51
SEm (±)	**0.04**	**0.03**	**0.02**
CD(P=0.05)	**0.12**	**NS**	**0.07**
Age of crop (A)			
A_1-(Main crop)	1.39	1.51	1.45
A_2- (1st ratoon)	1.49	1.62	1.55
A_3- (2nd ratoon)	1.57	1.64	1.60
SEm (±)	**0.05**	**0.04**	**0.03**
CD(P=0.05)	**0.17**	**0.13**	**0.10**
Interaction (S×A)			
S_1A_1	1.44	1.58	1.50
S_1A_2	1.56	1.61	1.59
S_1A_3	1.59	1.63	1.61
S_2A_1	1.35	1.45	1.40
S_2A_2	1.41	1.62	1.52
S_2A_3	1.56	1.64	1.60
SEm±	**0.07**	**0.05**	**0.04**
CD(P= 0.05)	**NS**	**NS**	**NS**

Table 4.2: Effect of cropping season, age of crop and their interaction on the fibre yield (%) of pineapple crown

Particulars	Year		
	2019-20	2020-2021	Pooled
Cropping season (S)			
S_1 - Summer	1.41	1.43	1.42
S_2 - Winter	1.34	1.32	1.33
SEm±	**0.03**	**0.02**	**0.02**
CD(P= 0.05)	**0.08**	**0.06**	**0.06**
Age of crop (A)			
A_1-(Main crop)	1.33	1.34	1.34
A_2- (1st ratoon)	1.36	1.34	1.35
A_3- (2nd ratoon)	1.44	1.43	1.43
SEm (±)	**0.04**	**0.03**	**0.03**
CD(P=0.05)	**0.12**	**0.09**	**0.09**
Interaction (S×A)			
S_1A_1	1.35	1.41	1.38
S_1A_2	1.36	1.42	1.39
S_1A_3	1.52	1.46	1.49
S_2A_1	1.31	1.28	1.30
S_2A_2	1.35	1.27	1.31
S_2A_3	1.36	1.40	1.38
SEm (±)	**0.05**	**0.04**	**0.03**
CD(P=0.05)	**NS**	**NS**	**NS**

Table 4.3: *t*-test on fibre yield, fibre fineness and tensile strength between pineapple sucker and crown

Treatments	Fibre yield			Fibre fineness			Tensile strength		
	t-test	*t*-critical (two tailed)	*p*-value	*t*-test	*t*-critical (two tailed)	*p*-value	*t*-test	*t*-critical (two tailed)	*p*-value
Cropping season (S)	11^{NS}	12.71	0.058	3.50^{NS}	12.71	0.177	7.06^{NS}	12.71	0.09
Age of crop (A)	6.05*	4.30	0.026	2.80^{NS}	4.30	0.108	5.16*	4.30	0.04
Interaction (S×A)	7.36*	2.57	0.001	2.81*	2.57	0.038	7.15*	2.57	0.001

*significant at 5 per cent level, NS: non-significant

from bananas is significantly lower as compared to pineapples, which could be due to distinct anatomical structures and fibre composition. These differences underscore the significant impact of extraction methods, plant parts utilized and varietal characteristics on the fibre yield. From the perusal of data from Table 4.3, the *t*-test on fibre yield between pineapple leaf and crown with respect to the age of crop (t= 6.05, p=0.026) and the interaction effect (t=7.36, p=0.001) were found to be highly significant. However, there was no significant effect in cropping season between leaf and crown concerning fibre yield (t=11, p=0.058).

4.1.1.2. Fineness (tex)

4.1.1.2. a. Fineness of pineapple sucker fibre

The result obtained for fineness on fibre extracted from pineapple sucker is presented in Table 4.4 and Fig. 4.1. Cropping season was found to have significant effect on fineness of fibre extracted from pineapple suckers. A similar trend was observed in both the years, with higher fineness observed during summer season. From the pooled data, higher fineness was exhibited in summer season (2.56 tex) compared to winter season (2.63 tex).

Age of crop showed profound effect on the fineness of fibre extracted from pineapple sucker. The highest fineness was recorded in first ratoon (2.35 tex) followed by second ratoon (2.67 tex) and the lowest in main crop (2.77 tex).

The interaction between cropping season and age of crop with regard to fineness of fibre were found to have significant difference. The highest fineness was recorded in S_1A_2 (2.27 tex) and the lowest in S_2A_1 (2.85 tex).

Table 4.4: Effect of cropping season, age of crop and their interaction on the fineness (tex) of fibre extracted from pineapple sucker

Particulars	Year		
	2019-20	2020-2021	Pooled
Cropping season (S)			
S_1 - Summer	2.55	2.56	2.56
S_2 - Winter	2.66	2.61	2.63
SEm (±)	0.023	0.032	0.018
CD(P=0.05)	0.072	NS	0.056
Age of crop (A)			
A_1-(Main crop)	2.85	2.69	2.77
A_2- (1st ratoon)	2.40	2.29	2.35
A_3- (2nd ratoon)	2.57	2.77	2.67
SEm (±)	0.033	0.046	0.026
CD(P=0.05)	0.102	0.141	0.080
Interaction (S × A)			
S_1A_1	2.72	2.65	2.68
S_1A_2	2.32	2.22	2.27
S_1A_3	2.62	2.80	2.71
S_2A_1	2.98	2.72	2.85
S_2A_2	2.48	2.36	2.42
S_2A_3	2.52	2.74	2.63
SEm (±)	**0.040**	**0.056**	**0.032**
CD(P=0.05)	**0.124**	**NS**	**0.097**

4.1.1.2. b. Fineness of pineapple crown fibre

The experimental results pertaining to effect of fineness of crown fibre with regard to cropping season, age and their interaction is illustrated in Table 4.5. Cropping season showed a significant effect on the fineness of crown extracted fibre. The highest fineness was exhibited in summer season (2.29 tex) and the lowest was noted in winter season (2.48 tex).

Age of crop also showed significant difference on crown fibre fineness in both the years and in pooled data. Highest fineness was recorded in first ratoon (2.22 tex) followed by second ratoon (2.31 tex) and the lowest in main crop (2.63 tex).

Further, the interaction between cropping season and crop age were found to be significant in crown extracted fibre in both the years. From the pooled data, the highest fineness was recorded in S_1A_3 (2.16 tex) followed by S_1A_1 (2.50 tex) and the lowest in S_2A_1 (2.76 tex).The fineness of the fibre is the relative size of the diameter expressed in terms of the weight of the unit length. The value of smoothness is expressed in tex and smaller the tex value finer is the fibre. Fiber fineness is crucial as it significantly influences fibre spinnability and the characteristics of final product like yarns, composites, and fabrics (Grishanov *et al.,* 2006). In this study, the fineness of pineapple leaf fibres ranged from 2.27 to 2.85 tex, while crown fibers ranged from 2.16 to 2.76 tex, suggesting a moderate fineness suitable for diverse textile applications. Banik *et al.* (2011) reported a fineness value of 2.8 tex for pineapple fibres, which is consistent with our findings. Conversely, Jalil *et al.* (2019) observed a higher fineness of 3.20 tex in pineapple leaf fibre, suggesting potential variations linked to specific pineapple varieties or growth conditions. measurements (1.39-7.07 tex) from Azores pineapple fibres, highlighting significant geographical influences on fibre characteristics. The textile industry increasingly values finer fibres due to their improved spinnability and yarn quality (Deussen, 1993; Haigler, 2010). Factors influencing optimal fibre quality include plant age, genetics, metabolism and extraction methods (McDougall *et al*., 1993; Bourmaud *et al*., 2010). Further, the effect of fibre fineness between pineapple leaf and crown (Table 4.3) with regard to cropping season (t=3.50, p=0.177) and age of crop (t=2.80, p=0.108) did not show any significant difference. However, the interaction between season and age of crop showed a significant influence on fibre fineness between pineapple leaf and crown (t=2.81, p=0.038).

Table 4.5: Effect of cropping season, age of crop and their interaction on the fineness (tex) of fibre extracted from pineapple crown

Particulars	Year		
	2019-20	2020-2021	Pooled
Cropping season (S)			
S_1 - Summer	2.29	2.29	2.29
S_2 - Winter	2.46	2.50	2.48
SEm (±)	**0.02**	**0.04**	**0.03**
CD(P=0.05)	**0.07**	**0.11**	**0.08**
Age of crop (A)			
A_1-(Main crop)	2.74	2.52	2.63
A_2- (1^{st} ratoon)	2.12	2.32	2.22
A_3- (2^{nd} ratoon)	2.27	2.35	2.31
SEm (±)	**0.03**	**0.05**	**0.04**
CD(P=0.05)	**0.10**	**0.16**	**0.11**
Interaction (S X A)			
S_1A_1	2.57	2.43	2.50
S_1A_2	2.14	2.29	2.22
S_1A_3	2.17	2.14	2.15
S_2A_1	2.90	2.61	2.76
S_2A_2	2.10	2.34	2.22
S_2A_3	2.36	2.56	2.46
SEm (±)	**0.04**	**0.06**	**0.04**
CD(P=0.05)	**0.13**	**0.20**	**0.14**

4.1.2. Mechanical properties

4.1.2.1. Tensile strength (cN/tex)

4.1.2.1. a. Tensile strength of pineapple sucker fibre

From the analysis of the data shown in Table 4.6, it was observed that cropping season showed significant difference on the tensile strength of fibre extracted from pineapple suckers in both the years and in pooled data analysis. From the pooled data, highest tensile strength was observed during summer season *i.e.* S_1 (34.03 cN/tex), while lower value of tensile strength was observed during winter season crop *i.e.* S_2 (32.72 cN/tex).

Further, the age of crop also significantly affected the tensile strength of fibres extracted from the suckers. First ratoon crop (A_2) recorded the highest tensile strength with 35.73 cN/tex, followed by second ratoon (A_3) with 32.66 cN/tex and the lowest was exhibited in A_1 (main crop) with 31.74 cN/tex.

The interaction between cropping season and age of crop was non-significant in fibre extracted from pineapple suckers in both the years and pooled data. However, highest tensile strength was recorded in S_1A_2 (summer season + 1st ratoon) with 36.13 cN/tex followed by S_2A_2 (winter season + 1st ratoon) with 35.32 cN/tex while the lowest tensile strength was recorded in S_2A_1 (winter season + main crop) with 31.04 cN/tex.

4.1.2.1. b. Tensile strength of pineapple crown fibre

The data pertaining to effect of cropping season was found to have significant influence on tensile strength of crown fibre as depicted in Table 4.7. Highest tensile strength was recorded in summer season (S_1) with 26.73 cN/tex and the lowest in winter season (S_2) with 23.01 cN/tex.

Age of crop also showed significant effect on the tensile strength of crown fibres in both the years and pooled data. The highest tensile strength was recorded from second ratoon (A_3) with 27.45 cN/tex followed by first ratoon (A_2) with 25.56 cN/tex and the lowest value was exhibited in main crop (A_1) with 21.61 cN/tex.

Further, interaction between cropping season and age of crop showed significant influence on tensile strength of crown fibre. The highest value of tensile strength was recorded in S_1A_3 (summer season + second ratoon crop) with 30.15 cN/tex followed by S_1A_2 (summer season + 1st ratoon) with 27.08 cN/tex and the lowest value was noted in S_2A_1 (winter season + main crop) with 20.25 cN/tex.

The analysis of tensile strength in fibres extracted from pineapple sucker and crown across cropping seasons and crop age revealed significant trends. From the pooled data, the tensile strength of fibres extracted from pineapple sucker varied in between 31.04 to 36.13 cN/tex, whereas the tensile strength of pineapple crown fibres ranged from 20.25 to 30.15 cN/tex. These findings align with previous studies; Alam *et al*. (2022) reported 28.56 g/tex for pineapple fibre and 21.1 cN/tex for decorticated pineapple leaf fibre of queen variety (Jose *et al*., 2018). Similarly, Banik *et al*. (2011) reported a tensile strength of 26.1 g/tex from pineapple leaf while Jalil *et al*. (2024) noted a tensile strength of 26.1 g/tex for bleached pineapple fibre of queen variety. Comparatively, Sengupta and Debnath (2009) reported 23 cN/tex for jute and Saikia *et al*. (2023) found 22.4 g/tex for banana fibre. The observed tensile strengths of pineapple leaf fibre extracted from sucker and crown in the present study fall within or exceed the ranges from the previous findings and are also comparatively higher than jute and banana fibres. Summer season crop exhibited higher tensile strength, this could possibly be due to elevated temperature and greater sunlight exposure, which may have enhanced the mechanical properties of pineapple fibres through more robust fibre development. This is supported by Zeng and Pettigrew (2015), who noted that temperature significantly influences cotton fibre quality by enhancing fibre strength. Furthermore, lower temperatures and environmental stress may reduce plant vigour and alter fibre properties by decreasing cellulose within secondary walls (Yfoulis and Fasoulas, 1978). Fibre strength is primarily linked to secondary wall thickening, which is notably influenced by elevated temperatures. Growth and development of cellular components largely depends on assimilate production during photosynthesis, which are restricted by solar radiation availability in field grown plants (Meshram *et al.*, 2013). Fibre quality may diminish under reduced sunlight conditions (Pettigrew, 2001). Therefore, fibres produced under higher temperature conditions exhibited higher strength due to increased secondary wall thickening. In pineapple sucker fibres, higher tensile strength was noted in first ratoon (A_2) across both the years, while in crown fibres second ratoon (A_3) exhibited higher tensile strength. This variation in tensile strength across different crop ages could be attributed to its cellulose content. This suggests that older crops tend to produce fibres with superior tensile properties due to increased lignifications and fibre maturation over time. Cellulose content is a critical factor affecting tensile strength and Young's modulus (De Farias *et al.*, 2017), with lower value of cellulose content resulting in reduced tensile strength (Komuraiah *et al.*, 2014). From the table (Table 4.3), cropping season exhibited no significant difference on tensile strength between pineapple sucker and crown fibre (t= 7.06, p =0.09). However, age of crop and interaction showed significant effect on tensile strength between pineapple sucker and crown (t= 5.16 & 7.15 and p =0.04 & 0.001).

Table 4.6: Effect of cropping season, age of crop and their interaction on the tensile strength (cN/tex) of fibre extracted from pineapple sucker

Particulars	Year		
	2019-20	2020-2021	Pooled
Cropping season (S)			
S_1 - Summer	33.77	34.29	34.03
S_2 - Winter	32.45	32.99	32.72
SEm (±)	**0.51**	**0.36**	**0.32**
CD(P=0.05)	**1.58**	**1.1**	**0.98**
Age of crop (A)			
A_1-(Main crop)	32.26	31.21	31.74
A_2- (1st ratoon)	36.06	35.40	35.73
A_3- (2nd ratoon)	31.01	34.31	32.66
SEm (±)	**0.73**	**0.51**	**0.45**
CD(P=0.05)	**2.23**	**1.57**	**1.39**
Interaction (S X A)			
S_1A_1	32.58	32.28	32.43
S_1A_2	36.54	35.72	36.13
S_1A_3	32.20	34.87	33.54
S_2A_1	31.94	30.14	31.04
S_2A_2	35.57	35.07	35.32
S_2A_3	29.82	33.74	31.78
SEm (±)	**0.89**	**0.62**	**0.55**
CD(P=0.05)	**NS**	**NS**	**NS**

Table 4.7: Effect of cropping season, age of crop and their interaction on the tensile strength (cN/tex) of fibre extracted from pineapple crown

Particulars	Year		
	2019-20	2020-2021	Pooled
Cropping season (S)			
S_1 - Summer	27.17	25.97	26.73
S_2 - Winter	23.66	22.02	23.01
SEm (±)	**0.19**	**0.14**	**0.15**
CD(P=0.05)	**0.59**	**0.43**	**0.45**
Age of crop (A)			
A_1-(Main crop)	22.04	20.69	21.61
A_2- (1st ratoon)	25.87	24.75	25.56
A_3- (2nd ratoon)	28.34	26.55	27.45
SEm (±)	**0.27**	**0.20**	**0.21**
CD(P=0.05)	**0.84**	**0.60**	**0.64**
Interaction (S x A)			
S_1A_1	23.65	22.29	22.97
S_1A_2	27.89	26.26	27.08
S_1A_3	30.96	29.35	30.15
S_2A_1	21.42	19.08	20.25
S_2A_2	24.85	23.24	24.04
S_2A_3	25.72	23.75	24.74
SEm (±)	**0.33**	**0.24**	**0.26**
CD(P=0.05)	**1.02**	**0.74**	**0.79**

4.1.2.2. Modulus of elasticity (cN/tex)

4.1.2.2. a. Modulus of elasticity of pineapple sucker fibre

A perusal of data in Table 4.8 indicated that fibre extracted from pineapple sucker exhibited a significant influence on modulus of elasticity in regards to cropping season, age of crop and their combined interaction. This trend was consistent in both the years as well as in pooled data analysis. The highest modulus of elasticity was exhibited in summer season crop *i.e.* S_1 (1238.08 cN/tex) and lower modulus of elasticity was noted in winter season crop *i.e.* S_2 (1073.82 cN/tex).

With regard to age of crop, the highest modulus of elasticity was recorded from first ratoon (1458.22 cN/tex), followed by main crop (1190.24 cN/tex) and the lowest value was recorded in second ratoon (819.40 cN/tex).

The interaction between the cropping season and age of crop showed significant effect on modulus of elasticity in pineapple sucker fibres. The highest modulus of elasticity was obtained in S_1A_2 (1548.33 cN/tex) followed by S_2A_2 (1368.12 cN/tex) and lowest was recorded in S_2A_3 (792.75 cN/tex).

4.1.2.2. b. Modulus of elasticity of pineapple crown fibre

The data pertaining to effect of cropping season, age of crop and their interaction on modulus of elasticity in crown fibre is presented in Table 4.9. Data analysis showed significant effect on cropping season on modulus of elasticity across both the years as well as pooled data. The highest modulus of elasticity was recorded in summer season crop (1181.26 cN/tex) and the lowest in winter season crop (956.17 cN/tex).

Table 4.8: Effect of cropping season, age of crop and their interaction on modulus of elasticity (cN/tex) of fibre extracted from pineapple sucker

Particulars	Year		
	2019-20	2020-2021	Pooled
Cropping season (S)			
S_1 - Summer	1360.90	1115.27	1238.08
S_2 - Winter	1288.78	858.87	1073.82
SEm (±)	**17.66**	**23.20**	**18.43**
CD(P=0.05)	**54.40**	**71.49**	**56.78**
Age of crop (A)			
A_1-(Main crop)	1191.68	1188.80	1190.24
A_2- (1st ratoon)	1586.23	1330.22	1458.22
A_3- (2nd ratoon)	1196.61	442.19	819.40
SEm (±)	**24.97**	**32.81**	**26.06**
CD(P=0.05)	**76.94**	**101.10**	**80.30**
Interaction (S x A)			
S_1A_1	1242.61	1397.13	1319.87
S_1A_2	1687.93	1408.72	1548.33
S_1A_3	1152.16	539.95	846.06
S_2A_1	1140.75	980.47	1060.61
S_2A_2	1484.52	1251.71	1368.12
S_2A_3	1241.07	344.43	792.75
SEm (±)	**30.58**	**40.18**	**31.92**
CD(P=0.05)	**94.23**	**123.82**	**98.35**

Age of crop showed significant difference on modulus of elasticity in crown extracted fibres. From the pooled data, the highest modulus of elasticity was recorded in second ratoon (1179.97 cN/tex) which was statistically at par with first ratoon (1153.68 cN/tex) and the lowest in main crop (872.50 cN/tex).

The interaction effect between the cropping season and age of crop had significant effect on the modulus of elasticity of crown fibres. The highest modulus of elasticity was observed in S_1A_3 (1275.73 cN/tex) followed by S_1A_2 (1201.71 cN/tex) and the lowest in S_2A_1 (678.86 cN/tex).

The modulus of elasticity is the ratio of tensile or compressive stress to the corresponding strain below the materials proportional limit. It characterizes the stiffness or rigidity of natural fibres and indicates how much the fibre can stretch or deform under a given load before reaching its proportional limit. Understanding this property is crucial for applications like textile manufacturing and composite materials. Pineapple fibre extracted from sucker exhibited a modulus of elasticity ranging from 792.75 cN/tex to 1548.33 cN/tex, while crown ranged from 678.86 to 1275.73 cN/tex. Similar findings were reported by Jose *et al*. (2018), who found a modulus of 1038 cN/tex for pineapple fibres, whereas Soriashram *et al.* (2018) reported 1727.65 cN/tex for banana fibres. The present study observed a wide range of modulus of elasticity values in its results, significantly influenced by both cropping season and crop age. Further, a *t*-test (Table 4.10) comparing pineapple leaf and crown fibres indicated that the effects of cropping season, crop age and their interaction on modulus of elasticity were non-significant (t= 2.87, 0.39 & 0.61 and (p = 0.21, 0.73 & 0.57).

Table 4.9: Effect of cropping season, age of crop and their interaction on modulus of elasticity (cN/tex) of fibre extracted from pineapple crown

Particulars	Year		
	2019-2020	2020-2021	Pooled
Cropping season (S)			
S_1 - Summer	1227.52	1135.00	1181.26
S_2 - Winter	1092.31	820.03	956.17
SEm (±)	**31.64**	**7.08**	**16.42**
CD(P=0.05)	**97.49**	**21.82**	**50.60**
Age of crop (A)			
A_1-(Main crop)	1070.19	674.82	872.50
A_2- (1st ratoon)	1141.65	1165.70	1153.68
A_3- (2nd ratoon)	1267.90	1092.04	1179.97
SEm (±)	**44.74**	**10.01**	**23.23**
CD(P=0.05)	**137.87**	**30.85**	**71.56**
Interaction (S X A)			
S_1A_1	1117.07	1015.60	1066.33
S_1A_2	1242.08	1161.34	1201.71
S_1A_3	1323.4	1228.06	1275.73
S_2A_1	1023.31	334.03	678.68
S_2A_2	1041.23	1170.06	1105.64
S_2A_3	1212.39	956.01	1084.20
SEm (±)	**54.80**	**12.26**	**28.45**
CD(P=0.05)	**168.86**	**37.79**	**87.65**

Table 4.10: *t*-test on Modulus of elasticity, Elongation at break point and Cellulose between pineapple sucker and crown

Treatments	Modulus of elasticity			Elongation at break point			Cellulose		
	t-test	*t*-critical (two tailed)	*p* value	*t*-test	*t*-critical (two tailed)	*p*=value	*t*-test	*t*-critical (two tailed)	*p* value
Cropping season (S)	2.87^{NS}	12.71	0.21	3.91 ^{NS}	12.71	0.159	35.03*	12.71	0.018
Age of crop (A)	0.39 ^{NS}	4.30	0.73	8.35*	4.30	0.014	8.93*	4.30	0.012
Interaction (S×A)	0.61 ^{NS}	2.57	0.57	6.99*	2.57	0.001	13.45*	2.57	4.07E-05

*significant at 5 per cent level, NS: non-significant

4.1.2.3. Elongation at break point (%)

4.1.2.3. a. Elongation at break point of pineapple sucker fibre

Table 4.11 elucidate the effect of cropping season on elongation at break point of fibre extracted from pineapple sucker. Cropping season was found to have significant effect on elongation at break in fibre extracted from pineapple sucker across the investigated years and in pooled data. The highest elongation at break was exhibited in summer season (2.61%), while a comparatively lower value was recorded in winter season (2.36%).

Age of crop also significantly affected the elongation at break point of fibres extracted from pineapple sucker. The data revealed that the highest elongation at break was exhibited in first ratoon (2.54%) which was at par second ratoon (2.53%), while lowest elongation at break was exhibited in main crop (2.38%).

The interaction between the cropping season and crop age significantly affected the elongation at break point in pineapple sucker fibres. The highest elongation at break point was recorded in S_1A_2 (2.70%) followed by S_1A_3 (2.60%) and the lowest was noted in S_2A_1 (2.24%).

4.1.2.3. b. Elongation at break point of pineapple crown fibre

The elongation at break point of crown fibre as cited in Table 4.12, exhibited significant variation on cropping season in both the years of experiment and in pooled data. The highest value of elongation at break point was recorded in summer season (2.45%) and the lowest in winter season (2.09 %).

Age of crop had significant effect on elongation at break point of crown fibres. The highest elongation at break point was found in second ratoon crop *i.e.* A_3 (2.37%) followed by first ratoon crop *i.e.* A_2 (2.31%) and lowest was exhibited in main crop *i.e.* A_1 (2.14%).

The interaction between the cropping season and age of crop had significant effect on elongation at break point in crown fibres. It is evident from the data that the highest elongation at break point was recorded in S_1A_2 (2.54%), followed by S_1A_3 (2.49%) and the lowest in S_2A_1 (1.96%).

Elongation at break point also known as fracture strain is the ratio between changed length and initial length after breakage of the test specimen. It expresses the capability of natural plant fibre to resist changes of shape without crack formation. Furthermore, the elongation percentage serves as an indicator of the materials ductility. In the present study, the elongation at break point in fibre extracted from pineapple sucker was found to be in the range of 2.24 to 2.70 % and 1.96 to 2.54% in crown fibre. Several studies have reported a varying elongation at break values for pineapple leaf fibre; 2.45% (Gebino *et al.*, 2018), 2.5-4.0% (Jalil *et al.*, 2019), 1.21% (Alam *et al.*, 2022), 3.0% (Banik *et al.*, 2011) and 2.19% in crown fibre (Johny *et al.*, 2023). The elongation at break point values observed in this study aligns with those reported in the literature. Differences between the present findings and previous research may be attributed to variations in pineapple variety and its geographical conditions. The present results show that elongation at break point was higher during the summer season and increased with crop age, peaking in the first ratoon crop and remaining consistent in the second ratoon crop. Moreover, summer season crop exhibited a greater elongation at break point compared to winter season crop, this may be due to higher content of lignin as observed in summer and also its subsequent increase in regard to age of plant. This finding is consistent with prior research indicating that higher lignin content can enhance the extension ability of natural fibres (Agu *et al.*, 2012). Also, Mortazavi and Moghaddam (2010) reported that leafiran fibres containing 26% lignin exhibited greater elongation as compared to fibre from kenaf (17% lignin), jute (9% lignin) and pineapple (8.3% lignin). From the *t*-test results (Table 4.10), the difference in elongation at the break point between pineapple sucker and crown with respect to cropping season was not significant (t=3.91, p = 0.159). However, elongation at the break point was highly significant with respect to the age of the crop (t = 8.35, p = 0.014). Also, the t-test showed that interaction of cropping season and age of crop also significantly influenced the elongation at the break point between pineapple sucker and crown (t= 6.99, p= 0.001).

Table 4.11: Effect of cropping season, age of crop and their interaction on elongation at break point (%) of fibre extracted from pineapple sucker

Particulars	Year		
	2019-20	2020-2021	Pooled
Cropping season (S)			
S_1 - Summer	2.60	2.62	2.61
S_2 - Winter	2.32	2.39	2.36
SEm (±)	**0.02**	**0.03**	**0.01**
CD(P=0.05)	**0.05**	**0.09**	**0.04**
Age of crop (A)			
A_1-(Main crop)	2.41	2.36	2.38
A_2- (1st ratoon)	2.51	2.58	2.54
A_3- (2nd ratoon)	2.47	2.58	2.53
SEm (±)	**0.03**	**0.04**	**0.02**
CD(P=0.05)	**0.08**	**0.11**	**0.06**
Interaction (S x A)			
S_1A_1	2.53	2.52	2.53
S_1A_2	2.76	2.64	2.70
S_1A_3	2.51	2.69	2.60
S_2A_1	2.28	2.20	2.24
S_2A_2	2.25	2.51	2.38
S_2A_3	2.44	2.47	2.46
SEm (±)	**0.03**	**0.04**	**0.02**
CD(P=0.05)	**0.09**	**0.14**	**0.08**

Table 4.12: Effect of cropping season, age of crop and their interaction on elongation at break point (%) of fibre extracted from pineapple crown

Particulars	Year		
	2019-20	2020-2021	Pooled
Cropping season (S)			
S_1 - Summer	2.51	2.39	2.45
S_2 - Winter	2.08	2.11	2.09
SEm (±)	0.03	0.03	0.03
CD(P=0.05)	0.10	0.10	0.09
Age of crop (A)			
A_1-(Main crop)	2.19	2.09	2.14
A_2- (1st ratoon)	2.32	2.29	2.31
A_3- (2nd ratoon)	2.36	2.38	2.37
SEm (±)	**0.05**	**0.05**	**0.04**
CD(P=0.05)	**0.14**	**0.15**	**0.13**
Interaction (S x A)			
S_1A_1	2.44	2.20	2.32
S_1A_2	2.52	2.56	2.54
S_1A_3	2.56	2.41	2.49
S_2A_1	1.94	1.97	1.96
S_2A_2	2.12	2.01	2.07
S_2A_3	2.17	2.34	2.26
SEm (±)	**0.06**	**0.06**	**0.05**
CD(P=0.05)	**NS**	**0.18**	**0.15**

4.1.3. Bio-chemical properties

4.1.3.1. Cellulose (%)

4.1.3.1. a. Cellulose content in pineapple sucker fibre

Effect of cropping season, age of crop and their interaction on cellulose content of fibre extracted from pineapple sucker are depicted in Table 4.13. Cellulose content of pineapple sucker fibre as affected by cropping season showed significant variation, with highest content obtained in summer season (68.24%) and the lowest in winter season (66.70%).

From the perusal of data, it is evident that age of crop showed significant difference on cellulose content in fibre extracted from pineapple sucker. The highest content of cellulose was recorded from first ratoon (69.24%) followed by second ratoon (67.26%) and the lowest in main crop (65.92%).

The interaction effect of cropping season and crop age also showed significant effect in fibre extracted from pineapple sucker. The highest value was exhibited in S_1A_2 (70%) followed by S_2A_2 (68.47%) and lowest in S_2A_1 (65.29%).

4.1.3.1. b. Cellulose content in pineapple crown fibre

Effect of cropping season, age of crop and their interaction on cellulose content of fibre extracted from pineapple crown is presented in Table 4.14 Cropping season had significant effect on cellulose content in both the years as well as pooled data, with highest content recorded in summer season (58.20%) and lowest in winter season (56.07%).

Age of crop also showed significant difference in cellulose content of crown fibre. The highest cellulose content was observed in second ratoon (59.21%), followed by first ratoon (57.45%) and the lowest in main crop (54.74%).

Further, the interaction effect of cropping season and crop age also had a significant influence in crown fibre. The highest level of cellulose content was recorded in S_1A_3 (60.53%) followed by S_1A_2 (57.93%), which was statistically at par with S_2A_3 (57.90%) and the lowest was noted in S_2A_1 (53.34%).

The cellulose content of pineapple leaf fibres extracted from sucker ranged from 65.29% to 70% and 53.34% to 60.53% in crown fibres. The lower cellulose content observed during the winter season may be attributed to environmental factors like temperature and sunlight, which influences cellulose synthesis and plant metabolism. This is consistent with findings of Shu *et al.* (2009), who observed that sucrose synthesis is particularly sensitive to lower temperatures, as cool temperatures inhibits cellulose synthesis in cotton fibres by disrupting sucrose synthesis which is a key process for directing carbon towards cellulose. Moreover, enzymes that are involved in cellulose synthesis are negatively impacted by decreasing temperatures, leading to reduced cellulose production and change in sucrose metabolism (Martin and Haigler, 2004). As sucrose is essential for the rapid synthesis of callose and secondary-wall cellulose and its metabolism is especially sensitive to shading and cool temperatures (Haigler *et al*., 2001). As observed in the present study, cellulose content increased as the crop progressed from main crop to subsequent ratoon crops, possibly due to continuous development and thickening of cell walls over time. The cellulose content found in this study closely aligns with previous reports. Banik *et al.* (2011) reported a cellulose content of 69.5% in pineapple leaf fibres, while Johny *et al.* (2023) documented 67.3% in pineapple crown fibres. However, Khalil *et al.* (2006) reported a higher cellulose content of 73.4% in pineapple fibre. Furthermore, the *t*-test (Table 4.10) revealed a

Table 4.13: Effect of cropping season, age of crop and their interaction on cellulose content (%) of fibre extracted from pineapple sucker

Particulars	Year		
	2019-20	2020-2021	Pooled
Cropping season (S)			
S_1 - Summer	69.49	67.00	68.24
S_2 - Winter	67.68	65.72	66.70
SEm (±)	**0.02**	**0.01**	**0.01**
CD(P=0.05)	**0.07**	**0.03**	**0.02**
Age of crop (A)			
A_1-(Main crop)	66.99	64.84	65.92
A_2- (1st ratoon)	70.43	68.05	69.24
A_3- (2nd ratoon)	68.34	66.19	67.26
SEm (±)	**0.05**	**0.02**	**0.01**
CD(P=0.05)	**0.15**	**0.07**	**0.03**
Interaction (S x A)			
S_1A_1	67.55	65.54	66.54
S_1A_2	71.12	68.89	70.00
S_1A_3	69.81	66.57	68.19
S_2A_1	66.43	64.14	65.29
S_2A_2	69.74	67.20	68.47
S_2A_3	66.87	65.80	66.34
SEm (±)	**0.07**	**0.03**	**0.02**
CD(P=0.05)	**0.22**	**0.10**	**0.05**

Table 4.14: Effect of cropping season, age of crop and their interaction on cellulose content (%) of fibre extracted from pineapple crown

Particulars	Year		
	2019-20	2020-2021	Pooled
Cropping season (S)			
S_1 - Summer	59.13	57.27	58.20
S_2 - Winter	56.12	56.02	56.07
SEm (±)	**0.04**	**0.04**	**0.03**
CD(P=0.05)	**0.12**	**0.12**	**0.08**
Age of crop (A)			
A_1-(Main crop)	55.19	54.30	54.74
A_2- (1st ratoon)	57.91	56.99	57.45
A_3- (2nd ratoon)	59.77	58.65	59.21
SEm (±)	**0.07**	**0.08**	**0.05**
CD(P=0.05)	**0.23**	**0.25**	**0.16**
Interaction (S x A)			
S_1A_1	56.94	55.36	56.15
S_1A_2	58.77	57.08	57.93
S_1A_3	61.69	59.37	60.53
S_2A_1	53.44	53.24	53.34
S_2A_2	57.05	56.90	56.97
S_2A_3	57.86	57.93	57.90
SEm (±)	**0.11**	**0.12**	**0.08**
CD(P=0.05)	**0.35**	**0.37**	**0.24**

significant effect in cellulose content between pineapple sucker and crown with respect to cropping season (t =35.03, p = 0.018), crop age (t = 8.93, p = 0.012) and their interaction (t = 13.45, p = 4.07E-05).

4.1.3.2. Hemicellulose (%)

4.1.3.2. a. Hemicellulose content in pineapple sucker fibre

The result on effect of cropping season, age of crop and their interaction on hemicellulose content of fibre from pineapple sucker are presented in Table 4.15. Cropping season showed significant differences, with highest hemicellulose content recorded in summer season (19.37%) and lowest observed in winter season crop (18.29%).

Age of crop showed significant difference on the hemicellulose content of fibre extracted from pineapple sucker. The highest hemicellulose content was observed in first ratoon crop (19.67%), followed by second ratoon crop (19.16%) and lowest content was obtained in main crop (17.66%).

The interaction of cropping season and age of crop significantly influenced the hemicellulose content of fibre from pineapple sucker. The highest hemicellulose was exhibited in S_1A_2 (20.49%) followed by S_1A_3 (19.53%) and the lowest was recorded in S_2A_1 (17.22%).

4.1.3.2. b. Hemicellulose content in crown fibre

The data regarding the effect of cropping season, age of crop and their interaction on the hemicellulose content of crown fibres are presented in Table 4.16. Across both the years of study and in pooled data, the cropping season showed significant effect on hemicellulose content in crown fibres. The highest hemicellulose content was recorded in summer season (17.16%), while the lowest was exhibited in winter season (15.83%)

Age of crop also had a significant effect on the hemicellulose content of crown fibres. From the pooled data, the highest hemicellulose content was recorded in second ratoon (17.22%) followed by first ratoon (16.77%), with the lowest value observed in main crop (15.50%).

The interaction effect of cropping season and age of crop on hemicellulose content showed significant difference in both the years and in pooled data. The highest hemicellulose content was noted in S_1A_3 (18.36 %), followed by S_1A_2 (17.35%) and the lowest content was recorded in S_2A_1 (15.18%).

Hemicellulose together with cellulose plays a critical role in forming the plants structural framework (Rowell, 2012). In pineapple sucker, the hemicellulose content ranged from 17.22% to 20.49% while in crown it varied between 15.18% and 18.36%. These findings closely corroborate previous reports; Rahman *et al*. (2011) reported 12.31% in PALF and 16.9% in pineapple crown fibre (Johny *et al*., 2023). Comparable values are documented for other plant fibres as well, with hemicellulose content ranging from 18.94% to 19.69% in dewaxed jute fibre (Meshram *et al*., 2013). The variations in hemicellulose content can be attributed to the differences in fibre extraction methods and plant cultivars. This aligns with the findings of Zainuddin *et al*., 2014, who reported variability in lignocellulosic content across varieties and different parts of pineapple plant. Also chemical treatments are frequently employed to enhance cellulose and reduce the hemicellulose content for improving the quality of fibre. However, the effectiveness of these chemical treatments in selectively and efficiently removing hemicellulose varies (Vijay *et al*., 2019), resulting in differences in hemicellulose content of the present study where mechanical extraction method was employed. Furthermore, environmental factors such as temperature, growing site, local climatic conditions, seasons and harvesting time significantly influences the structure

Table 4.15: Effect of cropping season, age of crop and their interaction on hemicellulose content (%) of fibre extracted from pineapple sucker

Particulars	Year		
	2019-20	2020-2021	Pooled
Cropping season (S)			
S_1 - Summer	18.95	19.80	19.37
S_2 - Winter	17.54	19.03	18.29
SEm (±)	**0.03**	**0.02**	**0.01**
CD(P=0.05)	**0.10**	**0.07**	**0.04**
Age of crop (A)			
A_1-(Main crop)	17.40	17.92	17.66
A_2- (1st ratoon)	18.21	20.72	19.67
A_3- (2nd ratoon)	19.13	19.60	19.16
SEm (±)	**0.06**	**0.04**	**0.03**
CD(P=0.05)	**0.19**	**0.13**	**0.08**
Interaction (S x A)			
S_1A_1	17.95	18.27	18.11
S_1A_2	19.04	21.11	20.49
S_1A_3	19.86	20.02	19.53
S_2A_1	16.85	17.58	17.22
S_2A_2	17.37	20.33	18.85
S_2A_3	18.40	19.18	18.79
SEm (±)	**0.09**	**0.07**	**0.04**
CD(P=0.05)	**0.29**	**NS**	**0.12**

Table 4.16: Effect of cropping season, age of crop and their interaction on hemicellulose content (%) of fibre extracted from pineapple crown

Particulars	Year		
	2019-20	2020-2021	Pooled
Cropping season (S)			
S_1 - Summer	16.62	17.70	17.16
S_2 - Winter	15.31	16.37	15.83
SEm (±)	**0.03**	**0.07**	**0.03**
CD(P=0.05)	**0.10**	**0.22**	**0.08**
Age of crop (A)			
A_1-(Main crop)	15.05	15.96	15.50
A_2- (1st ratoon)	16.50	17.02	16.76
A_3- (2nd ratoon)	16.35	18.13	17.22
SEm (±)	**0.06**	**0.14**	**0.05**
CD(P=0.05)	**0.19**	**0.43**	**0.15**
Interaction (S x A)			
S_1A_1	15.19	16.47	15.83
S_1A_2	17.12	17.58	17.35
S_1A_3	17.55	19.04	18.30
S_2A_1	14.90	15.45	15.18
S_2A_2	15.88	16.45	16.16
S_2A_3	15.15	17.22	16.15
SEm (±)	**0.09**	**0.21**	**0.07**
CD(P=0.05)	**0.29**	**NS**	**0.23**

Table 4.17: *t*-test on hemicellulose, lignin and ash content between pineapple sucker and crown

Treatments	Hemicellulose			Lignin			Ash		
	t-test	*t*-critical (two tailed)	*p*-value	*t*-test	*t*-critical (two tailed)	*p*-value	*t*-test	*t*-critical (two tailed)	*p*-value
Cropping season (S)	18.68*	12.71	0.034	18.33*	12.71	0.035	156.67*	12.71	0.0041
Age of crop (A)	7.96*	4.30	0.015	13.60*	4.30	0.005	49.03*	4.30	0.0004
Interaction (S×A)	4.45*	2.57	0.007	14.65*	2.57	2.68E-05	37.69*	2.57	2.48E-07

*significant at 5 per cent level, NS: non-significant

and quality of natural fibres (Kumar *et al*., 2018). Statistical analysis using *t*-test (Table 4.10), indicated significant effect in hemicellulose content between pineapple sucker and crown with respect to its cropping season (t= 18.68, p = 0.034), crop age (t=7.96, p = 0.015) and their interaction (t=4.45, p = 0.007).

4.1.3.3. Lignin (%)

4.1.3.3. a. Lignin content in sucker fibre

It is evident from the data presented in Table 4.18 that lignin content of pineapple sucker fibre was significantly affected by cropping season. A thorough scanning of data indicated that the lignin content was higher during summer season as compared to winter season in both the years as well as pooled data. The highest content was exhibited in summer season (5.26%) and the lowest in winter season (4.81%).

Age of crop also showed a pronounced effect on the lignin content, with highest content obtained in second ratoon (5.25%) followed by first ratoon (5.17%) and lowest in main crop (4.68%).

The interaction effect of cropping season and age of crop on lignin content showed a significant variation in pineapple sucker fibre. The highest content of lignin was recorded in S_1A_3 (5.57%) which was on par with S_1A_2 (5.47%) and the lowest in S_2A_1 (4.62%).

4.1.3.3. b. Lignin content in crown fibre

As cited in Table 4.19, cropping season had significant influence on lignin content of crown fibre. The highest content of lignin was observed in summer season (4.39%) and the lowest was recorded in winter season (4.03%).

From the perusal of the data, it was apparent that the lignin content was affected by crop age. The highest content of lignin was observed in second ratoon crop (4.48%) followed by first ratoon crop (4.23%) and the lowest in main crop (3.93%).

The interaction effect of cropping season and age of crop showed no significant effect on the lignin content of crown fibres. However, highest content was observed in S_1A_3 (4.67%), followed by S_1A_2 (4.45%) while lowest content was recorded in S_2A_1 (3.80%).

In this study, lignin content in fibre extracted pineapple sucker and crown was found to be significantly influenced by cropping season and crop age. The decrease in lignin content during the winter season may be attributed to reduced light levels, which limits lignin biosynthesis due to decreased availability of carbon skeletons (Rogers *et al.*, 2005). Light intensity is reported to play a critical role in regulating lignin biosynthetic enzyme activity, where shaded plants exhibits a lower lignification levels (Buxton, 1996). In regard to crop age, lignin content increased from the main crop to the ratoon crop, reaching a peak as the plant matures (Armstrong *et al.*, 1950). Studies using Py-GC-MS on Chinese kenaf demonstrated an increase in the lignin S-G ratio with respect to plant maturity (Mazumder *et al.*, 2005). The lignin content in pineapple sucker fibre ranged from 4.62% to 5.57%, while in crown fibres, it ranged from 3.80% to 4.67%. Banik *et al.* (2011) reported a content of 4.4% lignin, which closely aligns with our findings, whereas Nadirah *et al.* (2012) reported a higher lignin content of 10.41%. Lignin plays a crucial role for growth and adaptation of herbaceous and woody plants, although its content may vary significantly across different plant parts (Shen *et al.*, 2009). However, specific quantitative requirements for lignin and its compositional variations across plant species remain underexplored. Further, the *t*-test results from Table 4.10 indicated significant differences in lignin content between pineapple sucker and crown concerning cropping season (t=18.33, p=0.035),

Table 4.18: Effect of cropping season, age of crop and their interaction on lignin content (%) of fibre extracted from pineapple sucker

Particulars	Year		
	2019-20	2020-2021	Pooled
Cropping season (S)			
S_1 - Summer	5.62	4.91	5.26
S_2 - Winter	5.27	4.34	4.81
SEm (±)	0.00	0.01	0.00
CD(P=0.05)	0.01	0.04	0.01
Age of crop (A)			
A_1-(Main crop)	5.10	4.27	4.68
A_2- (1st ratoon)	5.48	4.86	5.17
A_3- (2nd ratoon)	5.75	4.75	5.25
SEm (±)	0.01	0.03	0.01
CD(P=0.05)	0.02	0.08	0.02
Interaction (S x A)			
S_1A_1	5.25	4.25	4.75
S_1A_2	5.68	5.26	5.47
S_1A_3	5.93	5.21	5.57
S_2A_1	4.94	4.29	4.62
S_2A_2	5.29	4.46	4.87
S_2A_3	5.58	4.28	4.93
SEm (±)	**0.01**	**0.04**	**0.01**
CD(P=0.05)	**NS**	**0.12**	**0.03**

Table 4.19: Effect of cropping season, age of crop and their interaction on lignin content (%) of fibre extracted from pineapple crown

Particulars	Year		
	2019-20	2020-2021	Pooled
Cropping season (S)			
S_1 - Summer	4.50	4.28	4.39
S_2 - Winter	4.13	3.93	4.03
SEm (±)	**0.02**	**0.01**	**0.01**
CD(P=0.05)	**0.06**	**0.04**	**0.03**
Age of crop (A)			
A_1-(Main crop)	4.03	3.82	3.93
A_2- (1st ratoon)	4.31	4.15	4.23
A_3- (2nd ratoon)	4.62	4.34	4.48
SEm (±)	**0.04**	**0.02**	**0.02**
CD(P=0.05)	**0.12**	**0.07**	**0.06**
Interaction (S x A)			
S_1A_1	4.16	3.94	4.05
S_1A_2	4.52	4.38	4.45
S_1A_3	4.83	4.50	4.67
S_2A_1	3.90	3.70	3.80
S_2A_2	4.10	3.91	4.01
S_2A_3	4.40	4.19	4.29
SEm (±)	**0.06**	**0.03**	**0.03**
CD(P=0.05)	**NS**	**NS**	**NS**

crop age (t= 13.60, p=0.005) and their interaction effect (t= 14.65, p= 2.68E-05).

4.1.3.4. Ash (%)

4.1.3.4. a. Ash content in pineapple sucker

The data pertaining to the ash content of pineapple sucker as affected by cropping season, age of crop and their interaction are documented in Table 4.20. Cropping season showed significant influence on ash content of pineapple sucker with the highest ash content recorded in summer season (6.15%) and the lowest in winter season (5.96%).

Similarly, age of the crop also exhibited significant differece on ash content of pineapple sucker. Highest content was observed in main crop (6.20%) and the lowest in second ratoon (5.93%) which was statistically at par first ratoon (6.02%).

The interaction of cropping season and age of crop did not yield any significant effect on the ash content of pineapple sucker. However, highest content of ash was recorded in S_1A_1 (6.30%) and lowest in S_2A_3 (5.86%).

4.1.3.4. b. Ash content in pineapple crown

The effect of cropping season, age of crop and their interaction on ash content of pineapple crown are depicted in Table 4.21. Data indicated that cropping season significantly influenced on ash content of crown, with the highest value recorded in summer season (5.44%) and the lowest in winter season (5.23%).

Age of crop was found to have significant influence on ash content of crown. From the pooled data, the highest content was observed in main crop (5.51%) followed by first ratoon (5.28%) and the lowest in second ratoon (5.22%).

The interaction effect of cropping season and age of crop did not show any significant difference on the ash content of crown on both the years of investigation as well as in pooled data analysis. However, notable variations were observed where the highest level of ash content obtained in S_1A_1 (5.58%) followed by S_1A_2 (5.41%) and the lowest in S_2A_3 (5.09%).

Ash content varied significantly in regard to cropping season and age of crop in pineapple sucker and crown. The ash content in pineapple sucker varied between 5.86% and 6.30%, while in crown samples it varied between 5.09% and 5.58%. Earlier studies have reported variation in he ash content of pineapple compared to the present study, Nadirah *et al.* (2012) found 4.73%, Faria *et al.* (2020) reported 6.73% and Braga *et al.* (2015) recorded 5.22% in pineapple crown leaves. In regard to other biomass sources in the literature, *Cynara cardunculus* L. exhibited 7.7% ash content in its whole stalk (Gominho *et al.*, 2001) and *Arundo donax* showed 6.1% ash content (Shatalov and Pereira, 2002). The current study observed a significant increase in ash content during the summer season and in the main crop of sucker and crown samples of pineapple. This seasonal variation is likely due to an increased metabolic activity and nutrient absorption in warmer weather, affecting the accumulation of minerals in plant tissues. This observation aligns with Belkhir *et al.* (2013), who reported similar seasonal trends in ash content of esparto leaf, with low ash content during winter and a peak level during the summer season. Furthermore, the *t*-test results (Table 4.10) indicated highly significant variations in ash content between pineapple sucker and crown concerning cropping season (t= 156.67, p=0.0041), crop age (t= 49.03, p= 0.0004) and their interaction (t=37.69, p=2.48E-07).

Table 4.20: Effect of cropping season, age of crop and their interaction on the ash content (%) of fibre extracted from pineapple sucker

Particulars	Year		
	2019-20	2020-2021	Pooled
Cropping season (S)			
S_1 - Summer	6.34	5.96	6.15
S_2 - Winter	6.02	5.87	5.95
SEm (±)	**0.09**	**0.07**	**0.07**
CD(P=0.05)	**0.27**	**NS**	**0.21**
Age of crop (A)			
A_1-(Main crop)	6.35	6.06	6.20
A_2- (1st ratoon)	6.20	5.83	6.02
A_3- (2nd ratoon)	5.99	5.87	5.93
SEm (±)	**0.12**	**0.10**	**0.09**
CD(P=0.05)	**0.38**	**NS**	**0.29**
Interaction (S x A)			
S_1A_1	6.40	6.19	6.30
S_1A_2	6.40	5.94	6.17
S_1A_3	6.23	5.77	6.00
S_2A_1	6.30	5.92	6.11
S_2A_2	6.00	5.72	5.86
S_2A_3	5.75	5.98	5.86
SEm (±)	**0.15**	**0.12**	**0.12**
CD(P=0.05)	**NS**	**NS**	**NS**

Table 4.21: Effect of cropping season, age of crop and their interaction on the ash content (%) of fibre from pineapple crown

Particulars	Year		
	2019-20	2020-2021	Pooled
Cropping season (S)			
S_1 - Summer	5.34	5.55	5.44
S_2 - Winter	5.07	5.39	5.23
SEm (±)	**0.05**	**0.04**	**0.02**
CD(P=0.05)	**0.15**	**0.13**	**0.07**
Age of crop (A)			
A_1-(Main crop)	5.44	5.59	5.51
A_2- (1st ratoon)	5.11	5.44	5.28
A_3- (2nd ratoon)	5.06	5.38	5.22
SEm (±)	**0.07**	**0.06**	**0.03**
CD(P=0.05)	**0.21**	**0.18**	**0.10**
Interaction (S x A)			
S_1A_1	5.49	5.67	5.58
S_1A_2	5.29	5.54	5.41
S_1A_3	5.24	5.44	5.34
S_2A_1	5.39	5.50	5.45
S_2A_2	4.94	5.34	5.14
S_2A_3	4.87	5.32	5.09
SEm (±)	**0.08**	**0.07**	**0.04**
CD(P=0.05)	**NS**	**NS**	**NS**

4.1.3.5. Moisture content (%)

4.1.3.5. a. Moisture content in pineapple sucker

From the perusal of data in Table 4.22, cropping season showed no significant difference on moisture content of sucker significant difference in both the years. However, highest content of moisture was consistently observed during summer season (11.50%) and the lowest in winter season (11.34%).

Age of crop showed no significant difference on moisture content of pineapple sucker. However, the highest moisture content was recorded in main crop (11.82%) followed by first ratoon crop (11.28%) and the lowest in second ratoon crop (11.17%).

Further, the interaction of cropping season and age of crop did not yield significant results. However, S_1A_1 (11.94%) recorded the highest moisture content followed by S_2A_1 (11.70%) while S_2A_3 (10.96%) recorded the lowest content.

4.1.3.5. b. Moisture content in crown

The effect of cropping season on moisture content of crown is presented in Table 4.23. The data from the table revealed that cropping season showed no significant effect on moisture content during both the experimental years and in pooled data. From the pooled data, summer season (10.59%) exhibited the highest and winter season (10.40%) reported the lowest moisture content.

Age of crop also showed no significant influence on moisture content of crown. However, main crop (10.72%) recorded the highest moisture followed by first ratoon crop (10.55%) and the lowest in second ratoon crop (10.21%).

Further, the interaction effect of cropping season and age of crop did not show significant variation in both the years of investigation as well as in pooled data. However, the highest level of moisture content was observed in S_1A_1

(11.03%) and the lowest was recorded in S_2A_3 (10.19%) which was on par with S_1A_3 (10.24%).

The moisture content in pineapple sucker ranged varied between 10.96% and 11.94%, while in the crown, it varied between 10.19% and 10.24%. These findings align closely with Mohanty *et al.* (2000), who reported a moisture content of 11.8 %. Zainuddin *et al.* (2014) also reported moisture content in the range of 8.78% to 10.79% in pineapple leaves and stems. The average moisture content in both the sucker and crown did not exceed 15%, indicating the materials suitability for long-term storage (Kaliyan and Morey, 2006). Furthermore, the *t*-test (Table 4.24) indicated significant differences in moisture content between pineapple sucker and crown concerning cropping season (t=61.67, p= 0.010), crop age (t=8.62, p= 0.0013) and their interaction (t=9.55, p= 0.0002).

Table 4.22: Effect of cropping season, age of crop and their interaction on the moisture content (%) of pineapple sucker

Particulars	Year		
	2019-20	2020-2021	Pooled
Cropping season (S)			
S_1 - Summer	10.92	12.07	11.50
S_2 - Winter	10.88	11.80	11.34
SEm (±)	**0.07**	**0.08**	**0.04**
CD(P=0.05)	**NS**	**NS**	**NS**
Age of crop (A)			
A_1-(Main crop)	11.21	12.42	11.82
A_2- (1st ratoon)	10.79	11.76	11.28
A_3- (2nd ratoon)	10.70	11.63	11.17
SEm (±)	**0.14**	**0.15**	**0.08**
CD(P=0.05)	**NS**	**NS**	**NS**
Interaction (S x A)			
S_1A_1	11.17	12.71	11.94
S_1A_2	10.68	11.67	11.18
S_1A_3	10.90	11.84	11.37
S_2A_1	11.25	12.1	11.70
S_2A_2	10.90	11.9	11.38
S_2A_3	10.50	11.4	10.96
SEm (±)	**0.21**	**0.23**	**0.13**
CD(P=0.05)	**NS**	**NS**	**NS**

Table 4.23: Effect of cropping season, age of crop and their interaction on the moisture content (%) of pineapple crown

Particulars	Year		
	2019-20	2020-2021	Pooled
Cropping season (S)			
S_1 - Summer	10.19	10.99	10.59
S_2 - Winter	10.46	10.33	10.40
SEm (±)	**0.08**	**0.09**	**0.03**
CD(P=0.05)	**NS**	**NS**	**NS**
Age of crop (A)			
A_1-(Main crop)	10.40	11.04	10.72
A_2- (1st ratoon)	10.54	10.57	10.55
A_3- (2nd ratoon)	10.04	10.39	10.21
SEm (±)	**0.15**	**0.17**	**0.05**
CD(P=0.05)	**NS**	**NS**	**NS**
Interaction (S x A)			
S_1A_1	10.52	11.53	11.03
S_1A_2	10.22	10.80	10.51
S_1A_3	9.82	10.65	10.24
S_2A_1	10.27	10.55	10.41
S_2A_2	10.85	10.34	10.59
S_2A_3	10.26	10.12	10.19
SEm (±)	**0.23**	**0.26**	**0.08**
CD(P=0.05)	**NS**	**NS**	**NS**

Table 4.24: *t*-test on moisture content, crude fibre and total nitrogen between pineapple sucker and crown

Treatments	Moisture content			Crude fibre			Total nitrogen		
	t-test	*t*-critic al (two tailed)	*p*-value	*t*-test	*t*-critic al (two tailed)	*p*-value	*t*-test	*t*-critic al (two tailed)	*p*-value
Cropping season (S)	61.67*	12.71	0.010	7.65^{NS}	12.71	0.083	-110.88*	12.71	0.0057
Age of crop (A)	8.62*	4.30	0.013	38.20*	4.30	0.001	-12.56*	4.30	0.0063
Interaction (S×A)	9.55*	2.57	0.0002	13.26*	2.57	4.37E-05	-17.70*	2.57	1.05707E-05

*significant at 5 per cent level, NS: non-significant

4.1.3.6. Crude fibre (%)

4.1.3.6. a. Crude fibre content in pineapple sucker

The result on effect of cropping season, age of crop and their interaction on the crude fibre content of pineapple sucker are presented in Table 4.25. the data clearly indicate that cropping season had significant effect on the crude fibre of pineapple sucker. From the pooled data, summer season (22.08%) had the highest content of crude fibre and winter season (22.10%) recorded the lowest..

Age of crop showed significant influence on the crude fibre content of pineapple sucker. The second ratoon crop (22.78%) recorded the highest crude fibre, at par with first ratoon crop (22.55%) and lowest in main crop (22.03%).

The interaction effect of cropping season and crop age on crude fibre content showed no significant difference in pineapple sucker, as per the findings. However, highest value of crude fibre was noted in S_1A_3 (23.21) at par with S_1A_2 (22.96%), while S_2A_1 (21.79%) recorded the lowest.

4.1.3.6. b. Crude fibre content in pineapple crown

The data pertaining to effect of cropping season, age of crop and their interaction on the crude fibre content of pineapple crown are presented in Table 4.26. The data revealed that cropping season showed no significant effect on crude fibre content of crown. However, the highest value of crude fibre was recorded in summer season (20.45%) and winter season (20.35%) obtained the lowest.

Age of the crop also had no significant impact on the crude fibre of pineapple crown. However, notable variations were observed with the highest value of crude fibre recorded in second ratoon (20.61%) and main crop (20.05%) exhibited the lowest.

Table 4.25: Effect of cropping season, age of crop and their interaction on the crude fibre content (%) of pineapple sucker

Particulars	Year		
	2019-20	2020-2021	Pooled
Cropping season (S)			
S_1 - Summer	22.34	23.29	22.82
S_2 - Winter	21.31	22.88	22.10
SEm (±)	**0.33**	**0.10**	**0.19**
CD(P=0.05)	**1.03**	**0.30**	**0.57**
Age of crop (A)			
A_1-(Main crop)	20.88	23.19	22.03
A_2- (1^{st} ratoon)	22.09	23.01	22.55
A_3- (2^{nd} ratoon)	22.51	23.05	22.78
SEm (±)	**0.47**	**0.14**	**0.26**
CD(P=0.05)	**1.45**	**NS**	**0.81**
Interaction (S x A)			
S_1A_1	21.17	23.39	22.28
S_1A_2	22.73	23.19	22.96
S_1A_3	23.12	23.29	23.21
S_2A_1	20.59	22.98	21.79
S_2A_2	21.46	22.84	22.15
S_2A_3	21.90	22.81	22.35
SEm (±)	**0.58**	**0.17**	**0.32**
CD(P=0.05)	**NS**	**NS**	**NS**

Table 4.26: Effect of cropping season, age of crop and their interaction on the crude fibre content (%) of pineapple crown

Particulars	Year		
	2019-20	2020-2021	Pooled
Cropping season (S)			
S_1 - Summer	21.44	19.46	20.45
S_2 - Winter	21.30	19.25	20.28
SEm (±)	**0.32**	**0.31**	**0.19**
CD(P=0.05)	**NS**	**NS**	**NS**
Age of crop (A)			
A_1-(Main crop)	20.76	19.33	20.05
A_2- (1st ratoon)	21.71	19.16	20.43
A_3- (2nd ratoon)	21.64	19.58	20.61
SEm (±)	**0.46**	**0.44**	**0.27**
CD(P=0.05)	**NS**	**NS**	**NS**
Interaction (S x A)			
S_1A_1	20.23	19.47	19.85
S_1A_2	22.03	19.69	20.86
S_1A_3	22.06	19.22	20.64
S_2A_1	21.30	19.19	20.24
S_2A_2	21.39	18.62	20.00
S_2A_3	21.22	19.95	20.59
SEm (±)	**0.56**	**0.54**	**0.33**
CD(P=0.05)	**NS**	**NS**	**NS**

The interaction effect of cropping season and age of crop on crude fibre content showed no significant effect in pineapple crown. However, S_1A_2 (20.86%) recorded the highest crude fibre at par with S_1A_3 (20.64%) and S_2A_3 (20.59%) and the lowest value was obtained in S_1A_1 (19.85%).

In the present study, crude fibre in pineapple sucker varied between 21.79% and 23.21%, while in crown, it ranged from 19.85% to 20.86%. These findings differ from those of Zainuddin *et al.* (2014), who reported a higher crude fibre content ranging from 30.93% to 31.04% in three varieties of pineapple leaves. This variation emphasizes that crude fibre content are influenced by variety and maturation age. The *t*-test showed no significant difference between pineapple leaf and crown in regard to the cropping season (t=7.65, p=0.083). While, age of crop and the interaction effect significantly impacted the crude fiber content between pineapple sucker and crown (t= 38.20, 13.26) and (p= 0.001 & 4.37E-05) (Table 4.24).

4.1.3.6. Total nitrogen (%)

4.1.3.6. a. Total nitrogen content in pineapple sucker

Tables 4.27 illustrate the influence of cropping season, age of crop and their interaction on total nitrogen content of pineapple sucker. The data indicated that cropping season significantly affected total nitrogen in both the years and in pooled data. The highest total nitrogen content was recorded in summer season *i.e.* S_1 (1.25 %) and lower value was observed in winter season *i.e.* S_2 (1.13%).

From the perusal of data, it is evident that age of crop showed significant difference on total nitrogen of pineapple sucker. From the pooled data, main crop (1.28 %) recorded highest total nitrogen followed by first ratoon crop (1.20%) and second ratoon crop (1.10%) obtained the lowest.

The interaction of cropping season and age of crop showed no significant effect on pineapple sucker. However, S_1A_1 (1.35%) was found to have the highest nitrogen followed by S_2A_1 (1.24%) and the lowest was recorded in S_2A_3 (1.05%).

4.1.3.6. b. Total nitrogen content in pineapple crown

Table 4.28 illustrates the influence of cropping season, age of crop and their interaction on total nitrogen of pineapple crown. Cropping season showed no significant effect on total nitrogen, but summer season (1.55%) recorded highest nitrogen content and winter season (1.45%) exhibited the lowest.

The data revealed that age of crop also showed no significant difference on the total nitrogen content in crown. However, main crop (1.55%) reported highest content of total nitrogen and second ratoon crop (1.45%) obtained the lowest.

The interaction between cropping season and age of crop also had no profound effect on total nitrogen of crown. However, the highest value was reported in S_1A_1 (1.61%) at par with S_1A_2 (1.53%), whereas the lowest content was reported in S_2A_3 (1.38%).

The results showed that the percentage of total nitrogen content from pineapple sucker varied between 1.05% and 1.35%, whereas for crown, it varied between 1.38% and 1.61%. Statistical analysis using the *t*-test (Table 4.24) revealed that the cropping season (t = -110.88, p = 0.0057) and crop age (t = -12.56, p = 0.0063) significantly affected the total nitrogen content between pineapple sucker and crown. Additionally, the interaction between cropping season and crop age also had a significant effect on total nitrogen content (t = -17.70, p = 1.05707E-05). These findings suggest that pineapple crown generally contained higher nitrogen levels compared to pineapple sucker.

Table 4.27: Effect of cropping season, age of crop and their interaction on total nitrogen (%) in pineapple sucker

Particulars	Year		
	2019-20	2020-2021	Pooled
Cropping season (S)			
S_1 - Summer	1.28	1.22	1.25
S_2 - Winter	1.17	1.10	1.13
SEm (±)	**0.05**	**0.04**	**0.03**
CD(P=0.05)	**0.15**	**0.11**	**0.10**
Age of crop (A)			
A_1-(Main crop)	1.31	1.24	1.28
A_2- (1st ratoon)	1.23	1.16	1.20
A_3- (2nd ratoon)	1.14	1.07	1.10
SEm (±)	**0.07**	**0.05**	**0.05**
CD(P=0.05)	**NS**	**0.16**	**0.14**
Interaction (S x A)			
S_1A_1	1.40	1.30	1.35
S_1A_2	1.26	1.22	1.24
S_1A_3	1.18	1.13	1.16
S_2A_1	1.22	1.18	1.20
S_2A_2	1.19	1.10	1.15
S_2A_3	1.09	1.02	1.05
SEm (±)	**0.08**	**0.06**	**0.06**
CD(P=0.05)	**NS**	**NS**	**NS**

Table 4.28: Effect of cropping season, age of crop and their interaction on total nitrogen (%) in pineapple crown

Particulars	Year		
	2019-20	2020-2021	Pooled
Cropping season (S)			
S_1 - Summer	1.58	1.52	1.55
S_2 - Winter	1.49	1.36	1.43
SEm (±)	**0.08**	**0.10**	**0.05**
CD(P=0.05)	**NS**	**NS**	**NS**
Age of crop (A)			
A_1-(Main crop)	1.60	1.51	1.55
A_2- (1^{st} ratoon)	1.51	1.42	1.47
A_3- (2^{nd} ratoon)	1.50	1.40	1.45
SEm (±)	**0.11**	**0.14**	**0.08**
CD(P=0.05)	**NS**	**NS**	**NS**
Interaction (S x A)			
S_1A_1	1.65	1.56	1.61
S_1A_2	1.57	1.48	1.53
S_1A_3	1.52	1.50	1.51
S_2A_1	1.54	1.45	1.50
S_2A_2	1.45	1.36	1.40
S_2A_3	1.47	1.29	1.38
SEm (±)	**0.14**	**0.18**	**0.09**
CD(P=0.05)	**NS**	**NS**	**NS**

4.2. To study the qualitative parameters of vinegar produced from pineapple waste

4.2.1. Physico-chemical characteristics of wine

For vinegar production, two-step fermentation was employed involving alcoholic and acetic fermentation. In the first step involving alcoholic fermentation, alcohol content in fruit wine was influenced by fermentation characteristics of each fruit must, with lower-sugar fruit juices yielding wines with reduced ethanol content. In this study, given the low sugar content in pineapple waste, amelioration with sugar was necessary for alcoholic fermentation. The data on physico-chemical characteristics of wine used for acetic fermentation is depicted in Table 4.29. The alcoholic fermentation process required 7 days which yielded an alcohol content of 7.68%, 6.7%, and 7.24% in peel, core and pomace wines, respectively. The pH levels were 3.9 in peel wine, 4.2 in core wine, and 4.1 in pomace wine. The Total Soluble Solids (TSS) obtained from the wines was 5.1 brix^0 for peel, 5.5 brix^0 in core, and 5.3 brix^0 in pomace wine. Titratable acidity values for peel, core, and pomace wines were 0.76%, 0.40%, and 0.55% respectively, while acetic acid content was measured at 0.71% (peel wine), 0.38% (core) and 0.55% (pomace wine).

In a similar study on pineapple wine, Bertan *et al.* (2022) reported an alcohol content of 8.39% (v/v) and 7.28% (v/v) in pineapple pulp and peel wines respectively. Also, pineapple fruit juice ameliorated with 20 °Brix sugar resulted in an alcohol content of 10.2%, 5.4 °Brix soluble solids and a pH of 3.5 (Qi *et al.*, 2017). Furthermore, an alcohol content of 8.35% to 8.4% from two varieties of pineapple was reported by Patil and Patil (2006). In another separate study, Chowdhury and Ray (2007) produced wine from jamun with a low alcohol concentration of 6% after six days of fermentation with pH of 3.5 and TSS of 2.8 °Brix.

Further, the colour properties of wines derived from pineapple waste were analyzed, encompassing parameters such as color intensity, color density, color tone, Y% (yellow), %R (red) and %B (blue). In peel wine, the measurements were 1.13 for color intensity, 0.93 for color density, 1.96 for color tone, 54.9 for y%, 27.67 for %R, and 18.12 for %B. Core wine exhibited values of 0.87, 0.64, 1.51, 46.31, 30.64, and 23.04 for color intensity, color density, color tone, y%, %R and %B, respectively. In pomace wine, the respective values were 0.93, 0.70, 1.42, 44.08, 30.98 and 24.92 for color intensity, color density, color tone, y%, %R, and %B.

It is apparent from the data that in the prepared wines, the measured value of colour tone showed greater prominence compared to colour density and colour intensity. This observation can be attributed to the distinct noticeable yellow colour present in the prepared wines. The results align with the findings from Tsegay and Gebremedhin (2019), who reported a higher colour tone value of 1.40 in wine produced from blended cactus pear and *Lantana camara* fruit as opposed to colour intensity and density. Also, in the present study prevalence of yellow to orange color of pineapple waste used for alcoholic fermentation could be a contributing factor, whereby the resulting wine exhibited a predominantly yellowish hue in the range of 44.08% to 54.19%. The peel wine particularly displayed a higher Y% among the prepared wines. Similar finding was reported by Joshi *et al*. (2014), where a more predominant yellowish color (Y %) was observed in citrus wine.

Table 4.29: Physico-chemical characteristics of wine

Parameters	Peel wine	Core wine	Pomace wine
pH	3.9	4.2	4.1
TSS (Brix^0)	5.1	5.5	5.3
Alcohol (%)	7.68	6.7	7.24
Titratable acidity (%)	0.76	0.40	0.59
Acetic acid (%)	0.71	0.38	0.55
Colour intensity	1.13	0.868	0.93
Colour density	0.93	0.635	0.70
Colour tone	1.96	1.51	1.42
%Y(yellow)	54.19	46.31	44.08
%R(red)	27.67	30.64	30.98
%B(blue)	18.12	23.04	24.92

4.2.2. Physico-chemical characteristics of prepared vinegar

4.2.2.1. pH

The pH levels of vinegar derived from pineapple waste demonstrated significant difference, as presented in Table 4.30. The maximum pH was recorded in core (3.02) followed by pomace (2.81) and the minimum in peel (2.69). In addition, the pH of vinegar during secondary fermentation decreased notably from 3.9 to 2.69 in peel, 4.2 to 3.02 in core and from 4.1 to 2.81 in pomace. This result indicates a visible trend of decreasing pH among all the treatments after acetic fermentation.

The variation in pH among the treatments can be attributed to the distinct wine substrates used in the vinegar production. It is established that as acetic acid concentration increases, the pH decreases correlating with higher acidity, as noted by Jamaludin *et al*. (2017). Decrease in pH and increase in acidity content may be due to accumulation of acetic acid and various organic acids resulted by *Acetobacter* and yeast during the process of fermentation (Habiba *et al*., 2024).This relationship is evident in the present study, where different substrates led to varying levels of acetic acid production and therefore, different pH values. Furthermore, the pH values observed in this study ranged from 2.69 to 3.02. The pH results are comparable to those reported by Roda *et al.* (2017), who reported a pH value of 3 in pineapple vinegar. Chalchisa and Dereje (2021) also documented pH values ranging from 3 and 3.5 in pineapple peel vinegar. This study confirms that the type of substrate used, significantly impacts the pH and acidity of the resulting vinegar.

4.2.2.2. TSS (^{0}Brix)

TSS of vinegar prepared from different pineapple waste showed no significant difference (Table 4.30). However, the highest TSS was recorded in vinegar prepared from pineapple core (3.36 °Brix) and the lowest in vinegar prepared from pineapple peel (3.25 °Brix).

The decline in TSS may be attributed to the hydrolysis of sucrose into glucose and fructose, which are more soluble and can result in a decrease in TSS. Shi *et al*. (2019) also reported a reduction of soluble solids after fermentation process in kiwifruit vinegar.

4.2.2.3. Specific gravity

The specific gravity of vinegar prepared from different pineapple waste was found to be non-significant, as illustrated in Table 4.30. Specific gravity readings of 1.014 in peel, 1.012 in core and 1.012 in pomace were recorded.

Specific gravity from the present study ranged from 1.012 to 1.014, showing close conformity with previous research findings. Raichurkar and Dadagkhair (2017) reported a specific gravity of 1.019 in custard apple vinegar, indicating similar density characteristics. Similarly, Constance *et al.* (2021) observed specific gravity values ranging from 1.001 to 1.083 in Garcinia and jackfruit vinegar, demonstrating a broad spectrum of densities within vinegar products derived from different fruit sources. Sahin *et al.* (1977) also reported specific gravity values falling within the range of 1.010 to 1.0119 for grape vinegars.

4.2.2.4. Titratable acidity (%)

From Table 4.31, the titratable acidity (as percent citric acid) of vinegar prepared from different pineapple waste varied significantly with highest value recorded in peel (5.03%), followed by pomace (4.80%) and the lowest in Core (4.50%). The titratable acidity in vinegar prepared from different waste components increased during the acetic fermentation period compared to the initial wine values. Titratable acidity rose from 0.76 to 5.03%, 0.40 to 4.50%, and 0.59 to 4.80% in peel, core and pomace respectively.

This increasing trend in acidity could be due to the addition of *Acetobacter aceti* broth and the prevailing fermentation conditions. Further, peel vinegar exhibited the highest titratable acidity probably due to its elevated alcohol concentration, resulting in a higher acetic acid content and lower pH in the prepared vinegar. Comparable results on titratable acidity were reported by Bertan *et al*. (2022) in pineapple vinegar, with titratable acidity values of 4.5% in peel and 5.5% in pulp. Roda *et al*. (2017) also recorded acidity values of 5.0% in pineapple peel vinegar, aligning with the present findings.

4.2.2.5. Acetic acid (%)

The data regarding the acetic acid of vinegar prepared from different pineapple waste is presented on Table 4.31. From the data, peel (4.75%) recorded the highest value of acetic acid followed by pomace (4.50%) and core (4.22%) obtained the lowest acetic acid.

The acetic acid value is a crucial parameter influencing the quality and acceptability of vinegar, given its prominence as the most abundant acid in vinegar. In the present study, vinegar prepared from peel recorded the highest percentage of acetic acid among the different pineapple waste. This may be due to peel wine having higher alcohol content of 7.68% (v/v), as compared to 7.24% (v/v) and 6.7% (v/v) in pomace and core wine respectively. These findings align with results from coconut water vinegar (Beegum *et al*., 2018), where higher alcohol content was associated with increased acetic acid content. The gradual increase in acetic acid concentration corresponded with the decrease in alcohol concentration. Yeast cells experience stress from alcohol, resulting in cell death and flocculation (Jimoh *et al*., 2013). This stress is mainly associated with acetaldehyde, the primary intermediate product of ethanol. Acetaldehyde undergoes oxidation to acetic acid facilitated by acetic-acid-producing bacteria. Interestingly, this acetaldehyde also disrupts the enzymatic activity of yeast (Claro *et al*., 2007). These interactions illustrate the complex relationship between alcohol, yeast, and acetic acid production during fermentation. Furthermore, in accordance with FDA (Food and Drug Administration (USA)

Table 4.30: pH, TSS, specific gravity of vinegar prepared from different waste of pineapple

Treatments	pH	TSS (brix^0)	Specific gravity
T_1 (Peel)	2.69	3.25	1.014
T_2(Core)	3.02	3.36	1.012
T_3 (Pomace)	2.81	3.28	1.012
SEm (±)	**0.02**	**0.02**	**0.00**
CD(P=0.05)	**0.07**	**NS**	**NS**

Table 4.31: Titratable acidity and acetic acid of vinegar prepared from different waste of pineapple

Treatments	Titratable acidity (%)	Acetic acid (%)
T_1 (Peel)	5.03	4.75
T_2(Core)	4.50	4.22
T_3 (Pomace)	4.80	4.50
SEm (±)	**0.05**	**0.04**
CD(P=0.05)	**0.16**	**0.14**

standards, vinegar is required to contain at least 4% acetic acid, produced through alcoholic and acetous fermentation of starchy and sugary substances. In present study, vinegar prepared from pineapple waste (peel, core, and pomace) fell within the specified range of 4-4.75%. Similar results on acetic acid content have been reported by Raji *et al*. (2012) with a 4.77% acetic acid value and 4.91-5.01% of total acidity in mango steen vinegar (Suksamran *et al*., 2022).

4.2.2.6. Colour properties

There were significant differences on all the colour properties of vinegar prepared from different pineapple waste, as depicted in Table 4.42. Among the developed vinegar, the highest intensity was recorded in vinegar prepared from peel (4.05) followed by pomace (3.52) and the lowest in core (3.27). In colour density, vinegar prepared from peel exhibited the highest value of 2.99, followed by pomace (2.63) and lowest in core (2.46). While highest tone was obtained in core (1.39) which was at par with pomace (1.38) and the lowest in peel (1.20). The analysis of %Y (percentage of yellow values) indicated the highest yellow percentage in core (43.92%) which was at par with pomace (43.30%), while the lowest %Y was noted in peel (40.32%). Furthermore, %R (percentage of red values) was the highest in peel (33.59%) and the lowest noted in pomace (31.45%) at par with core (31.47%). Regarding %B (percentage of blue values), peel (26.09%) exhibited the highest blue percentage followed by Pomace (25.25%) and the lowest %B was obtained in core (24.57%).

From the present study, developed vinegars exhibited a higher value of colour intensity and density after undergoing acetic fermentation, in contrary to initial value where colour tone value was higher. This variation may be attributed to secondary fermentation involving acetic bacteria. Moreover, factors such as adverse pH changes, temperature fluctuations (especially heat), and processing methods collectively influence the final colour of the product (Vagiri and Jensen, 2017). The colour properties of different types of vinegar can vary depending on the colour of the raw materials, biochemical processes and the production technology used (Kilic *et al.,* 2021). Overall, all the prepared vinegars showed a tendency towards yellow values in the range of 40.31 to 43.92%.

4.2.3. Sensory evaluations

Vinegar prepared from different pineapple waste was evaluated organoleptically for colour and appearance, odour, sourness and overall acceptability on a 9 point hedonic scale by a panel of semi-trained judges. The results of the evaluation are stated below in Table 4.33, the sensory evaluation plays an important role in quality of food.

4.2.3.1. Colour and Appearance

Colour and appearance of prepared vinegar were significantly affected by different pineapple waste. The highest rating for colour and appearance was recorded under the treatment T_1 (peel) with a score of 7.65 followed by 6.32 in T_3 (pomace) and the lowest rating was recorded in treatment T_3 (6.32). The most preferred vinegar in terms of colour and appearance was adjudged in treatment T_1 (peel). Individual preferences play a crucial role but the prevailing inclination among judges towards peel vinegar may have arise from its prominent yellowish hue while both the pomace and core exhibited a light pale yellow colour.

4.2.3.2. Flavour

Flavour was found to be significantly affected in vinegar prepared from the different pineapple waste (Table 4.33). From the data, peel (T_1) scored the highest value of 6.96, followed by pomace (T_3) with 6.62 and the lowest value of 6.50 was obtained in core (T_2).

Table 4.32: Colour properties of vinegar prepared from different pineapple waste

Treatments	Colour intensity	Colour density	Colour tone	%Y	%R	%B
T_1 (Peel)	4.05	2.99	1.20	40.32	33.59	26.09
T_2 (Core)	3.27	2.46	1.39	43.92	31.47	24.57
T_3 Pomace)	3.52	2.63	1.38	43.30	31.45	25.25
SEm (±)	**0.07**	**0.05**	**0.02**	**0.29**	**0.21**	**0.16**
CD(P=0.05)	**0.21**	**0.15**	**0.06**	**0.90**	**0.65**	**0.48**

Table 4.33: Sensory evaluation of vinegar prepared from different pineapple waste

Treatments	Colour/appearance	Flavour	Sourness	Overall acceptability
T_1 (Peel)	7.65	6.96	8.02	8.31
T_2 (Core)	6.17	6.50	7.66	7.50
T_3 (Pomace)	6.32	6.62	7.82	7.76
SEm(±)	**0.025**	**0.028**	**0.034**	**0.044**
CD (P=0.05)	**0.079**	**0.085**	**0.106**	**0.134**

As a food-grade product, quality of vinegar is determined on a range of attributes with aroma being identified as the foremost quality criterion (Chen *et al.*, 2020). Among the prepared vinegars, peel vinegar exhibited a more pronounced aromatic flavour compared to the rest. This may be attributed to the raw material used for preparation of vinegar. In fruit vinegar, aroma is related to the presence of organic acids which are usually present naturally in the raw materials used or which occur during the fermentation process (Chen *et al.*, 2016).

4.2.3.3. Sourness

Sourness of the prepared vinegar was shown to have significant difference among the treatments. The most elevated sourness rating was attributed to peel (8.02) followed by pomace (7.82), while the lowest score was observed in pomace (7.66).

4.2.3.4. Overall acceptability

It is evident that overall acceptability had significant effect on vinegar prepared from different pineapple waste. Vinegar derived from peel waste exhibited the highest level of preference from the judges, attaining an overall acceptability score of 8.31, followed by pomace vinegar (7.76) and the lowest score of 7.50 in core vinegar.

In general, all the prepared vinegar had a good acceptability rating among the judges as a product. However, significant preference towards peel vinegar was observed which is probably due to influence of colour/appearance and flavour of the peel vinegar. As colour and appearance attract the consumers to a product and the quality in texture, aroma and flavour determine impulse purchasing (Barett *et al.*, 2010).

4.3. To study the preparation of candy from pineapple core

4.3.1. Physico-chemical properties of candy

4.3.1.1. Moisture content (%)

As shown in Table 4.34, moisture content was significantly affected by varying concentrations of sugar solution and decreased with the progress of storage period. From the pooled data, prior to storage the minimum value was obtained in 70% sugar (19.79%), while the maximum was found in treatment with no sugar (25.64%). A gradual decrease in moisture content was noted with increase in osmotic concentration. After six months of storage, similar trend was observed with maximum moisture content recorded in 70% sugar (23.21%) whereas the minimum value was recorded in no sugar treatment (17.39 %). It is evident from the data that the minimum moisture content was consistently recorded in 70% sugar and maximum in treatment with no sugar during storage period. Further, the overall mean values of moisture content decreased from 22.24 % to 19.96 % during six months of storage period.

In the present study, moisture content was significantly affected by the effect of different sugar solution. The decrease in moisture content during storage of pineapple core candy may likely be attributed to the evaporation of moisture from product. As storage time increased, the moisture content declined across all treatments, suggesting that prolonged storage enhanced moisture loss. A similar trend of reduction in moisture content was also reported by Gupta and Kaul (2013) during their study on the effect of sugar concentration and time interval on the quality and storability of ber chuhara. Similarly, Mondal *et al.* (2017) also reported a decline in moisture content of aonla candy.

4.3.1.2. Ascorbic acid (mg/100g)

The data pertaining to effect of sugar concentration on ascorbic acid showed significant difference, with ascorbic acid content declining as its storage period progressed (Table 4.35). The highest content of ascorbic acid prior to storage (0 month) was reported in 40% sugar (6.28 mg/100gm) followed by 50% sugar (6.09 mg/100gm) and the lowest in treatment with no sugar (5.47 mg/100gm). After six months, highest value of ascorbic acid was recorded in 40% sugar (5.02 mg/100gm) and the lowest in treatment with no sugar (3.72 mg/100gm). It is evident that ascorbic acid was higher in the initial period, but it gradually declined during the course of storage. The mean values of ascorbic acid decreased significantly from an initial value of 5.93 to 4.64 mg/100g after six months of storage.

The decline in ascorbic acid content may be attributed to thermal degradation during processing and subsequent oxidation during storage period (Brock *et al*., 1998). This may also be attributed to oxidation or the irreversible conversion of L-ascorbic acid into dehydroascorbic acid oxidase (ascorbimase). In addition, small amount of ascorbic acid is also lost due to leaching in hypertonic solution. Similar reports on decreasing trend of ascorbic acid content during storage has been reported by Divya *et al*., (2014) in sapota candy, Mahato *et al*., 2020 in unripe mango candy, Kaikadi *et al*., (2006) in ber candy and Mondal *et al*., (2017) in aonla candy.

Table 4.34: Effect of sugar level on moisture content (%) of pineapple core candy during storage

Treatments	Ist trial						
	Storage period (months)						
	0	1	2	3	4	5	6
T_1 (40% sugar)	22.91	22.59	22.20	21.82	21.38	21.02	20.75
T_2 (50% sugar)	21.84	21.57	21.22	20.79	20.37	20.05	19.84
T_3 (60% sugar)	20.37	20.12	19.73	19.35	18.98	18.56	18.14
T_4 (70% sugar)	19.54	19.28	18.93	18.49	18.09	17.65	17.21
T_5 (No sugar)	25.70	25.56	25.27	24.94	24.57	23.98	23.52
Mean	**22.07**	**21.82**	**21.47**	**21.08**	**20.68**	**20.25**	**19.89**
Sem±	**0.108**	**0.094**	**0.126**	**0.117**	**0.138**	**0.134**	**0.168**
CD(P= 0.05)	**0.340**	**0.296**	**0.396**	**0.370**	**0.434**	**0.423**	**0.528**
IInd trial							
Treatments	Storage period (months)						
	0	1	2	3	4	5	6
T_1 (40% sugar)	23.24	22.75	22.40	22.14	21.74	21.30	21.06
T_2 (50% sugar)	22.03	21.78	21.47	21.11	20.65	20.21	19.93
T_3 (60% sugar)	21.11	20.79	20.26	19.99	19.33	18.95	18.65
T_4 (70% sugar)	20.03	19.69	19.21	18.81	18.18	17.80	17.57
T_5 (No sugar)	25.58	25.21	24.76	23.82	23.71	23.41	22.89
Mean	22.40	22.04	21.62	21.17	20.72	20.33	20.02
SEm ±	**0.130**	**0.139**	**0.153**	**0.198**	**0.181**	**0.172**	**0.135**
CD (P= 0.05)	**0.408**	**0.439**	**0.482**	**0.623**	**0.570**	**0.541**	**0.427**
Pooled							
Treatments	Storage period (months)						
	0	1	2	3	4	5	6
T_1 (40% sugar)	23.08	22.67	22.30	21.98	21.56	21.16	20.91
T_2 (50% sugar)	21.94	21.67	21.34	20.95	20.51	20.13	19.89
T_3 (60% sugar)	20.74	20.46	19.99	19.67	19.15	18.76	18.40
T_4 (70% sugar)	19.79	19.49	19.07	18.65	18.14	17.73	17.39
T_5 (No sugar)	25.64	25.38	25.02	24.58	24.14	23.70	23.21
Mean	**22.24**	**21.93**	**21.54**	**21.17**	**20.70**	**20.30**	**19.96**
SEm ±	**0.050**	**0.058**	**0.076**	**0.112**	**0.134**	**0.116**	**0.110**
CD (P= 0.05)	**0.159**	**0.182**	**0.240**	**0.351**	**0.422**	**0.365**	**0.346**

Table 4.35: Effect of sugar level on ascorbic acid content (mg/100 gm) of pineapple core candy during storage

Treatments	Ist trial						
	Storage period (months)						
	0	1	2	3	4	5	6
T_1 (40% sugar)	6.22	5.98	5.84	5.50	5.38	5.17	4.99
T_2 (50% sugar)	6.02	5.80	5.60	5.35	5.15	4.95	4.86
T_3 (60% sugar)	5.88	5.63	5.51	5.29	5.11	4.89	4.76
T_4 (70% sugar)	5.80	5.66	5.49	5.21	5.07	4.82	4.71
T_5 (No sugar)	5.51	5.27	5.05	4.87	4.36	4.00	3.82
Mean	**5.89**	**5.67**	**5.50**	**5.24**	**5.01**	**4.77**	**4.63**
Sem±	**0.049**	**0.043**	**0.032**	**0.025**	**0.030**	**0.038**	**0.042**
CD(P= 0.05)	**0.153**	**0.135**	**0.102**	**0.079**	**0.094**	**0.121**	**0.132**
IInd trial							
Treatments	Storage period (months)						
	0	1	2	3	4	5	6
T_1 (40% sugar)	6.34	6.21	5.91	5.63	5.44	5.22	5.02
T_2 (50% sugar)	6.16	6.06	5.73	5.52	5.35	5.13	4.94
T_3 (60% sugar)	6.03	5.85	5.59	5.33	5.17	4.95	4.88
T_4 (70% sugar)	5.92	5.77	5.51	5.29	5.13	4.89	4.79
T_5 (No sugar)	5.43	5.18	4.88	4.57	4.21	3.86	3.62
Mean	**5.98**	**5.81**	**5.52**	**5.29**	**5.06**	**4.81**	**4.65**
SEm ±	**0.068**	**0.062**	**0.052**	**0.044**	**0.048**	**0.044**	**0.037**
CD (P= 0.05)	**0.214**	**0.196**	**0.163**	**0.140**	**0.150**	**0.138**	**0.116**
Pooled							
Treatments	Storage period (months)						
	0	1	2	3	4	5	6
T_1 (40% sugar)	6.28	6.10	5.88	5.57	5.41	5.19	5.01
T_2 (50% sugar)	6.09	5.93	5.67	5.44	5.25	5.04	4.90
T_3 (60% sugar)	5.96	5.74	5.55	5.31	5.14	4.92	4.82
T_4 (70% sugar)	5.86	5.72	5.50	5.25	5.10	4.85	4.75
T_5 (No sugar)	5.47	5.23	4.96	4.72	4.29	3.93	3.72
Mean	**5.93**	**5.74**	**5.51**	**5.26**	**5.04**	**4.79**	**4.64**
SEm ±	**0.044**	**0.031**	**0.021**	**0.029**	**0.024**	**0.030**	**0.031**
CD (P= 0.05)	**0.138**	**0.097**	**0.065**	**0.091**	**0.075**	**0.096**	**0.096**

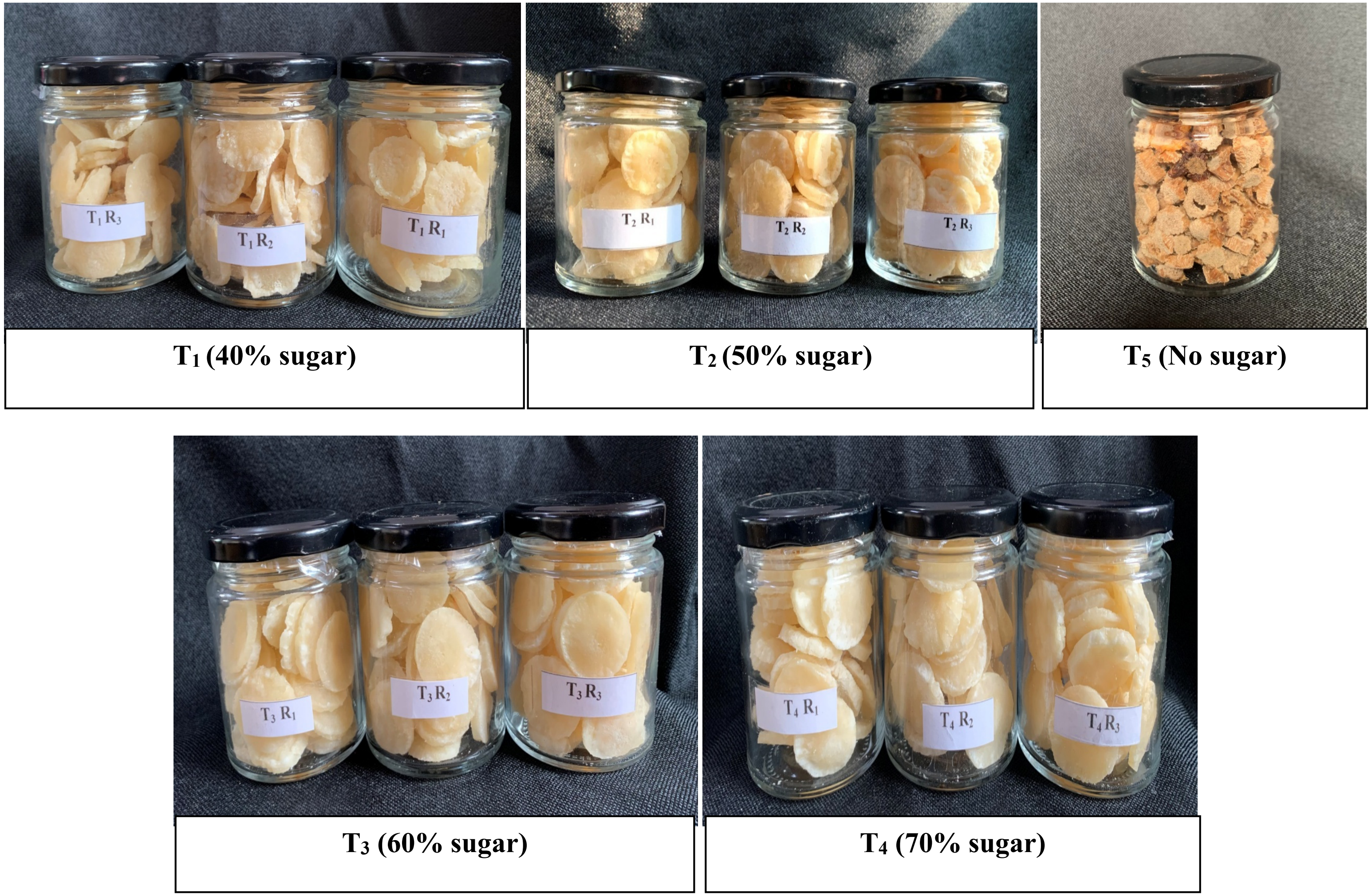


Plate 13: Pineapple core candy after one month of storage

4.3.1.3. Total sugar (%)

The results regarding the effect of sugar level on total sugar of pineapple core candy during storage is given in Table 4.36. Among the treatments, the total sugar content varied significantly in both the years as well as in pooled data. At initial period (0 day), the total sugar content in pineapple core candy was highest in 70% sugar (63.88 %) followed by 60% sugar (54.83) and treatment with no sugar (6.84%) had the lowest. The variations in total sugar content may be due to different concentration of sugar used among the treatments. The result further indicated a significant increase in total sugar content of candies from different treatments during its storage interval of six months. After six months of storage, a similar trend was noticed with maximum value recorded in 70% sugar (67.86%) followed by 60% sugar (58.61 %) and lowest in no sugar (8.44 %). This can be attributed to the high concentration of sugar solution used in treatment T_4 (70% sugar) and the absence of sugar solution in T_5 (No sugar). The mean value of total sugar increased significantly, rising from 41.42% initially to 44.73% after six months of storage.

The data indicated that irrespective of the treatments (sugar level), total sugar content showed an upward trend as storage period advanced which may be attributed to the decrease in moisture content of candy during storage. This increase could be due to hydrolysis of polysaccharides, resulting in conversion to soluble sugars (Singh *et al*., 2014). These results are in conformity with the findings reported by Verma *et al*. (2023) in osmo-dried karonda, where total sugar content increased significantly from 38.84% to 41.54% over 90 days of storage; Dwivedi and Pandey (2017) also observed a gradual increase in total sugar content from 68.62% to 73.36% in aonla candy over 120 days of storage; and Bansode *et al*., (2021) also reported an increase in total sugar in ginger candy.

Table 4.36: Effect of sugar level on total sugar (%) of pineapple core candy during storage

Treatments	Ist trial						
	Storage period (months)						
	0	1	2	3	4	5	6
T_1 (40% sugar)	36.78	37.30	37.96	38.53	39.21	39.86	40.19
T_2 (50% sugar)	45.83	46.52	47.14	47.94	48.34	48.94	49.34
T_3 (60% sugar)	54.55	55.32	56.18	56.83	57.10	57.65	58.34
T_4 (70% sugar)	63.15	64.03	64.88	65.64	65.94	66.56	67.30
T_5 (No sugar)	6.94	7.24	7.58	7.97	8.34	8.55	8.63
Mean	41.5	42.1	42.7	43.4	43.8	44.3	44.8
Sem±	**0.24**	**0.25**	**0.24**	**0.13**	**0.12**	**0.20**	**0.21**
CD(P= 0.05)	**0.73**	**0.80**	**0.74**	**0.43**	**0.39**	**0.63**	**0.66**
IInd trial							
Treatments	Storage period (months)						
	0	1	2	3	4	5	6
T_1 (40% sugar)	35.77	36.34	37.00	37.71	38.35	38.89	39.49
T_2 (50% sugar)	44.72	45.37	45.97	46.54	47.29	47.97	48.49
T_3 (60% sugar)	55.10	55.76	56.46	57.16	57.77	58.50	58.88
T_4 (70% sugar)	64.60	65.35	65.96	66.64	67.34	67.92	68.42
T_5 (No sugar)	6.74	7.02	7.35	7.51	7.81	8.08	8.25
Mean	41.39	41.97	42.55	43.11	43.71	44.27	44.71
Sem±	**0.18**	**0.17**	**0.13**	**0.15**	**0.17**	**0.18**	**0.15**
CD(P= 0.05)	**0.57**	**0.54**	**0.41**	**0.48**	**0.53**	**0.56**	**0.48**
Pooled							
Treatments	Storage period (months)						
	0	1	2	3	4	5	6
T_1 (40% sugar)	36.27	36.56	37.48	38.12	38.78	39.37	39.84
T_2 (50% sugar)	45.28	45.60	46.55	47.24	47.81	48.46	48.91
T_3 (60% sugar)	54.83	55.15	56.32	56.99	57.44	58.08	58.61
T_4 (70% sugar)	63.88	64.25	65.42	66.14	66.64	67.24	67.86
T_5 (No sugar)	6.84	6.98	7.46	7.74	8.08	8.32	8.44
Mean	41.42	41.71	42.65	43.25	43.75	44.29	44.73
Sem±	**0.17**	**0.17**	**0.14**	**0.11**	**0.10**	**0.13**	**0.12**
CD(P= 0.05)	**0.53**	**0.54**	**0.44**	**0.33**	**0.32**	**0.40**	**0.39**

4.3.1.4. Reducing sugar (%)

The data indicated that sugar level had a statistically significant difference on reducing sugar of pineapple core candy throughout the storage period (Table 4.37). From the pooled data, initially the highest value of reducing sugar was recorded in treatment with 70% sugar (26.5%), followed by 60% sugar (23.17%) and the lowest in treatment with no sugar (4.95%). Similarly, after six months of storage T_4 (70% sugar) recorded the maximum reducing sugar content of 29.35%, while T_5 (no sugar) exhibited a minimum value of 6.13%. Based on the findings, an upward trend of reducing sugar was observed across treatments throughout the storage period. The mean value of reducing sugar significantly increased from 18% to 20.76% after six months of storage.

During storage, the increase in reducing sugars may be due to degradation of polysaccharides through hydrolysis and the inversion of non-reducing into reducing sugars (Kour *et al*., 2020). Similar trend on increment of reducing sugar with advancement of storage from 41.01 % to 43.77% was reported in osmo-dried plums during three months of storage (Kour *et al*., 2021). Further, increase in reducing sugar content was also reported by Verma *et al*. (2023) in osmo-dried karonda and Divya *et al*. (2014) in sapota candy.

4.3.1.4. Titratable acidity (%)

The data regarding the effect of sugar level on titratable acidity content of pineapple core candy during storage is depicted in Table 4.38. The result indicated statistically significant differences among the treatments in both years and in pooled data. A decreasing trend in titratable acidity of pineapple core candies was observed across the treatments during storage interval. At initial period (before storage), the highest acidity value of 0.70% was recorded in T_5 (no sugar) followed by T_1 (40% sugar) with 0.50% and the lowest in T_4 (70%

Table 4.37: Effect of sugar level on reducing sugar (%) of pineapple core candy during storage

Treatments	I^st trial						
	Storage period (months)						
	0	1	2	3	4	5	6
T_1 (40% sugar)	16.10	16.60	17.10	17.86	18.12	18.47	18.88
T_2 (50% sugar)	19.62	20.11	20.66	21.39	21.74	22.22	22.67
T_3 (60% sugar)	23.36	23.88	24.42	25.18	25.73	26.33	26.68
T_4 (70% sugar)	25.85	26.37	26.69	27.52	28.19	28.65	29.22
T_5 (No sugar)	5.04	5.28	5.42	5.61	5.86	6.08	6.26
Mean	**17.99**	**18.45**	**18.86**	**19.51**	**19.93**	**20.35**	**20.74**
Sem±	**0.11**	**0.16**	**0.16**	**0.18**	**0.18**	**0.16**	**0.17**
CD(P= 0.05)	**0.35**	**0.52**	**0.50**	**0.55**	**0.57**	**0.49**	**0.54**
II^nd trial							
Treatments	Storage period (months)						
	0	1	2	3	4	5	6
T_1 (40% sugar)	16.44	16.92	17.56	18.26	18.72	19.05	19.35
T_2 (50% sugar)	19.48	20.10	20.50	21.27	21.74	22.11	22.53
T_3 (60% sugar)	22.98	23.38	24.23	24.99	25.61	26.07	26.35
T_4 (70% sugar)	26.19	26.67	27.07	27.66	28.43	28.89	29.49
T_5 (No sugar)	4.86	5.17	5.32	5.54	5.64	5.82	6.01
Mean	**17.99**	**18.45**	**18.94**	**19.54**	**20.03**	**20.39**	**20.75**
Sem±	**0.10**	**0.11**	**0.18**	**0.21**	**0.23**	**0.22**	**0.19**
CD(P= 0.05)	**0.32**	**0.36**	**0.55**	**0.65**	**0.73**	**0.70**	**0.59**
Pooled							
Treatments	Storage period (months)						
	0	1	2	3	4	5	6
T_1 (40% sugar)	16.27	16.76	17.33	18.06	18.42	18.76	19.11
T_2 (50% sugar)	19.61	20.10	20.58	21.33	21.74	22.17	22.71
T_3 (60% sugar)	23.17	23.63	24.33	25.08	25.67	26.20	26.52
T_4 (70% sugar)	26.02	26.52	26.88	27.59	28.31	28.77	29.35
T_5 (No sugar)	4.95	5.22	5.37	5.58	5.75	5.95	6.13
Mean	**18.00**	**18.45**	**18.90**	**19.53**	**19.98**	**20.37**	**20.76**
Sem±	**0.08**	**0.10**	**0.12**	**0.14**	**0.16**	**0.14**	**0.12**
CD(P= 0.05)	**0.25**	**0.32**	**0.37**	**0.45**	**0.51**	**0.44**	**0.38**

Table 4.38: Effect of sugar level on titratable acidity (%) of pineapple core candy during storage

Treatments	Ist trial						
	Storage period (months)						
	0	1	2	3	4	5	6
T_1 (40% sugar)	0.47	0.46	0.44	0.43	0.41	0.38	0.36
T_2 (50% sugar)	0.38	0.37	0.36	0.33	0.31	0.29	0.28
T_3 (60% sugar)	0.34	0.33	0.31	0.30	0.28	0.26	0.25
T_4 (70% sugar)	0.28	0.26	0.24	0.23	0.22	0.21	0.20
T_5 (No sugar)	0.68	0.67	0.65	0.63	0.61	0.60	0.57
Mean	**0.43**	**0.42**	**0.40**	**0.38**	**0.37**	**0.35**	**0.33**
Sem±	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**
CD	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**
IInd trial							
Treatments	Storage period (months)						
	0	1	2	3	4	5	6
T_1 (40% sugar)	0.52	0.50	0.48	0.46	0.44	0.42	0.40
T_2 (50% sugar)	0.44	0.42	0.40	0.39	0.37	0.35	0.33
T_3 (60% sugar)	0.36	0.35	0.34	0.32	0.31	0.29	0.28
T_4 (70% sugar)	0.30	0.29	0.27	0.26	0.26	0.25	0.24
T_5 (No sugar)	0.73	0.71	0.69	0.66	0.63	0.61	0.58
Mean	0.47	0.454	0.436	0.418	0.402	0.384	0.366
SEm ±	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**
CD (P= 0.05)	**0.03**	**0.03**	**0.03**	**0.02**	**0.02**	**0.02**	**0.02**
Pooled							
Treatments	Storage period (months)						
	0	1	2	3	4	5	6
T_1 (40% sugar)	0.50	0.48	0.46	0.44	0.43	0.40	0.38
T_2 (50% sugar)	0.41	0.40	0.38	0.36	0.34	0.32	0.30
T_3 (60% sugar)	0.35	0.34	0.32	0.31	0.30	0.28	0.26
T_4 (70% sugar)	0.29	0.27	0.26	0.25	0.24	0.23	0.22
T_5 (No sugar)	0.70	0.69	0.67	0.64	0.62	0.60	0.58
Mean	**0.45**	**0.44**	**0.42**	**0.40**	**0.39**	**0.37**	**0.35**
SEm ±	**0.01**	**0.01**	**0.01**	**0.005**	**0.003**	**0.01**	**0.01**
CD (P= 0.05)	**0.02**	**0.02**	**0.02**	**0.02**	**0.01**	**0.02**	**0.01**

sugar) with 0.29%. After six months of storage, the highest acidity was recorded in treatment with no sugar (0.58%) followed by 40% sugar (0.38%) and the lowest in 70% sugar (0.22%). The data further indicated that regardless of the treatments, titratable acidity declined over time during storage. The mean titratable acidity in pineapple core candy decreased from 0.45% to 0.35% during storage.

Among the treatments, the lowest acidity was found in candy treated with the highest concentration of sugar *i.e.* 70% sugar (T_4) and the highest was obtained in treatment with no sugar (T_5). The sugar level in the candies determined the extent of reduction in acidity. This results from fruit acid leaching into the hypertonic solution (Kumar and Sagar, 2009). This osmotic process makes water moves out of the fruit into the solution and leach out the natural solutes. When galgal sticks were steeped in higher concentration of sugar solution, a decreasing trend in acid content was observed (Gupta *et al*., 2023). The degradation of organic acids occurs during storage, possibly attributed to the transformation of acids into sugar and salt by invertase enzymes (Jain *et al*., 1986). The acidity of candy decreased significantly in all treatments during 3 months of storage from 3.80 % to 3.51 % in osmo-dried karonda (Verma *et al*., 2023). Similar reports of decrease in titratable acidity were reported in carrot candy (Rajeshbhai *et al*., 2018) and in apricot fruit bar (Sharma *et al*., 2013). The present results are in agreement with the previous research findings.

T_1 (40% sugar)

T_2 (50% sugar)

T_5 (No sugar)

T_3 (60% sugar)

T_4 (70% sugar)

Plate 14: Pineapple core candy after two months of storage

4.3.2. Sensory evaluations

4.3.2.1. Colour and appearance

The colour and appearance score of pineapple core candy showed a significant effect on different concentration of sugar (Table 4.39). From pooled data, the highest score in freshly prepared candies for colour was noted in candy prepared with 70% sugar (8.72) followed by 60% sugar (8.49) and 50% sugar (7.46) while minimum score was noted in treatment with no sugar (4.45). Similar observations were recorded even after six months of storage with highest score recorded in 70 % sugar (7.85) and the lowest in no sugar (2.52). Treatments with lower sugar concentrations had lower scores compared to those with higher sugar concentrations. Candy treated with 70% sugar (T_4) consistently received higher preference for colour and appearance throughout the storage period.

The results regarding colour and appearance were greatly influenced by storage period, the mean score was found to decrease significantly during storage from 7.72 to 6.02. The decline in appeal could be attributed to browning reactions occurring in the candies, likely due to the non-enzymatic oxidation of ascorbic acid and enzymatic oxidation of polyphenols. Similar results have been reported by Kour *et al*. (2021) with a decrease in mean score of 7.37 to 6.77 after three months storage in osmo dried plums. Also, Mahato *et al.* (2020) and Shamrez *et al*. (2013) reported a decrease in colour and appearance score with the increase in storage period of six months in unripe mango candy and citron peel candy respectively.

Table 4.39: Effect of sugar level on colour/appearance of pineapple core candy during storage

Treatments	Ist trial						
	Storage period (months)						
	0	1	2	3	4	5	6
T_1 (40% sugar)	7.18	7.02	6.87	6.73	6.39	5.97	5.77
T_2 (50% sugar)	7.33	7.11	7.01	6.87	6.66	6.20	6.01
T_3 (60% sugar)	8.56	8.50	8.38	8.22	8.14	7.79	7.66
T_4 (70% sugar)	8.79	8.73	8.58	8.43	8.25	7.94	7.89
T_5 (No sugar)	4.23	4.08	3.88	3.59	3.24	2.82	2.46
Mean	7.22	7.09	6.94	6.77	6.54	6.14	5.96
Sem±	**0.04**	**0.04**	**0.05**	**0.04**	**0.05**	**0.04**	**0.05**
CD	**0.13**	**0.12**	**0.14**	**0.13**	**0.15**	**0.14**	**0.15**
IInd trial							
Treatments	Storage period (months)						
	0	1	2	3	4	5	6
T_1 (40% sugar)	7.32	7.16	7.03	6.91	6.59	6.32	6.17
T_2 (50% sugar)	7.58	7.41	7.24	7.12	6.83	6.50	6.27
T_3 (60% sugar)	8.42	8.27	8.13	8.02	7.91	7.77	7.58
T_4 (70% sugar)	8.65	8.52	8.39	8.21	8.11	8.02	7.82
T_5 (No sugar)	4.66	4.42	4.31	4.13	3.70	2.83	2.58
Mean	7.33	7.16	7.02	6.88	6.63	6.29	6.08
SEm ±	**0.03**	**0.04**	**0.04**	**0.04**	**0.04**	**0.04**	**0.04**
CD (P= 0.05)	**0.10**	**0.11**	**0.12**	**0.12**	**0.12**	**0.12**	**0.12**
Pooled							
Treatments	Storage period (months)						
	0	1	2	3	4	5	6
T_1 (40% sugar)	7.25	7.11	6.95	6.82	6.490	6.15	5.97
T_2 (50% sugar)	7.46	7.32	7.12	6.99	6.745	6.36	6.14
T_3 (60% sugar)	8.49	8.38	8.26	8.12	8.022	7.78	7.62
T_4 (70% sugar)	8.72	8.63	8.39	8.32	8.182	7.98	7.85
T_5 (No sugar)	4.45	4.25	4.10	3.86	3.472	2.83	2.52
Mean	7.27	7.14	6.96	6.82	6.58	6.22	6.02
SEm ±	**0.03**	**0.03**	**0.04**	**0.03**	**0.03**	**0.03**	**0.03**
CD (P= 0.05)	**0.10**	**0.09**	**0.18**	**0.08**	**0.09**	**0.10**	**0.10**

4.3.2.2. Flavour

Data obtained on flavour during the period of observation is shown in Table 4.40. The results indicated that sugar level had significant impact on flavour score throughout storage period. At initial period (0 day), the highest score was recorded in 70% sugar (8.72) followed by 60% sugar (8.49), 50% sugar (7.46) and the lowest in treatment with no sugat (4.45). Similarly, at the end of storage (six months), maximum flavour score was recorded in 70% sugar (7.85) whereas the minimum score was noted in no sugar treatment (2.52). It is evident that treatment with 70% sugar solution had the best flavour score among all the treatments throughout the period of storage. However, with progress in storage period a decline in flavour score was observed irrespective of the treatments. The mean score of pineapple core candy for flavour decreased significantly from 7.21 to 6.25 during storage.

The gradual decrease in flavour could be due to enzymatic, biochemical and physiological changes which may have attributed to the production of off-flavour in candy. The flavour score was reported to decrease with the progress of storage period in citron peel candy (Shamrez *et al.*, 2013) and in aonla candy (Dwivedi and Pandey, 2017).

4.3.2.3. Taste

The effect of sugar level on the taste of pineapple core candy during storage has been illustrated in Table 4.41. The data indicated that sugar level showed significant influence on taste and a decreasing score in score was recorded with advancement of storage period in pineapple core candy. Initially, candy with 70% sugar recorded the highest taste score (8.17) from the panelists, followed by 60% sugar candy (7.9) and the lowest was noted in treatment with no sugar (4.17). At six months of storage, the highest rating was obtained in 70% sugar candy (7.59), followed by the 60% sugar candy (7.36) and treatment with no sugar (2.08) recorded the lowest score.

T_1 (40% sugar)	T_2 (50% sugar)	T_5 (No sugar)

T_3 (60% sugar)	T_4 (70% sugar)

Plate 15: Pineapple core candy after four months of storage

Table 4.40: Effect of sugar level on flavour of pineapple core candy during storage

Treatments	Ist trial						
	Storage period (months)						
	0	1	2	3	4	5	6
T_1 (40% sugar)	7.34	7.23	7.07	6.93	6.70	6.56	6.46
T_2 (50% sugar)	7.47	7.38	7.24	7.11	6.89	6.72	6.65
T_3 (60% sugar)	7.66	7.62	7.53	7.42	7.32	7.24	7.16
T_4 (70% sugar)	7.77	7.73	7.64	7.55	7.49	7.33	7.23
T_5 (No sugar)	5.72	5.42	4.91	4.69	4.34	3.83	3.46
Mean	7.19	7.08	6.88	6.74	6.55	6.34	6.19
SEm ±	**0.01**	**0.01**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**
CD (P= 0.05)	**0.03**	**0.04**	**0.05**	**0.06**	**0.07**	**0.07**	**0.07**
	IInd trial						
Treatments	Storage period (months)						
	0	1	2	3	4	5	6
T_1 (40% sugar)	7.43	7.34	7.20	7.07	6.90	6.78	6.70
T_2 (50% sugar)	7.58	7.49	7.42	7.28	7.16	7.02	6.91
T_3 (60% sugar)	7.76	7.73	7.66	7.58	7.48	7.36	7.27
T_4 (70% sugar)	7.86	7.81	7.73	7.63	7.54	7.42	7.33
T_5 (No sugar)	5.55	5.28	4.74	4.47	4.20	3.75	3.29
Mean	7.24	7.13	6.95	6.81	6.66	6.47	6.30
SEm ±	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**
CD (P= 0.05)	**0.05**	**0.05**	**0.05**	**0.05**	**0.07**	**0.07**	**0.06**
	Pooled						
Treatments	Storage period (months)						
	0	1	2	3	4	5	6
T_1 (40% sugar)	7.39	7.29	7.14	7.00	6.80	6.67	6.58
T_2 (50% sugar)	7.52	7.44	7.33	7.19	7.03	6.87	6.78
T_3 (60% sugar)	7.71	7.67	7.60	7.50	7.40	7.30	7.22
T_4 (70% sugar)	7.82	7.77	7.68	7.59	7.50	7.37	7.28
T_5 (No sugar)	5.63	5.35	4.82	4.58	4.27	3.79	3.37
Mean	7.21	7.10	6.91	6.77	6.60	6.40	6.25
SEm ±	**0.01**	**0.01**	**0.01**	**0.01**	**0.02**	**0.02**	**0.02**
CD (P= 0.05)	**0.04**	**0.04**	**0.04**	**0.04**	**0.05**	**0.06**	**0.06**

It is apparent from the data that treatment with 70 % sugar solution (T_4) was the most preferred in relation to taste by the panelists and this may be due to higher sugar concentration. Further, the data indicated that taste score gradually decline towards the end of storage irrespective of its treatments. The highest mean score of 7.13 on flavour was observed at initial stage which decreased to 6.01 after six months of storage. Similar results on decline of flavour score with progress of storage period were reported by Nayak *et al.* (2012) in aonla candy and Jothi *et al.* (2014) in pineapple candy.

4.3.2.4. Texture

A review of data in Table 4.42 depicted that sugar concentration exhibited significant difference on texture rating of pineapple core candy in both the years. From pooled data, treatment with 70% sugar (T_4) solution scored the highest (8.26), while lowest score of 5.17 was obtained in treatment with no sugat (T_5). After six months of storage, T_4 (70% sugar) obtained maximum score of 7.54 followed by 60% sugar (7.40) and the lowest was recorded in no sugar treatment (1.80). From initial to final storage period, the candy treated with 70% sugar (T_4) received the highest rating in terms of texture followed by 60% sugar (T_3) up till the end of storage, whereas treatment with no sugar (T_5) scored the lowest.

The texture score of the pineapple core candy decreased continuously throughout the storage period, from a mean value of 7.31 to 5.98. This significant decline in texture score over six months may be attributed to moisture loss during storage. These findings align with Kour *et al.* (2021), who observed a decrease in the mean texture score from 7.24 to 6.93 during storage.

Table 4.41: Effect of sugar level on taste of pineapple core candy during storage

Treatments	Ist trial						
	Storage period (months)						
	0	1	2	3	4	5	6
T_1 (40% sugar)	7.22	7.12	6.86	6.70	6.48	6.32	6.18
T_2 (50% sugar)	7.68	7.60	7.43	7.28	7.09	6.99	6.86
T_3 (60% sugar)	7.94	7.87	7.81	7.75	7.64	7.54	7.42
T_4 (70% sugar)	8.13	8.08	7.97	7.88	7.73	7.65	7.54
T_5 (No sugar)	5.53	4.67	4.24	3.61	3.11	2.64	2.30
Mean	**7.30**	**7.07**	**6.86**	**6.64**	**6.41**	**6.23**	**6.06**
SEm ±	**0.04**	**0.03**	**0.03**	**0.02**	**0.02**	**0.03**	**0.03**
CD (P= 0.05)	**0.14**	**0.10**	**0.09**	**0.07**	**0.07**	**0.09**	**0.11**
IInd trial							
Treatments	Storage period (months)						
	0	1	2	3	4	5	6
T_1 (40% sugar)	7.32	7.27	7.13	6.94	6.79	6.51	6.35
T_2 (50% sugar)	7.50	7.44	7.36	7.18	6.98	6.87	6.65
T_3 (60% sugar)	7.86	7.78	7.71	7.65	7.55	7.41	7.29
T_4 (70% sugar)	8.20	8.16	8.09	8.00	7.90	7.78	7.64
T_5 (No sugar)	4.58	4.36	3.69	3.40	2.71	2.12	1.91
Mean	**7.09**	**7.00**	**6.80**	**6.63**	**6.39**	**6.14**	**5.97**
SEm ±	**0.03**	**0.02**	**0.03**	**0.03**	**0.03**	**0.03**	**0.02**
CD (P= 0.05)	**0.08**	**0.05**	**0.09**	**0.10**	**0.08**	**0.10**	**0.07**
Pooled							
Treatments	Storage period (months)						
	0	1	2	3	4	5	6
T_1 (40% sugar)	7.27	7.20	7.00	6.82	6.64	6.41	6.26
T_2 (50% sugar)	7.59	7.52	7.39	7.23	7.04	6.93	6.77
T_3 (60% sugar)	7.90	7.83	7.76	7.70	7.59	7.48	7.36
T_4 (70% sugar)	8.17	8.12	8.03	7.94	7.82	7.72	7.59
T_5 (No sugar)	4.70	4.52	3.97	3.51	3.26	3.01	2.08
Mean	**7.13**	**7.04**	**6.83**	**6.64**	**6.47**	**6.31**	**6.01**
SEm ±	**0.07**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.01**
CD (P= 0.05)	**0.05**	**0.05**	**0.07**	**0.05**	**0.06**	**0.07**	**0.04**

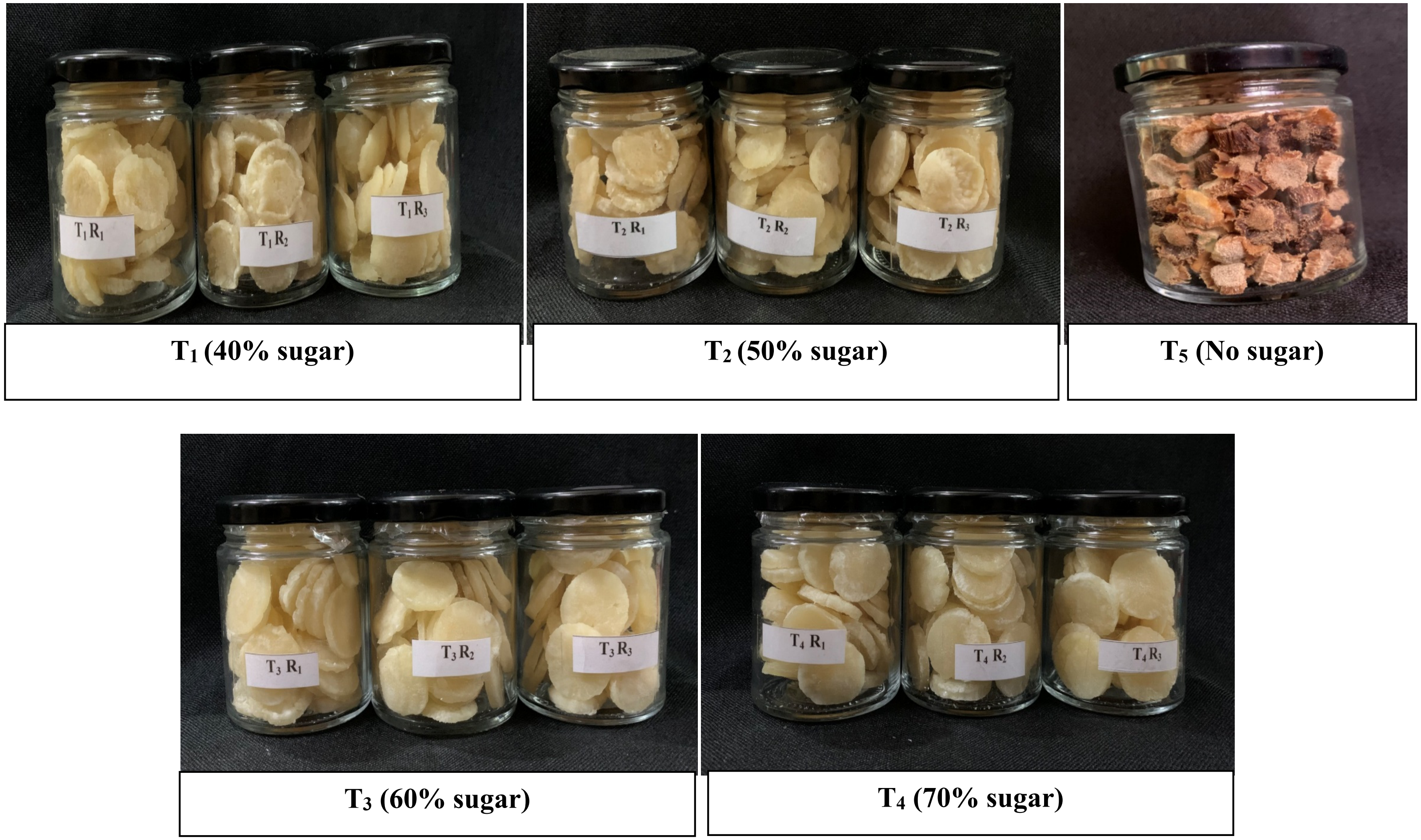


Plate 16: Pineapple core candy after six months of storage

Similarly, Shrivastava *et al*. (2023) reported a decreasing trend in texture scores during the storage of osmotically dried papaya candy.

4.3.2.5. Overall acceptability

The results regarding sensory scores on overall acceptability of pineapple core candy with varying sugar concentration are presented in Table 4.43. Initially, T_4 (70% sugar) received the highest score of 8.50, followed by T_4 (60% sugar) with 8.30 and the lowest was recorded in T_5 (no sugar) with 5.05. At six months of storage, similar trend persisted with T_4 (70% sugar) with the highest rating of 7.70, while T_5 (no sugar) scored the lowest with 1.98. Among all the treatments, T_4 (70% sugar) was the most preferred followed by T_3 (60% sugar), with the least acceptability recorded in T_5 (no sugar). Overall acceptability of pineapple core candy declined with storage duration, with mean score decreasing from 7.29 initially to 5.85 at the end of the storage period.

In the present study, candy treated with 70% sugar solution (T_4) effectively maintained better colour, flavour, taste and texture of the product, contributing to its highest overall acceptability rating. This finding is consistent with Mondal *et al.* (2017), who observed a decrease in overall acceptability scores for aonla candy with varying sugar syrup concentrations over four months of storage. Similar trends have been reported for papaya candy (Srivastava *et al.*, 2023), citron peel candy (Shamrez *et al.,* 2013), and honey-based carrot candy (Durrani *et al.,* 2011).

Table 4.42: Effect of sugar level on texture of pineapple core candy during storage

Treatments	Ist trial						
	Storage period (months)						
	0	1	2	3	4	5	6
T_1 (40% sugar)	7.23	7.10	6.97	6.84	6.68	6.43	6.24
T_2 (50% sugar)	7.61	7.55	7.43	7.32	7.18	6.91	6.67
T_3 (60% sugar)	8.02	7.95	7.90	7.79	7.67	7.48	7.30
T_4 (70% sugar)	8.18	8.11	8.05	8.00	7.88	7.68	7.51
T_5 (No sugar)	5.12	4.77	4.41	3.98	3.32	2.59	1.70
Mean	**7.23**	**7.10**	**6.95**	**6.79**	**6.55**	**6.22**	**5.88**
SEm ±	**0.02**	**0.04**	**0.03**	**0.03**	**0.05**	**0.03**	**0.04**
CD (P= 0.05)	**0.06**	**0.11**	**0.09**	**0.08**	**0.15**	**0.10**	**0.13**
IInd trial							
Treatments	Storage period (months)						
	0	1	2	3	4	5	6
T_1 (40% sugar)	7.46	7.40	7.26	7.06	6.91	6.78	6.51
T_2 (50% sugar)	7.73	7.64	7.51	7.42	7.30	7.07	6.94
T_3 (60% sugar)	8.24	8.17	8.09	8.01	7.84	7.68	7.51
T_4 (70% sugar)	8.35	8.29	8.19	8.10	7.96	7.84	7.57
T_5 (No sugar)	5.22	4.91	4.53	4.11	3.24	2.85	1.89
Mean	**7.40**	**7.28**	**7.12**	**6.94**	**6.65**	**6.44**	**6.08**
SEm ±	**0.02**	**0.03**	**0.02**	**0.06**	**0.03**	**0.04**	**0.05**
CD (P= 0.05)	**0.06**	**0.09**	**0.07**	**0.19**	**0.08**	**0.12**	**0.17**
Pooled							
Treatments	Storage period (months)						
	0	1	2	3	4	5	6
T_1 (40% sugar)	7.34	7.25	7.11	6.95	6.79	6.61	6.37
T_2 (50% sugar)	7.67	7.60	7.47	7.37	7.24	6.99	6.80
T_3 (60% sugar)	8.13	8.06	7.99	7.90	7.76	7.58	7.40
T_4 (70% sugar)	8.26	8.20	8.12	8.05	7.92	7.78	7.54
T_5 (No sugar)	5.17	4.84	4.47	4.16	3.28	2.72	1.80
Mean	**7.31**	**7.19**	**7.03**	**6.89**	**6.60**	**6.34**	**5.98**
SEm ±	**0.01**	**0.03**	**0.02**	**0.03**	**0.02**	**0.02**	**0.02**
CD (P= 0.05)	**0.04**	**0.08**	**0.07**	**0.09**	**0.07**	**0.05**	**0.07**

Table 4.43: Effect of sugar level on overall acceptability pineapple core candy during storage

Treatments	Ist trial						
	Storage period (months)						
	0	1	2	3	4	5	6
T_1 (40% sugar)	7.26	7.16	7.05	6.93	6.74	6.37	5.90
T_2 (50% sugar)	7.53	7.42	7.22	7.08	6.93	6.63	6.39
T_3 (60% sugar)	8.35	8.28	8.22	8.12	8.03	7.91	7.49
T_4 (70% sugar)	8.52	8.44	8.34	8.27	8.18	8.03	7.73
T_5 (No sugar)	4.84	4.57	4.23	3.76	3.27	1.93	1.74
Mean	**7.30**	**7.17**	**7.01**	**6.83**	**6.63**	**6.17**	**5.85**
SEm ±	**0.02**	**0.02**	**0.02**	**0.03**	**0.04**	**0.05**	**0.05**
CD (P= 0.05)	**0.05**	**0.07**	**0.07**	**0.09**	**0.12**	**0.17**	**0.16**
IInd trial							
Treatments	Storage period (months)						
	0	1	2	3	4	5	6
T_1 (40% sugar)	7.12	7.05	6.96	6.82	6.61	6.21	5.76
T_2 (50% sugar)	7.33	7.27	7.19	7.07	6.93	6.59	6.19
T_3 (60% sugar)	8.25	8.21	8.14	8.10	7.91	7.75	7.38
T_4 (70% sugar)	8.48	8.43	8.36	8.27	8.12	7.94	7.66
T_5 (No sugar)	5.25	4.94	4.28	4.05	3.53	2.55	2.22
Mean	**7.29**	**7.18**	**6.99**	**6.86**	**6.62**	**6.21**	**5.84**
SEm ±	**0.02**	**0.01**	**0.02**	**0.02**	**0.02**	**0.04**	**0.03**
CD (P= 0.05)	**0.06**	**0.04**	**0.07**	**0.06**	**0.07**	**0.11**	**0.07**
Pooled							
Treatments	Storage period (months)						
	0	1	2	3	4	5	6
T_1 (40% sugar)	7.19	7.11	7.01	6.87	6.68	6.29	5.83
T_2 (50% sugar)	7.43	7.35	7.20	7.08	6.93	6.61	6.29
T_3 (60% sugar)	8.30	8.25	8.18	8.11	7.97	7.83	7.44
T_4 (70% sugar)	8.50	8.44	8.35	8.31	8.15	7.98	7.70
T_5 (No sugar)	5.05	4.75	4.26	3.91	3.40	2.24	1.98
Mean	**7.29**	**7.18**	**7.00**	**6.86**	**6.63**	**6.19**	**5.85**
SEm ±	**0.01**	**0.01**	**0.02**	**0.02**	**0.02**	**0.04**	**0.04**
CD (P= 0.05)	**0.03**	**0.04**	**0.05**	**0.05**	**0.06**	**0.12**	**0.11**

CHAPTER V

SUMMARY AND CONCLUSIONS

SUMMARY AND CONCLUSIONS

The present investigation entitled "**Utilization of waste for various products from pineapple cv. Giant kew**" was undertaken at Department of Horticulture, School of Agricultural Sciences, Nagaland University during the year 2018-21. The investigation aimed to assess the quality of fibre extracted from pineapple leaf, to evaluate the qualitative parameters of vinegar produced from pineapple waste (peel, core, and pomace) and to examine the preparation of candy from pineapple core. The salient findings thus obtained from the study are summarized below:

5.1. Quality of fibre extracted from pineapple leaf

1. The fibre yield was significantly influenced by cropping season and age of crop, but interaction effect was non-significant for both sucker and crown fibres. The maximum fibre yield was obtained from summer season and second ratoon crop in both sucker (1.61%) and crown (1.49%). The minimum fibre yield was recorded from winter season and main crop in sucker (1.40%) and crown (1.30%).
2. Fineness was significantly affected by cropping season, age of crop for both sucker and crown fibres. The highest fineness was recorded in summer season + first ratoon crop for sucker fibres (2.27 tex) and in summer season + second ratoon crop for crown fibres (2.16 tex). Lower fineness was observed in winter season + main crop, with sucker fibres at 2.85 tex and crown fibres at 2.76 tex.
3. Tensile strength was significantly influenced by cropping season and age of crop in both sucker and crown fibres. The interaction effect was non-significant for sucker fibres but significant differences were observed for crown fibres. The highest tensile strength was recorded in summer season

+ first ratoon crop for sucker fibres (36.13 cN/tex) and in summer season + second ratoon crop for crown fibres (30.15 cN/tex). The lowest tensile strength was found in winter season and main crop for both sucker fibres (31.04 cN/tex) and crown fibres (20.25 cN/tex).

4. The modulus of elasticity was significantly affected by cropping season and age of crop and their interaction in both pineapple sucker and crown fibres. Maximum modulus of elasticity was recorded from summer season + first ratoon crop in sucker fibres (1548.33 cN/tex) and in summer season + second ratoon crop for crown fibres (1275.73 cN/tex). Minimum value was exhibited in winter season + second ratoon crop in sucker fibres (792.75 cN/tex) and winter season + main crop in crown fibres (678.86 cN/tex).
5. Elongation at the break point significantly varied with cropping season, age of crop and their interaction in both sucker and crown fibres. The highest elongation at break point was recorded from summer season + first ratoon crop for sucker fibres (2.70%) and in crown fibres (2.54%) from summer season in second ratoon crop. The lowest elongation in fibres was found in winter season from main crop for sucker fibres (2.24%) and crown fibres (1.96%).
6. Cellulose content had a profound effect on cropping season, age of crop and their interaction in both sucker and crown fibres. The highest cellulose content in sucker fibre (70%) was obtained from first ratoon crop in summer season and in second ratoon crop from summer season in crown fibres (60.53%). The lowest cellulose content was found in winter season and main crop in sucker (65.29%) and in crown (53.34%).
7. Hemicellulose content in both sucker and crown fibres varied significantly with cropping season, age of crop and their interaction. The highest hemicellulose content was obtained from summer season + first ratoon crop in sucker fibres (20.49%) and summer season + second ratoon crop in crown

fibres (18.30%). The lowest was reported in winter season + main crop for both sucker (17.22%) and crown fibres (15.18%).

8. Lignin content in both pineapple sucker and crown fibres had significant effect on cropping season and age of crop. The highest lignin content was found during summer season in first ratoon crop for both sucker fibres (5.57%) and crown fibres (4.67%) whereas, the lowest was observed in winter season and main crop in leaf (4.62%) and crown fibres (3.80%). Notable interaction effects were observed in sucker fibres, while no significant interaction effect was found in crown fibres.
9. Ash content was significantly influenced by cropping season and age of crop in both leaf and crown fibres. Highest ash content in sucker (6.30%) and crown (5.58%) were obtained from main crop in summer season while, the lowest from second ratoon in winter season for both sucker (5.86%) and crown (5.09%). However, no significant interaction was noted for both crown and sucker fibres.
10. Moisture content had no significant influence on cropping season and crop age in both pineapple sucker and crown. However, highest moisture content was recorded in summer season and main crop in both sucker (11.94%) and crown (11.03%) whereas, the lowest was found in winter season and second ratoon crop in sucker (11.70%) and crown (10.19%).
11. Crude fibre content was significantly influenced by cropping season and age of crop, while no significant interaction was observed. The highest crude fibre content was recorded from summer season+ second ratoon crop in sucker fibres (23.21%) and summer season + first ratoon crop (20.86%). Winter season and main crop recorded the lowest crude fibre content in sucker (21.79%) and crown (19.85%).
12. Total nitrogen content in sucker fibres was significantly influenced by cropping season and age of crop. However, the interaction effect between these factors was not significant. The highest nitrogen content was recorded

in summer season from the main crop in both sucker (1.35%) and crown (1.61%). The lowest content was found in winter season from the second ratoon crop in sucker (1.05%) and crown (1.38%).

5.2. Qualitative parameters of vinegar from pineapple waste

1. The pH levels of vinegar derived from pineapple waste exhibited significant differences across treatments. The highest pH was observed in core (2.81) and lowest in peel (2.69).
2. Total Soluble Solids (TSS) and specific gravity did not show a significant difference among the developed vinegar prepared from different pineapple waste. However, the highest TSS was recorded from core (3.36 °Brix) and lowest in peel (3.25 °Brix). Specific gravity in peel was 1.014, while both core and pomace had specific gravity of 1.012.
3. The titratable acidity in terms of citric acid varied significantly among the vinegar prepared from pineapple waste with highest value recorded in peel (5.03%) and core (4.50%) recorded the lowest.
4. Acetic acid content in the developed vinegar was profoundly influenced by different pineapple waste. The vinegar derived from peel (4.75%) had significantly higher acetic acid content and lowest in core (4.22%).
5. Significant variations were observed in the colour properties of vinegar prepared from pineapple waste. Peel showed the highest colour intensity (4.05) and density (2.99), while core had the highest colour tone (1.39). The highest percentage of yellow value was noted in core (43.92%), percentage of red value in peel (33.59%) and blue value was also noted in peel (26.09%). Pomace showed the lowest values in these categories except for the colour tone, where it was at par with core (1.38).
6. The sensory score also had significant influence on vinegar prepared from pineapple wastes. Among the vinegar, peel vinegar had the highest score in terms of colour (7.65), flavour (6.96), sourness (8.02) and overall acceptability (7.76) and the lowest score was obtained in pomace vinegar.

5.3. Preparation of candy from pineapple core

1. Moisture content was significantly influenced by varying concentrations of sugar solution and decreased consistently with progress of storage period across all treatments. The highest moisture content was recorded in treatment with no sugar and lowest in 70% sugar throughout the storage period. The mean moisture content decreased from 22.24% initially to 19.96% after six months.
2. Ascorbic acid was significantly influenced by sugar level and exhibited a declining trend with the progress in storage period irrespective of treatments. Throughout the storage period, the highest ascorbic acid content was observed in 40% sugar while the lowest was found in no sugar treatment. The mean value of ascorbic acid decreased significantly from 5.93 to 4.64 mg/100g in six months of storage.
3. Total sugar content registered significant difference among the treatments in both the years and increased consistently with the progression of storage period across all treatments. The highest total sugar content was recorded in candy treated with 70 % sugar and lowest in no sugar treatment throughout the storage period. The mean value of total sugar gradually increased from 41.42% to 44.73% after six months of storage interval.
4. Reducing sugar gradually increased as storage period advanced and significant differences on reducing sugar content was observed in core candy treated with different concentration of sugar solution in both the years. The highest reducing sugar was recorded in 70% sugar and the lowest in no sugar treatment throughout the storage period. The mean reducing sugar content significantly increased from 18% to 20.76% after six months of storage period.
5. Statistically significant differences in titratable acidity were noted among the various treatments of pineapple core candy in both years. Throughout

the storage period, the highest acidity content was obtained in no sugar treatment and lowest in 70% sugar. Acidity declined with the progress in storage interval, regardless of the treatments. The mean titratable acidity decreased from 0.45% to 0.35%.

6. On the basis of sensory evaluation, descriptors such as colour, flavour, taste, texture and overall acceptability were significantly influenced by sugar level in both the years. Candy treated with 70% sugar consistently received the highest scores for all the parameters throughout the storage period. However, a decline in all organoleptic attributes was noted across all treatments as storage period progresses. Among the treatments, candy prepared with 70% sugar consistently scored the highest in terms of colour (8.72), flavour (7.82), taste (8.17), texture (8.26) and overall acceptability (8.50), while candy prepared without sugar received the lowest ratings across all organoleptic parameters.

CONCLUSION

Based on the above findings of the present investigation, the following conclusions can be drawn:

1. From the leaf of sucker, fibre extracted from the first ratoon crop (A_2) during summer season (S_1) exhibited superior physical characteristics (fineness), chemical properties (cellulose) and mechanical attributes (tensile strength, elongation at break point and modulus of elasticity). Meanwhile, superior quality of crown fibres was obtained during summer season (S_2) from second ratoon crop (A_3). In general, sucker-extracted fibres exhibited better physiological, chemical and mechanical properties than crown fibres.
2. Among the vinegars prepared from pineapple waste (peel, core, and pomace), pineapple peel vinegar (T_1) recorded the highest acetic acid content, lowest pH value and was also the most preferred in sensory

evaluation exhibiting superior attributes in colour, flavour, sourness and overall acceptability.

3. Candy prepared with 70% sugar (T_4) was found superior in terms of sensory evaluation (colour, texture, taste, flavour and overall acceptability). After six months of storage under ambient condition, pineapple core candy treated with 70% sugar (T_4) consistently maintained superior organoleptic attributes without deterioration of nutritional quality.

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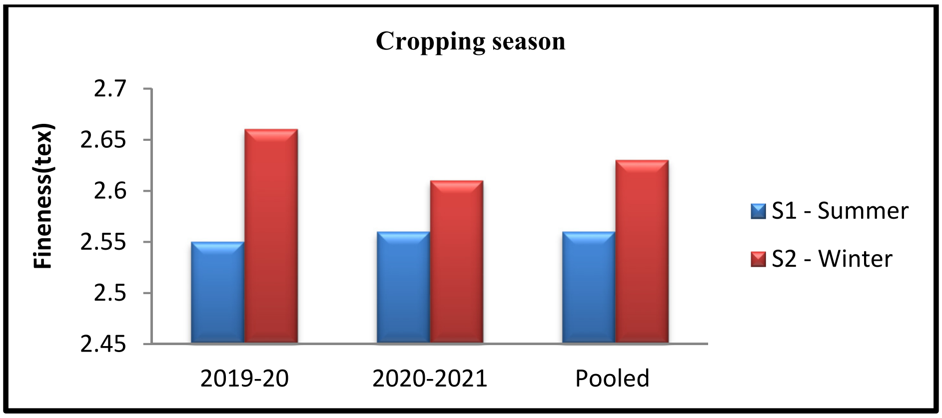
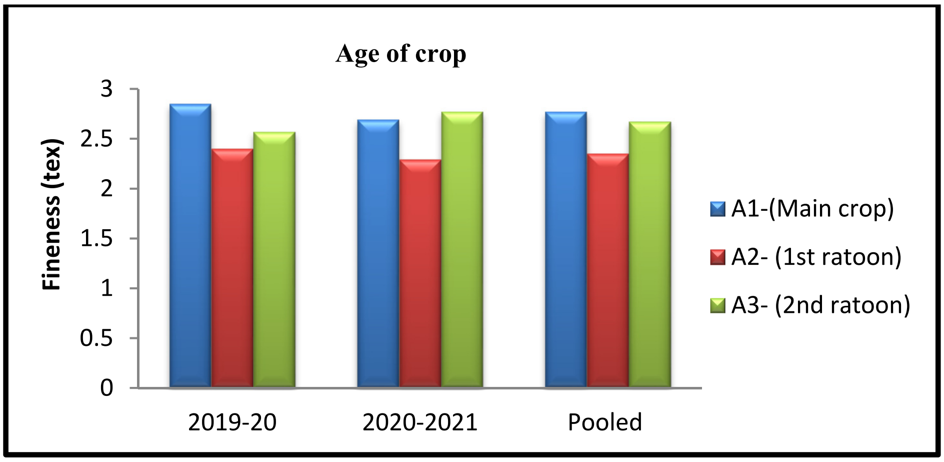
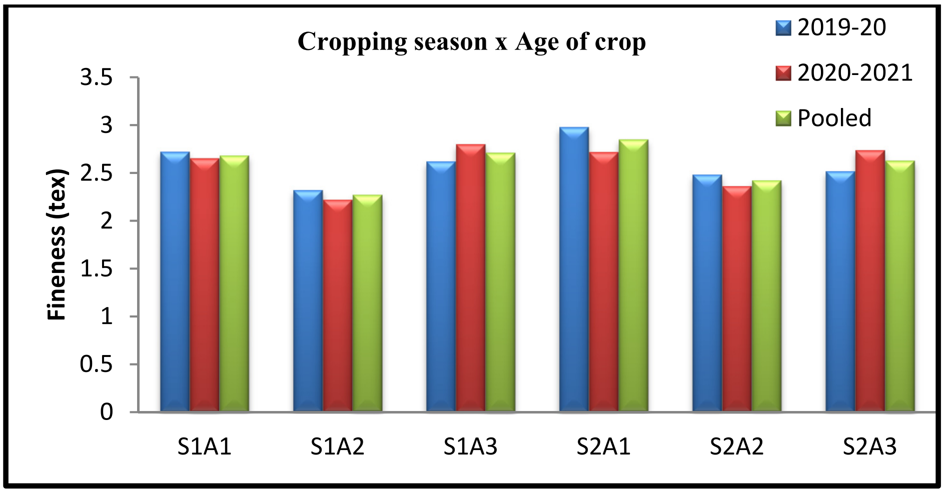
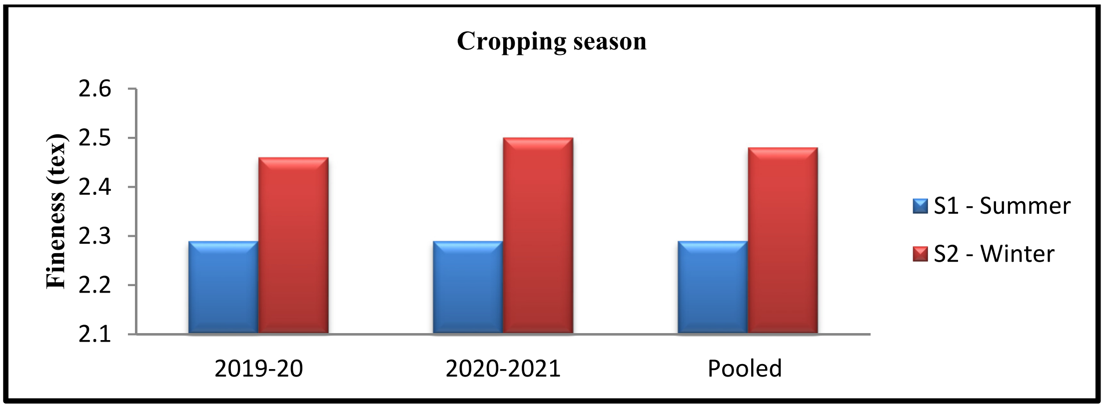
APPENDICES

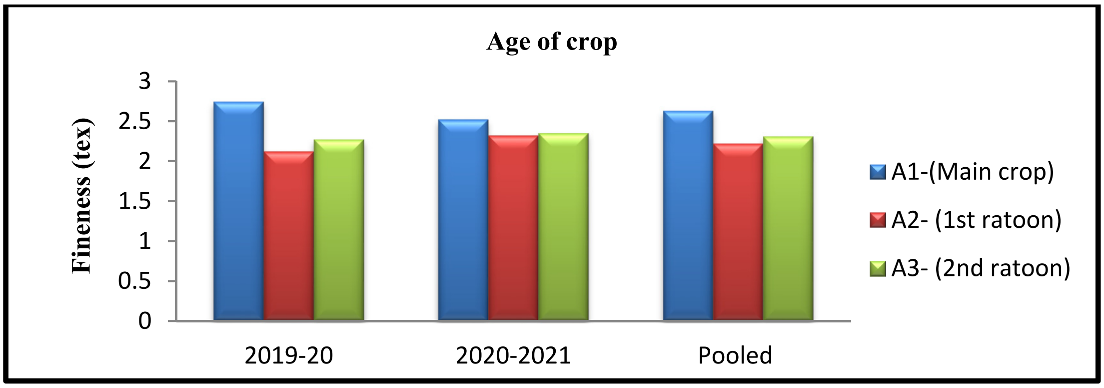


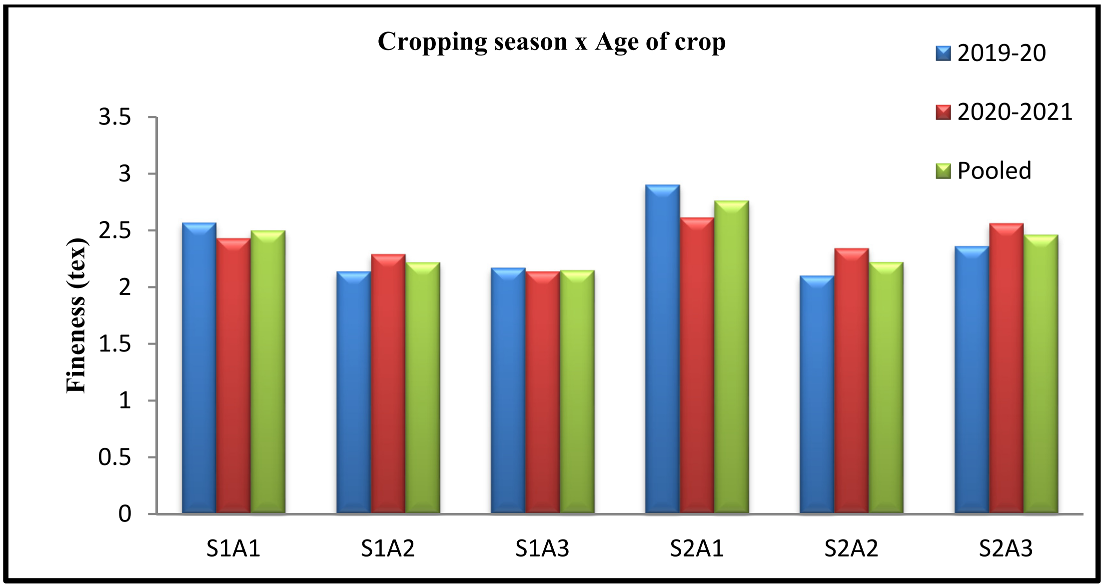




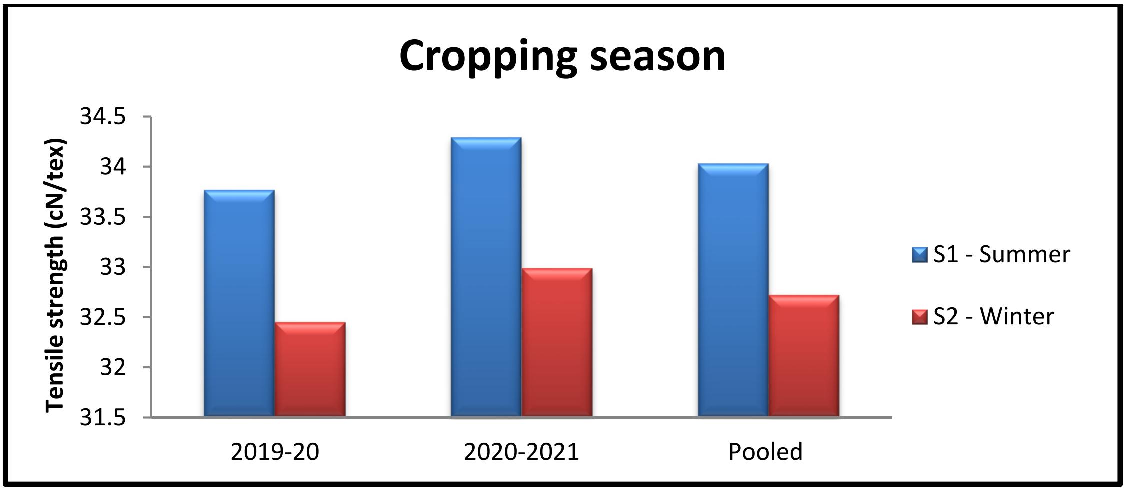
Appendix 1: Effect of cropping season, age of crop and their interaction on the fineness (tex) of fibre extracted from pineapple sucker

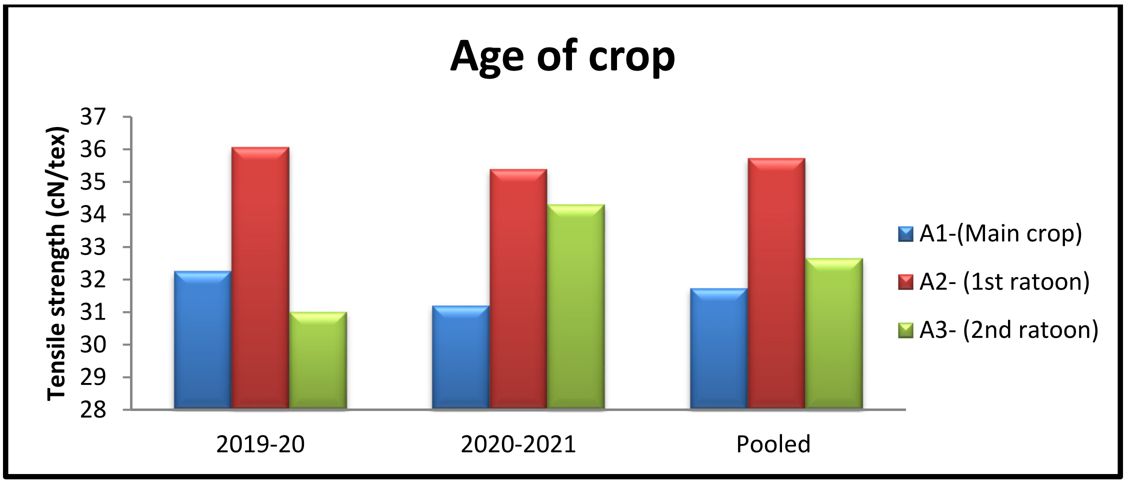


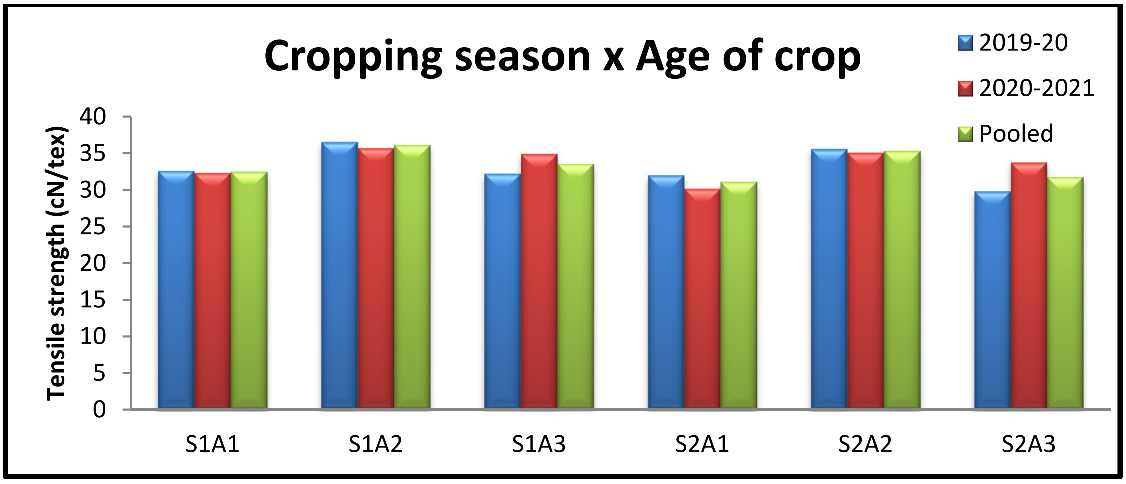




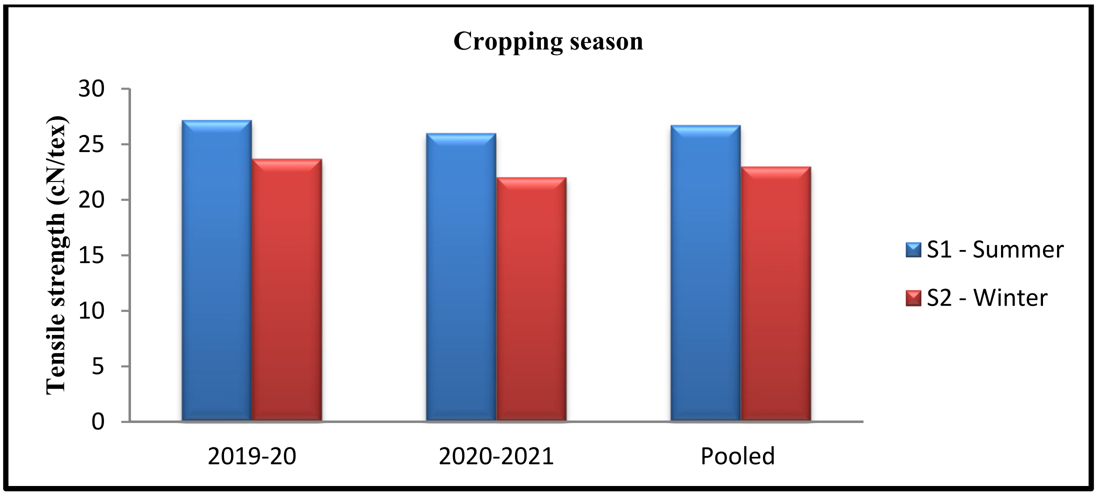
Appendix 2: Effect of cropping season, age of crop and their interaction on the fineness (tex) of fibre extracted from pineapple crown

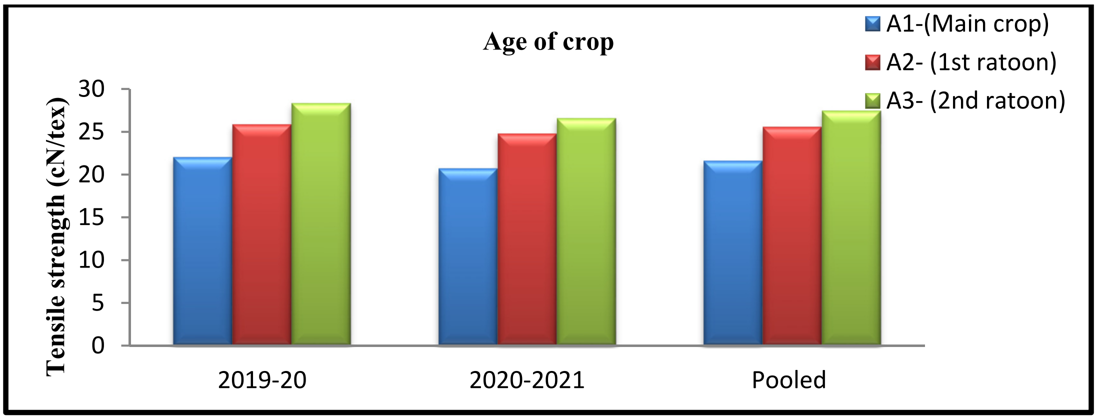


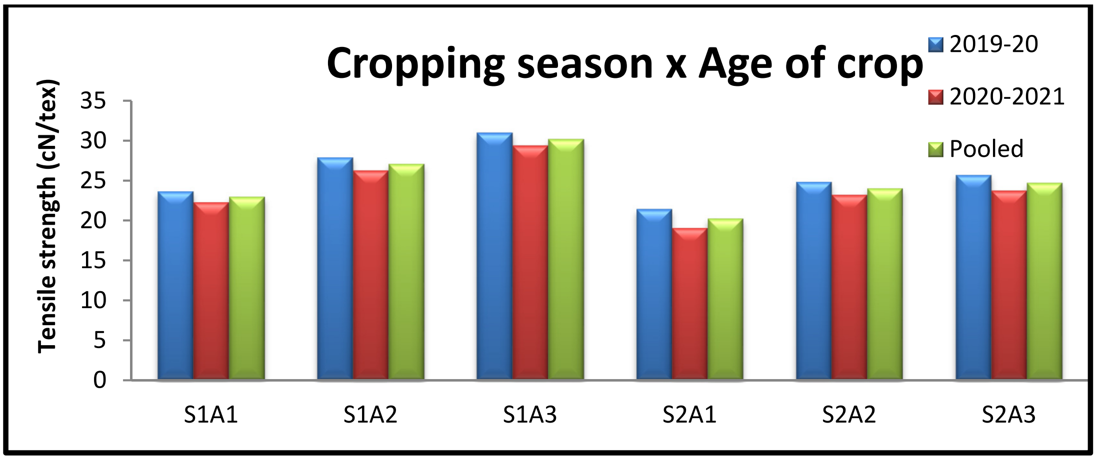




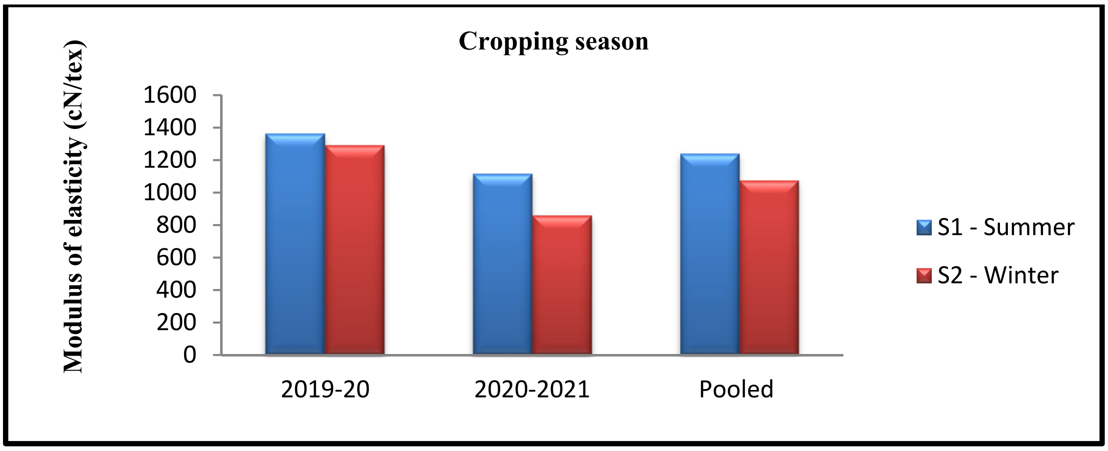
Appendix 3: Effect of cropping season, age of crop and their interaction on the tensile strength (cN/tex) of fibre extracted from pineapple sucker

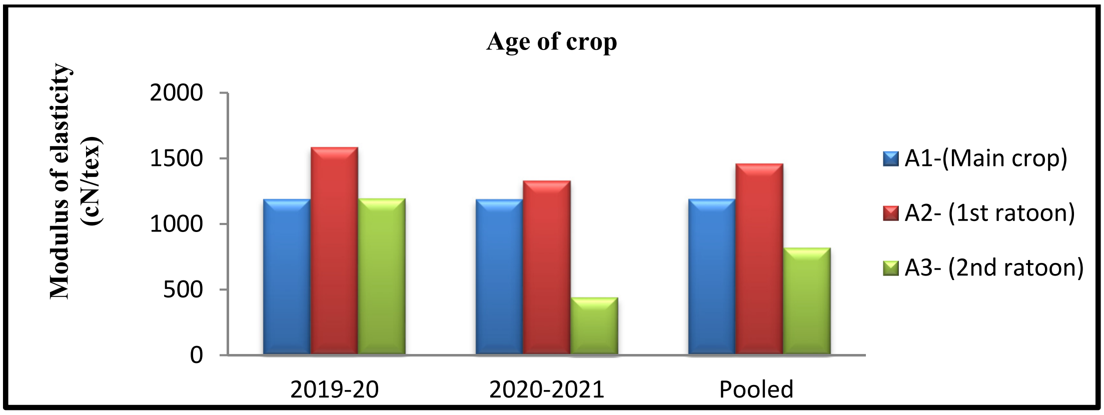


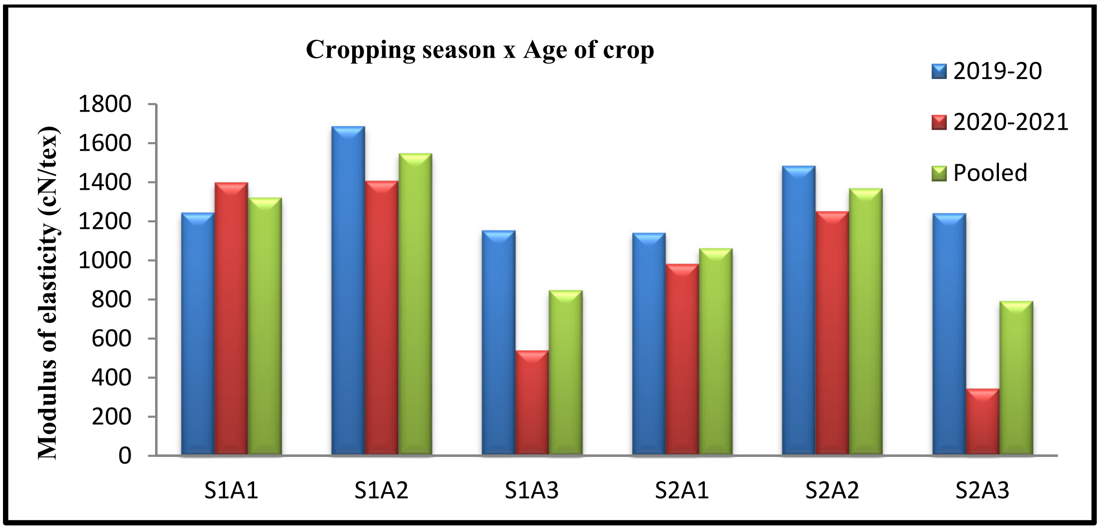




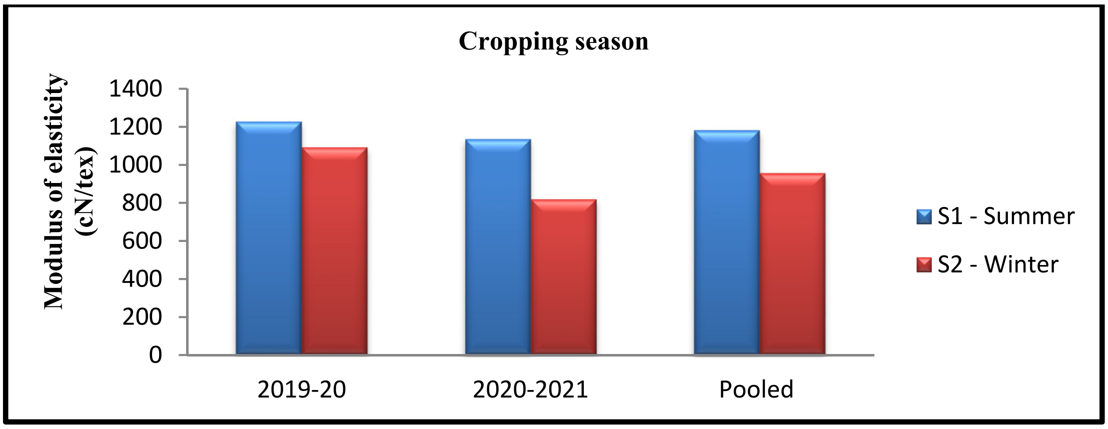
Appendix 4: Effect of cropping season, age of crop and their interaction on the tensile strength (cN/tex) of fibre extracted from pineapple crown

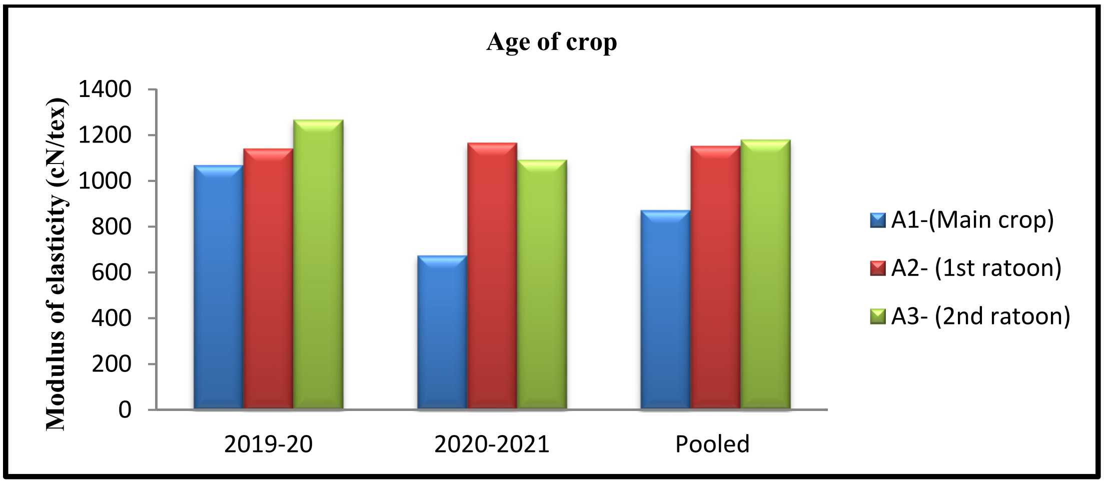


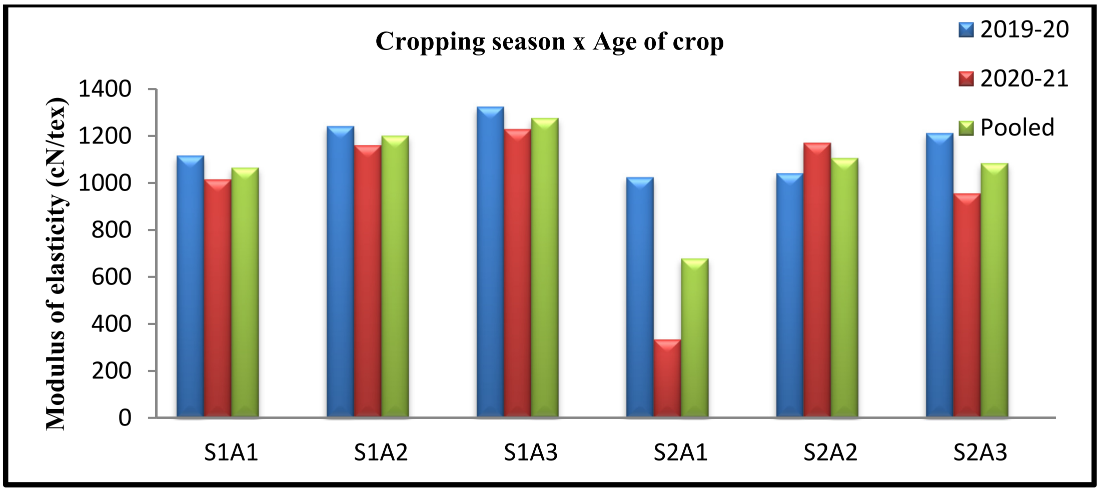




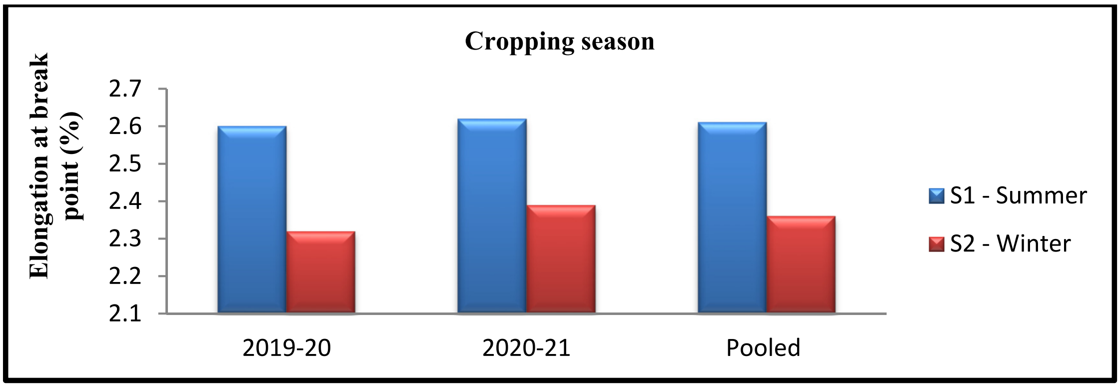
Appendix 5: Effect of cropping season, age of crop and their interaction on modulus of elasticity (cN/tex) extracted from pineapple sucker

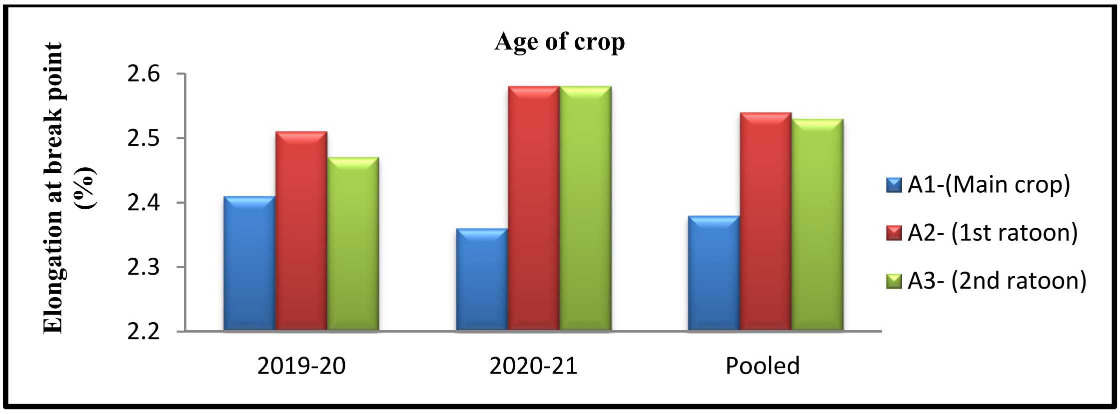


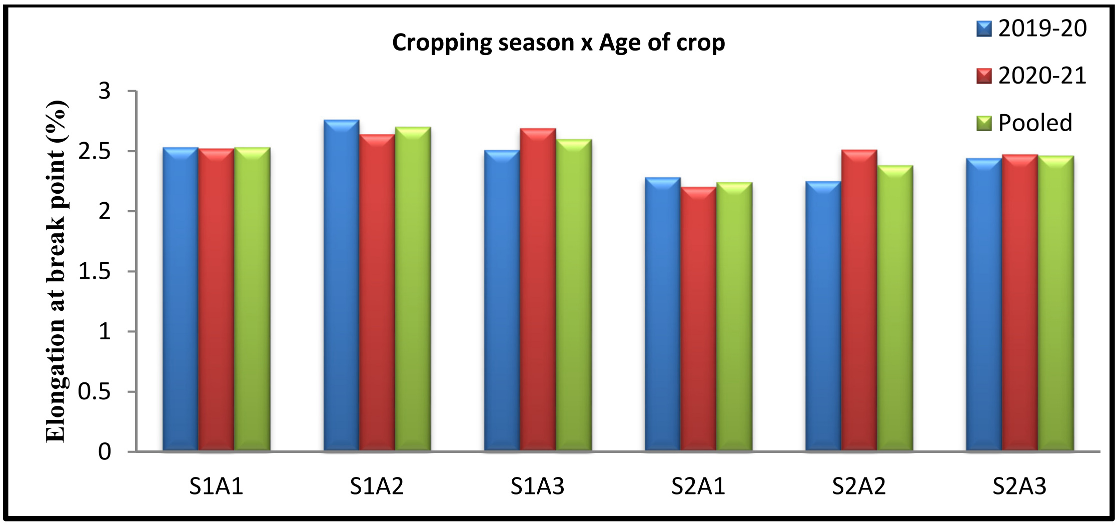




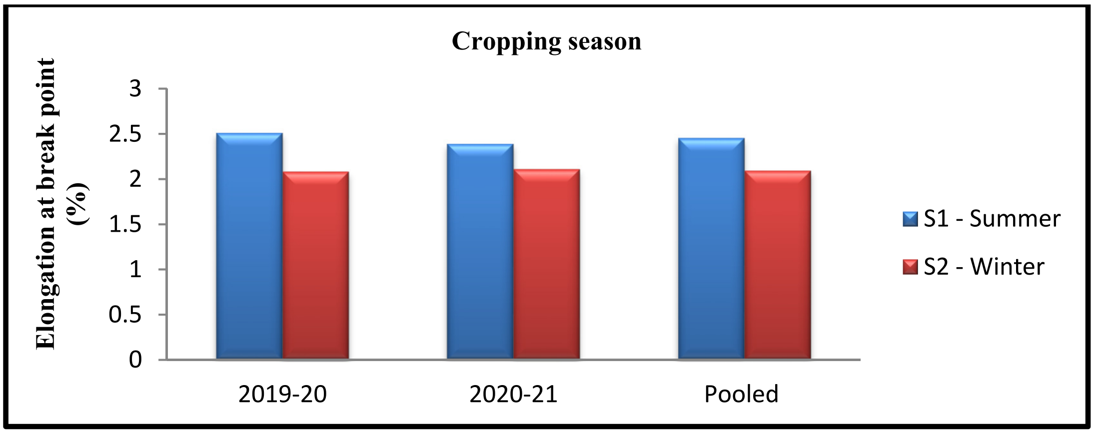
Appendix 6: Effect of cropping season, age of crop and their interaction on modulus of elasticity (cN/tex) of fibre extracted from pineapple crown

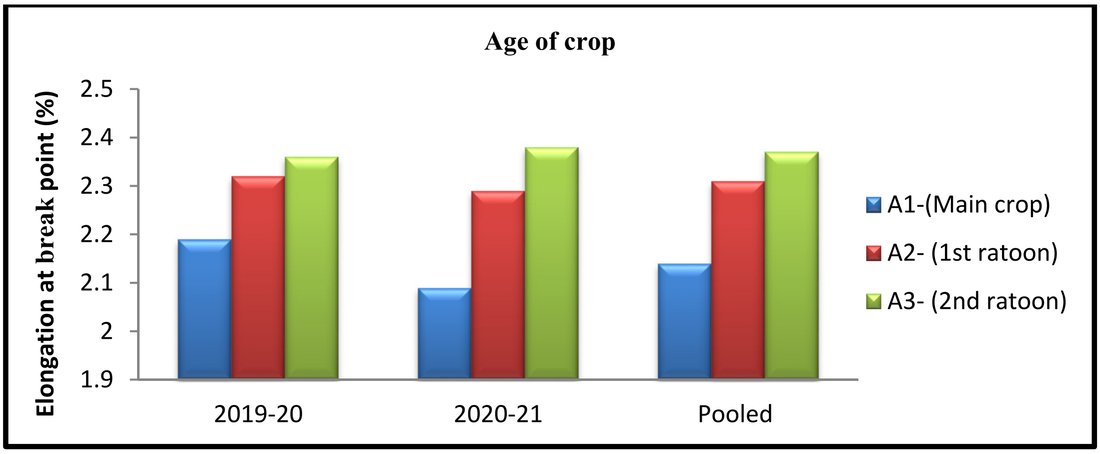


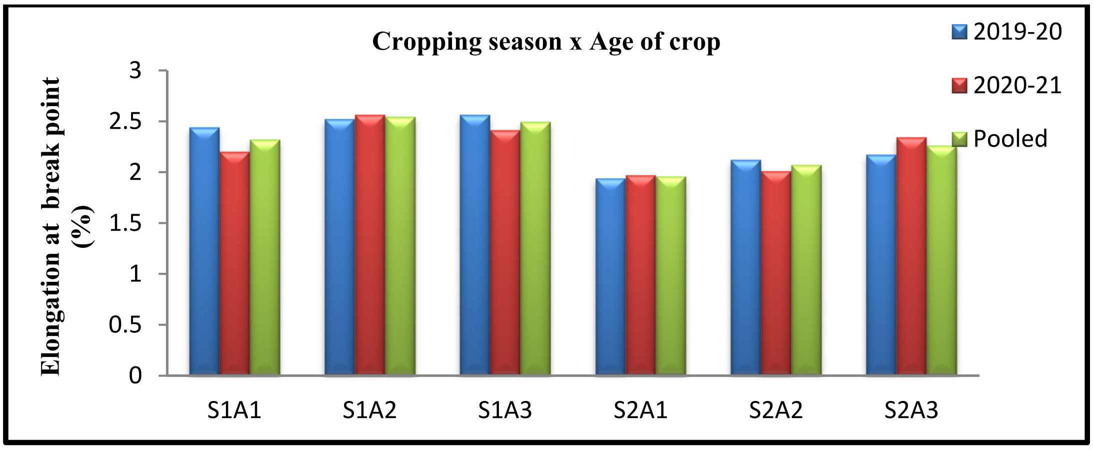




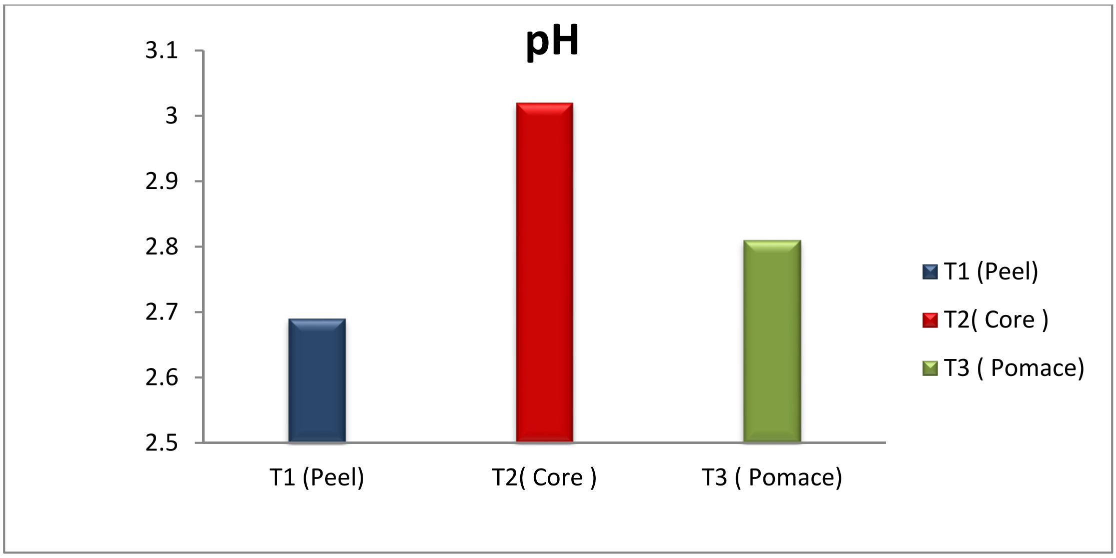
Appendix 7: Effect of cropping season, age of crop and their interaction on elongation at break point (%) of fibre extracted from pineapple sucker



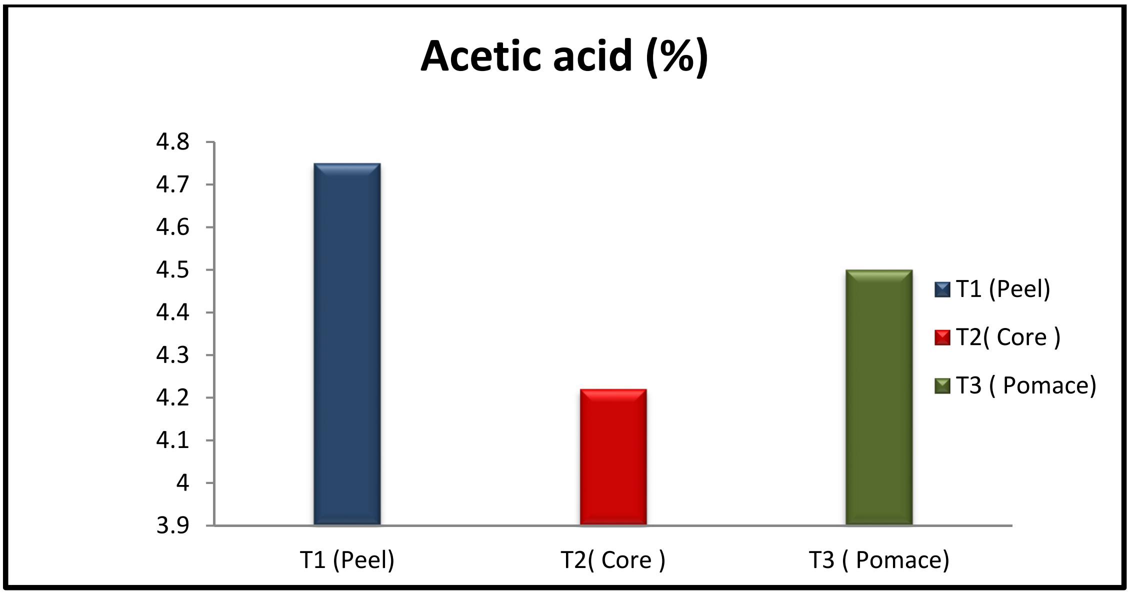




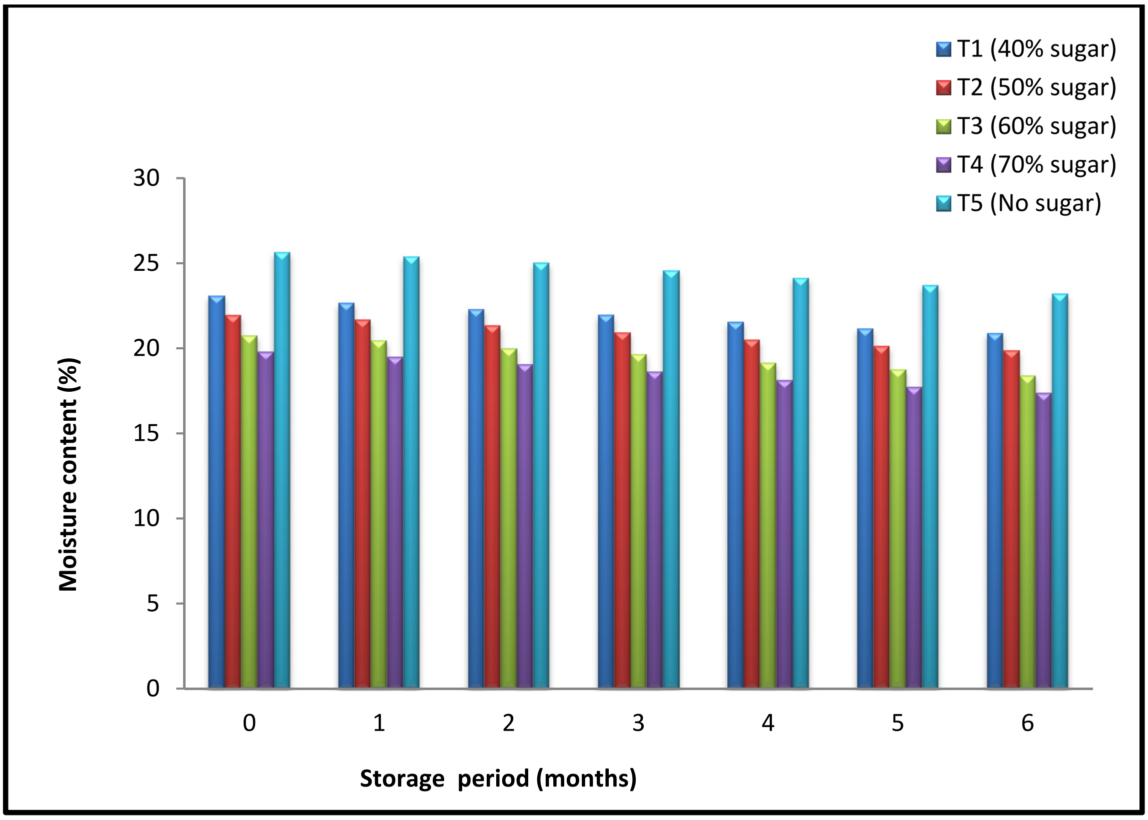
Appendix 8: Effect of cropping season, age of crop and their interaction on elongation at break point (%) of fibre extracted from pineapple crown



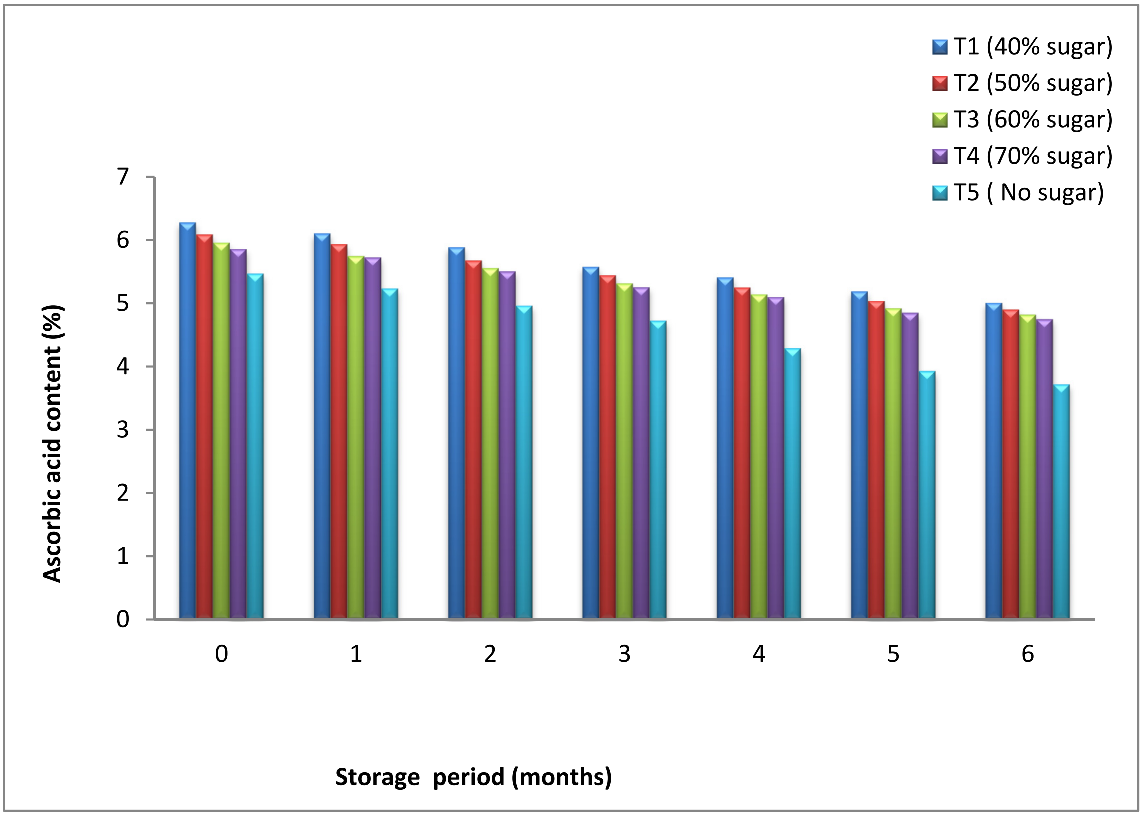
Appendix 9: pH of vinegar prepared from different waste of pineapple



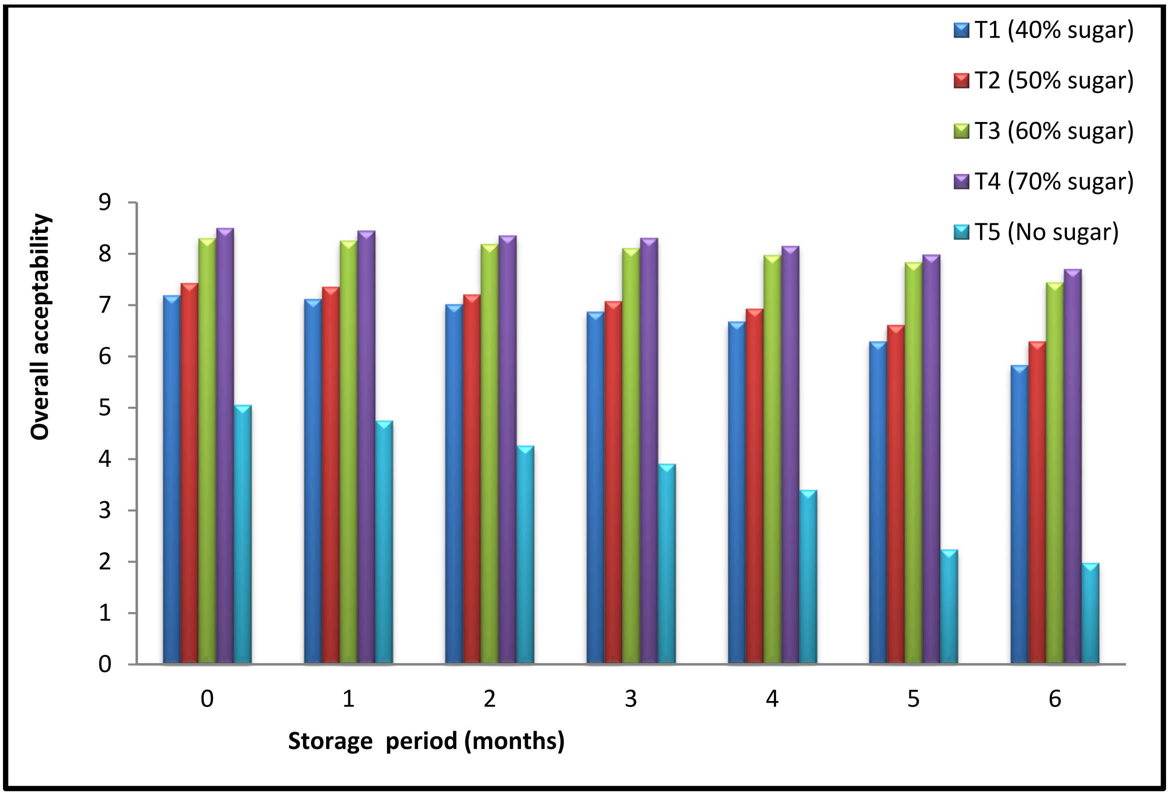
Appendix 10: Acetic acid content of vinegar prepared from different pineapple waste



Appendix 11: Effect of sugar level on moisture content (%) of pineapple core candy during storage



Appendix 12: Effect of sugar level on ascorbic acid content (%) of pineapple core candy during storage



Appendix 13: Effect of sugar level on overall acceptability pineapple core candy during storage