CHAPTER I

INTRODUCTION

1.1 Background and problem

Damage during transportation is a significant issue for fresh produce. Foam cushions are commonly used in the transport process, but these cushions are made from non-biodegradable materials, which creates a major waste problem. As an alternative, natural rubber latex (NR) is considered a suitable material choice, as NR is biodegradable. However, the manufacturing process of NR cushions involves numerous factors that must be addressed. To aid in solving this engineering problem, computer-aided design (CAD) software is used for the modification, analysis, and optimization of designs. CAD tools help improve the performance of models and create a database for manufacturing. In this study, the primary objective for the cushion design was to minimize physical damage. A 3D model of the cushion was created using SolidWorks software and simulated in ANSYS Workbench.

1.2 Research objectives.

1.2.1 To optimize the structural design parameters of natural rubber latex foam (NRLF) cushioning material for packaging applications.

1) To investigate the effects of filament number and filament diameter on the mechanical properties and cushioning performance of NRLF.

2) To study the influence of foam density variation on the impact of absorption efficiency and foam structure integrity.

1.2.2 To evaluate the impact protection performance of NRLF cushions using Finite Element Method (FEM) simulation.

1) To develop accurate CAD models of NRLF cushions and model fruit (Glom Sali guava) for drop test simulation.

2) To compare cushioning effectiveness of NRLF foam against commercial expanded polyethylene (EPE) foam and unprotected guava under various impact conditions.

1.2.3 To analyze the relationship between cushioning design parameters and maximum stress in fresh produce during impact.

1) To determine how variations in filament number, filament diameter, and foam density influence stress distribution and peak stress during simulated drop tests.

2) To identify optimal combinations of design parameters that minimize mechanical damage to fruit while maintaining lightweight and eco-friendly packaging solutions.

1.2.4 To demonstrate the feasibility of using computer-aided design (CAD) and FEM simulation as efficient tools for developing sustainable cushioning packaging.

1) To validate the FEM simulation approach as a time- and cost-effective alternative to traditional experimental testing.

2) To provide design guidelines for producing high-performance, environmentally friendly cushioning materials based on simulation results.

1.3 Goals

The goals are as follows.

1.3.1 Analyze and define the cushion performance of alternative materials.

1.3.2 Analyze and define damage of the foam net cushion design.

1.3.3 Analyze and define the foam net cushion design.

1.4 Scope and limitations

This study focuses on the development and evaluation of eco-friendly cushioning foam made from natural rubber latex foam (NRLF) for fruit packaging applications, with particular emphasis on impact protection performance. The research is divided into three main sections: first, the study compares the impact protection of unprotected guavas (without packaging) to those cushioned with commercial expanded polyethylene (EPE) foam through drop tests simulated at a height of 200 mm to evaluate cushion effectiveness under realistic impact conditions. Second, it investigates the effect of filament number (25, 20, and 15 filaments) and filament diameter (2.5, 3.5, and 4.5 mm) on the mechanical behavior and cushioning efficiency of NRLF cushions, with drop tests also conducted at 200 mm to assess cushioning under standard impact conditions. Third, the study explores how reducing foam density (420, 397, and 345 kg/m^3) influences the cushioning performance of NRLF cushions with different filament numbers, where drop tests were simulated at a height of 100 mm to specifically evaluate the effect of density reduction on cushioning efficiency. NRLF cushions were modeled using CAD software (SolidWorks®) and simulated under explicit dynamic conditions in ANSYS® to replicate these drop tests, with the guava fruit represented as a homogeneous elastic body. The primary evaluation metric was the maximum stress experienced by the fruit during impact, which was used to infer cushioning performance.

1.4.1. Limitations of the study

1) The simulation assumes idealized material properties and uniform foam structures, which may differ from actual heterogeneous foam behavior and manufacturing variability.

2) The guava model does not account for internal biological complexity or anisotropic properties, potentially affecting the accuracy of stress predictions.

3) Environmental factors such as temperature, humidity, and long-term foam durability under real transportation conditions were not considered.

4) Experimental validation was limited to simulation results; physical drop tests and empirical data collection were outside the scope of this research.

5) The biodegradability and life cycle assessment of NRLF materials were not addressed in this study and remain areas for future investigation.

Despite these limitations, the findings provide useful insights into the design of sustainable cushioning foam and demonstrate the effectiveness of FEM simulations as a tool for packaging development.

1.5 Research benefits

This research provides several important benefits to the field of sustainable packaging and material engineering:

1) Development of Eco-Friendly Packaging Solutions**:** By focusing on natural rubber latex foam (NRLF) as a biodegradable and renewable cushioning material, the study contributes to reducing environmental impact compared to conventional synthetic foams like expanded polyethylene (EPE).

2) Optimization of cushion Design on cushion performance: The investigation into the effects of filament number, filament diameter, and foam density on cushioning performance offers valuable insights for designing lightweight yet effective protective packaging. This optimization can help reduce material usage and packaging weight, leading to cost savings and improved transport efficiency.

3) Advancement of simulation techniques: Employing Finite Element Method (FEM) simulations to evaluate cushioning performance allows accurate

prediction of mechanical behavior without extensive physical prototyping. This accelerates the development process and reduces experimental costs.

4) Enhanced fruit protection: The research improves understanding of how cushioning parameters influence impact protection, helping to minimize mechanical damage to sensitive fruits like guava during handling and transportation, thereby reducing food waste.

The proposed method was able to determine the damage for transport process from transport process. The damage problem mitigation with cushion packaging method in case of different cushion foam material is also investigated.