DEVELOPMENT AND MECHANICAL ATTRIBUTES OF *Parkia speciosa* (HASSK) CHEWABLE TABLETS

By

FAGHIRA BINTI BAKARUDDIN

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Chairman : Assoc. Prof. Mohd Shamsul bin Anuar, PhD

Faculty : Engineering

Parkia speciosa Hassk is called stink bean, bitter bean or *petai* by Southeast Asian, and is a member of the Fabaceae family and belongs to the species Parkia. It is widely recognized for its folk medicinal use in treating kidney and liver issues due to its high antioxidant content. *Parkia speciosa* Hassk presents preservation challenges owing to its limited shelf life and seasonality. This research focuses on two key areas: formulating *Parkia speciosa* Hassk into chewable tablets and characterizing their mechanical integrity and chewing efficiency. Employing lactose-based excipients—Tablettose® 80, FlowLac® 90, and MicroceLac® 100—with compositions of 14.07%, 29.41%, and 44.11% w/w, this study involved a freeze-drying treatment to preserve phenolic compounds and color quality. The resulting dried seeds were analyzed for their physical and flow properties to

understand compaction and compression mechanisms. Tablets containing 500mg of *Parkia speciosa* Hassk powder were then produced via direct compaction at varied pressures (22.61 MPa to 67.82 MPa). The force-displacement profile was employed to examine the compaction characteristics, including elastic work, plastic work, and maximum ejection pressure. Mechanical tests were conducted using indirect tensile, friability, and dissolution tests to assess durability and dissolution rate. The optimal chewable tablet formulation, which was determined through measurement of chewing efficiency, comprises 500mg of *Parkia speciosa* Hassk powder and 44.11% MicroceLac® 100, compacted at 52.75 MPa. These findings highlight the potential of *Parkia speciosa* Hassk chewable tablets, offering a novel and convenient dosage form for delivering its bioactive compounds. The physical properties of the dried *Parkia speciosa* Hassk tablet, characterized by fine particle size, favorable bulk and tapped densities, and moderate flowability, establishes its suitability to be used as an additional excipient prior to compaction, providing potential health benefits owing to its antioxidant properties. The study emphasizes the significant impact of compaction pressure on tablet compaction behavior and mechanical characteristics. Compared to Tablet A (14.07% Tablettose® 80 at 22.61MPa), Tablet B (4.11% MicroceLac® 100 at 52.75MPa) exhibited superior performance, meeting stringent mechanical standards.

Tablet B emerged as a promising formulation for further development of *Parkia speciosa* Hassk chewable tablets. These findings underscore the crucial relationship between compaction parameters and excipient characteristics in

optimizing tablet formulations with potential implications for pharmaceutical and nutraceutical applications.

Keywords: Powder flowability, Tablet compactibility, Parkia speciosa hassk, Herbal tablet, Chewable tablet

SDG: GOAL 3: Good health and well-being, and GOAL 9: Industry, innovation and infrastructure

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Master Sains

PEMBENTUKAN AND CIRI CIRI MEKANIKAL TABLET KUNYAH *PARKIA SPECIOSA* (HASSK)

Oleh

FAGHIRA BINTI BAKARUDDIN

Mei 2024

Pengerusi : Prof. Madya Mohd Shamsul bin Anuar, PhD

Fakulti : Kejuruteraan

Parkia speciosa Hassk dipanggil kacang busuk, kacang pahit atau petai oleh Asia Tenggara, dan merupakan ahli keluarga Fabaceae dan termasuk dalam spesies Parkia. Ia digunakan secara meluas dalam perubatan tradisional untuk merawat masalah buah pinggang dan hati kerana kandungan antioksidannya yang tinggi. *Parkia speciosa* Hassk menghadapi cabaran pemeliharaan kerana jangka hayatnya yang pendek serta tumbuhan bermusim. Kajian ini memberi tumpuan kepada dua bidang utama: merumuskan formulasi *Parkia speciosa* Hassk ke dalam tablet yang boleh dikunyah dan pencirian integriti mekanikal dan kecekapan kunyahannya. Menggunakan eksipienberasaskan laktosa - Tablettose® 80, FlowLac® 90, dan MicroceLac® 100, dengan komposisi 14.07%, 29.41%, dan 44.11% w/w, kajian itu melibatkan rawatan pengeringan beku untuk mengekalkan sebatian fenolik dan kualiti warna. Sifat fizikal dan aliran benih kering yang terhasil dianalisa untuk memahami mekanisme pemadatan dan

pemampatan. Tablet yang mengandungi 500mg serbuk *Parkia speciosa* Hassk kemudiannya dihasilkan melalui pemadatan langsung pada tekanan yang berbeza-beza (22.61 MPa hingga 67.82 MPa).Profil anjakan daya digunakan untuk mengkaji ciri pemadatan, termasuk kerja kenyal, kerja plastik, dan tekanan lenting maksimum. Ujian mekanikal dijalankan menggunakan ujian tegangan tidak langsung, kerapuhan, dan pembubaran untuk menilai ketahanan dan kadar pembubaran. Formulasi tablet kunyah yang optimum, yang ditentukan melalui pengukuran kecekapan mengunyah, terdiri daripada 500mg serbuk *Parkia speciosa* Hassk dan 44.11% MicroceLac® 100, dipadatkan pada 52.75 MPa. Penemuan ini menyerlahkan potensi tablet kunyah *Parkia speciosa* Hassk, menawarkan bentuk dos yang baharu dan mudah untuk menyampaikan sebatian bioaktifnya. Sifat fizikal tablet *Parkia speciosa* Hassk yang dikeringkan., dicirikan oleh saiz zarah yang halus, ketumpatan pukal dan diketuk yang menggalakkan, dan kebolehaliran yang sederhana, mengekalkan kesesuaiannya untuk digunakan sebagai eksipien tambahan sebelum pemadatan, berpotensi memberi manfaat kesihatan kerana sifat antioksidannya. Kajian ini menekankan kesan ketara tekanan pemadatan ke atas tingkah laku pemadatan tablet dan ciri mekanikal. Dibanding dengan Tablet A (14.07% Tablettose® 80 pada 22.61MPa), Tablet B (44.11% MicroceLac® 100 pada 52.75MPa) mempamerkan prestasi yang lebih unggul serta memenuhi piawaian mekanikal yang ketat.

Tablet B muncul sebagai formulasi yang mempunyai harapan cerah untuk pembangunan tablet kunyah *Parkia speciosa* Hassk Penemuan ini menggariskan hubungan penting antara parameter pemadatan dan ciri eksipien dalam

mengoptimumkan formulasi tablet dengan potensi implikasi untuk aplikasi farmaseutikal dan nutraseutikal.

Kata kunci: Kebolehaliran serbuk, Kebolehan pemadatan tablet, Parkia speciosa hassk, Tablet herba, Tablet kunyah

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Mohd Shamsul bin Anuar, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Mohd Zuhair bin Mohd Nor, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Muhammad Syahmeer How bin Mohd Firdaus How, PhD
Senior Lecturer
Facultry of Engineering
Universiti Putra Malaysia
(Member)

ZALILAH MOHD SHARIFF, PHD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 7 November 2024

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LIST OF ABBREVIATIONS

DOA	Department of Agriculture
API	Active Pharmaceutical Ingredients
QbD	Quality by Design
HPLC	High-Performance Liquid Chromatography
UV-Vis	Ultraviolet-Visible Spectroscopy
USP	United States pharmacopeia
BP/IP	British pharmacopeia/ Indian pharmacopeia
SI	International System of Units
IR	Immediate release
FEA	Finite element analysis
CAD	Computer-Aided Design
CFP	Computational fluid dynamics
MATLAB	Matrix laboratory
AOAC	Association of Official Agricultural Chemists
V_A and V_B	Volume
M	Molarity
FRAP	Ferric reducing ability of plasma
DPPH	2,2-Diphenyl-1-picrylhydrazyl
Wb	Wet basis
w/w	weight in weight
MDE	Maximum daily exposure
CDER	Center for Drug Evaluation and Research
W_e	elastic work
W_p	plastic work

W_t	total work
h_t	maximum displacement
h_f	final displacement
$P_{unloading}$	reaction pressure during unloading
$P_{loading}$	reaction pressure during loading

CHAPTER 1

INTRODUCTION

1.1 Background and rationale

Parkia speciosa Hassk, also known as the stink bean or *petai*, is a tropical tree found in Southeast Asia belonging to the Fabaceae family. It is widely distributed in Southeast Asia and is known for its traditional medicinal properties. It has gained recognition not only for its unique flavour but also for its remarkable nutritional benefits and potential medicinal properties. The stinky bean seeds are known to be a rich source of vitamins, minerals, and antioxidants, making them a potential phytomedicine (Kamisah et al., 2013). They are particularly abundant in polyphenols, phytosterols, and flavonoids, which contribute to their health-promoting effects.

Parkia speciosa Hassk has been used for centuries in traditional medicine to treat various ailments, including diabetes, hypertension, inflammation, and gastrointestinal disorders. It is rich in bioactive compounds such as alkaloids, flavonoids, phenolic compounds, and saponins, which contribute to its pharmacological activities. The potential therapeutic benefits of *Parkia speciosa* Hassk have attracted the attention of researchers, leading to an increasing number of studies exploring its pharmacological properties (Azemi et al., 2022).

While *Parkia speciosa* Hassk offers numerous health benefits, but its consumption in its raw form may not be convenient or palatable for everyone. To

enhance its usability and accessibility, the development of *Parkia speciosa* Hassk chewable tablets present an innovative solution. Chewable tablets are a popular dosage form, especially for individuals who have difficulty swallowing conventional tablets or capsules (Dahiya et al., 2015).

However, limited research has been conducted on the development and evaluation of *Parkia speciosa* Hassk chewable tablets. Therefore, there is a significant knowledge gap regarding their physical, nutritional, and mechanical properties, as well as the impact of various formulation parameters on the quality of these tablets. Addressing this gap is crucial to optimize the experimental conditions employed in the formulation process and ensure that the resulting chewable tablets are of high quality and meet the standard parameters.

The present research aims to bridge this gap by conducting a comprehensive study on the development and evaluation of *Parkia speciosa* Hassk chewable tablets. The research will focus on analysing the physical and nutritional properties of *Parkia speciosa* Hassk after drying treatment, evaluating the effects of compaction pressure, different types of excipients used, and the excipient composition on the tablet's compaction behaviour, evaluating the effects of these parameters on the tablet's mechanical characteristics, and selecting the best formulation through chewing techniques that meets the standard parameters (tensile strength, friability and dissolution time).

The findings of this research will contribute to the scientific knowledge of *Parkia speciosa* Hassk and its formulation into chewable tablets. Furthermore, it will provide understandings of the impact of compaction pressure, excipients, and excipient composition on the tablet's properties, helping to get the best formulation process. Additionally, the utilization of chewing techniques will aid in selecting the most appropriate formulation that meets the standard parameters, ensuring the quality and efficacy of *Parkia speciosa* Hassk chewable tablets.

Ultimately, the outcomes of this research will have practical applications in the pharmaceutical industries, as well as for consumers seeking alternative and convenient ways to incorporate *Parkia speciosa* Hassk into their daily dietary and medicinal routines (Dahiya et al., 2015).

1.2 Problem statement

The development of *Parkia speciosa* Hassk chewable tablets require a comprehensive understanding of their physical, nutritional, and mechanical properties. Although *Parkia speciosa* Hassk is recognized for its nutritional and medicinal value, there is a lack of research focused specifically on the formulation and characterization of chewable tablets from this plant material. This knowledge gap poses a significant challenge in harnessing the full potential of *Parkia speciosa* Hassk for pharmaceutical and nutraceutical applications (Kamisah et al., 2013).

One of the key challenges in utilizing the medicinal properties of *Parkia speciosa* Hassk is developing appropriate dosage forms that can deliver its active constituents effectively. Chewable tablets have gained considerable popularity as a convenient and patient-friendly dosage form, especially for individuals who have difficulty swallowing conventional tablets or capsules. Chewable tablets offer advantages such as ease of administration, enhanced patient compliance, and improved bioavailability (Dahiya et al., 2015).

Furthermore, the impact of formulation variables, such as compaction pressure, excipient type, and excipient composition, on the compaction and frictional and mechanical characteristics of *Parkia speciosa* Hassk chewable tablets during compaction remain unexplored. Without a thorough understanding of these factors, it is difficult to achieve an acceptable standard of tablet quality, manufacturability, and performance.

This research thesis aims to develop and assess chewable tablets derived from *Parkia speciosa* Hassk with a primary focus on their mechanical properties. The study will focus on enhancing the formulation of these chewable tablets to ensure the quality with various excipients and formulation techniques explored to achieve desired characteristics, in terms of its strength, friability, and disintegration time.

Therefore, the problem to be addressed in this research is the lack of comprehensive knowledge on the nutritional and mechanical properties of *Parkia speciosa* Hassk chewable tablets, as well as the influence of formulation variables on tablet characteristics. The findings of this research thesis will contribute to the

development of a dosage form of *Parkia speciosa* Hassk, providing a convenient and effective means of delivering its therapeutic benefits. The results will provide an understanding of the formulation and evaluation of chewable tablets containing natural bioactive compounds, expanding the possibilities for the utilization of traditional medicinal plants in modern healthcare practices (Azemi et al., 2022; Kamisah et al., 2013)

Overall, this research thesis aims to bridge the gap between traditional medicine and modern pharmaceutical technology, paving the way for the development of innovative and accessible solutions for a range of health-related needs. To achieve this goal, it is essential to conduct a comprehensive exploration of the compaction and frictional properties, mechanical attributes, choice of excipients, and chewable modelling for *Parkia speciosa* Hassk chewable tablets. These parameters hold substantial significance, as they are fundamental in ensuring the tablets' performance, safety, and satisfaction of end-users. Thus, understanding and refining these elements are essential to addressing the research problem statement.

1.3 Research objectives

This research thesis aims to investigate the various aspects related to the development of *Parkia speciosa* Hassk chewable tablets. The primary objectives of this study are as follows:

1. To analyse the physical and nutritional properties of *Parkia speciosa* Hassk after drying treatment

2. To evaluate the effects of compaction pressure, different types of excipients used, and the excipient composition in the *Parkia speciosa* Hassk chewable tablet formulation on its compaction behaviour
3. To evaluate the effects of compaction pressure, different types of excipients used, and the excipient composition upon the *Parkia speciosa* Hassk chewable tablet mechanical characteristics
4. To select the best formulation of *Parkia speciosa* Hassk chewable tablets based on chewing efficiency

This research thesis intends to contribute to the development of *Parkia speciosa* Hassk chewable tablets with enhanced physical, nutritional, and mechanical properties. The findings of this study may have significant implications in the pharmaceutical industry, offering a convenient dosage form for the delivery of *Parkia speciosa* Hassk bioactive compounds.

1.4 Scope of study

This thesis explores the development and mechanical attributes of *Parkia speciosa* Hassk chewable tablets, with a comprehensive disclaimer regarding the study's limitations. The drying technique is constrained by instrument availability, with a preference for a vacuum condition. The tablet-making process is considered inefficient because it uses a universal testing machine (Instron) to directly compact each tablet despite the availability of more efficient tablet-making technologies. Time and labour constraints are significant factors, necessitating individual compaction and precise testing 24 hours later. The Instron machine's

load capacity constraints (3kN to 9kN) impact variations in tablet compression pressure. All tests employ the same batch of dried *Parkia speciosa* Hassk powder stored in a desiccator under controlled conditions, though subsequent nutritional and antioxidant analyses reveal a loss in accuracy and alterations in colour, smell, and taste. Despite these changes, the consistent moisture content and absence of mold support the continued use. In considering the economic aspects that haven't been studied extensively, it is important to note that the use of a universal testing machine for tablet compaction, despite its inefficiency, may have cost implications. The preference for a vacuum condition in the drying technique, while advantageous, might also involve additional expenses. Moreover, the time and labor constraints in the tablet-making process can impact overall production efficiency and costs.

The study focuses on mechanical attributes, specifically related to factors such as tablet hardness, friability, and other physical properties. Instead of utilizing statistical methods for optimizing the variables affecting these mechanical attributes, this study has opted not to use such approaches. While statistical methods are commonly employed to analyze data, identify patterns, and optimize conditions in research, this study encountered challenges in this regard. The data were either scattered or characterized by a limited range of tablet variation, making the application of statistical optimization techniques challenging or impractical. The research findings suggest the need for further exploration in health and medical backgrounds for a more comprehensive understanding of *Parkia speciosa* Hassk in nutritional, therapeutic, and pharmaceutical contexts.

1.5 Significance of the study

The significance of this research is highlighted by the substantial production and consumption of *Parkia speciosa* Hassk, particularly in Malaysia. According to the official Herbs & Spices Statistics by the National Department of Agriculture (DOA), the production of *petai* in Malaysia in 2020 amounted to 4,874.11 metric tons, with Sarawak alone accounting for more than half of this production (2,809.49 metric tons). This statistic reflects the prominent position of *petai* among other major herbs cultivated in the region. Notably, *petai* outperforms herbs such as *jering, mas cotek*, great morinda, *misai kucing, pandan, pegaga*, lemongrass, and *ulam raja*, securing its place as the most produced herb. Pandan and lemongrass follow closely behind in the second and third positions, respectively (Department of Agriculture Putrajaya, 2021).

Furthermore, it is worth mentioning that the availability of *Parkia speciosa* Hassk is seasonal, with its peak harvest period occurring from August to January. This temporal aspect adds another layer of significance to the development of suitable dosage forms that can extend the shelf life and preserve the nutritional and medicinal properties of the stinky beans beyond their seasonal availability.

Parkia speciosa Hassk is well-known for its rich nutritional content despite having a bad taste and smell. It is hypothesised that formulating it into chewable tablets will offer a convenient and accessible option for individuals to incorporate the health benefits of *Parkia speciosa* Hassk into their daily routines. This can contribute to improving nutrition and overall well-being, especially for individuals

who may have difficulty consuming it in its raw form. The study can also provide a useful understanding into the formulation process, compaction pressure, and excipient composition, leading to the development of high-quality chewable tablets of *Parkia speciosa* Hassk which will be beneficial for the pharmaceutical industry.

Understanding the impact of compaction pressure, excipients, and excipient composition on the physical, nutritional, and mechanical properties of *Parkia speciosa* Hassk chewable tablets are crucial for improving the formulation process. The study can provide an understanding of the parameters that lead to the desired tablet characteristics, such as good compaction behaviour and desirable mechanical properties. This knowledge can be applied to develop not just *Parkia speciosa* Hassk chewable tablets but also other chewable tablets with similar properties, enhancing formulation strategies in the pharmaceutical industry.

The utilization of chewing techniques to select the best formulation that meets standard parameters is an innovative approach. By integrating chewing techniques into the evaluation process, the study can provide a standardized and systematic method for assessing the quality of chewable tablets whilst contributing to the advancement of chewable tablet development and evaluation methodologies.

Overall, the study's significance lies in its potential to promote the utilization of *Parkia speciosa* Hassk as a nutritional and medicinal resource, optimize the

formulation process for chewable tablets, and contribute to the advancement of pharmaceutical industries. It also offers insight into the integration of chewing techniques in tablet evaluation, paving the way for future research in this area.

CHAPTER 2

LITERATURE REVIEW

2.1 *Parkia speciosa Hassk* and its physical and nutritional properties

"*Parkia speciosa* Hassk" and "*Parkia speciosa*" are taxonomical references to the same plant species. The addition of "Hassk" in "*Parkia speciosa* Hassk" is a reference to the botanist, Christian Hasskarl, who originally described this species. It is common in biological nomenclature for a species to be attributed to the person who first scientifically documented or described it. Figure 2.1 shows the closeup view of *Parkia speciosa* Hassk tree and its pods.

Figure 2.1: *Parkia speciosa* Hassk tree and its pods' closeup view (Source: Harimurti, 2014)

2.1.1 Overview of *Parkia speciosa* Hassk

Parkia speciosa Hassk, commonly known as the "bitter bean" or "stink bean". *Parkia speciosa* Hassk is also known as *petai* in Malaysia, Singapore, and Indonesia (Izzah Ahmad et al., 2019), 'sator' or 'sataw' in Thailand (Tangkanakul

et al., 2005), ‘u’pang’ in Philippines (Hayati Azizul, 2019) and ‘yongchak’ in India (Lim, 2015). It is a remarkable tropical tree native to Southeast Asia countries: Malaysia, Indonesia, Thailand, and Philippines (Izzah Ahmad et al., 2019). This unique plant species is renowned for its unusual, pungent-smelling edible beans, which are considered a delicacy in various cuisines across the region. The stink bean tree is not only valued for its culinary uses but also for its diverse applications in traditional medicine and its ecological significance.

Parkia speciosa Hassk belongs to the Parkia genus and family Fabaceae (Lim, 2015), which includes over 30 species of flowering plants distributed throughout tropical Africa and Asia. It thrives in lowland rainforests, riverbanks, and mangrove areas (Zaini & Mustaffa, 2017). The tree’s pinnate leaves and distinctive flowers, which resemble pom-poms, make it easily recognizable in its native habitat. The morphological characteristics of this plant show that it typically reaches a height of 15 to 40 metres. It has bipinnate leaves, oblong leaflets that are 31 to 38 pairs per pinna (42 pairs), and pinnae that are 14 to 24 pairs. The glands are situated between the junction of the 1-3 distal pairs of leaflets and the junction of the 1-4 distal pair of pinnae, above the base of the petiole. The flowers are head inflorescences. The tree produces twisted pods that contain horizontal seeds. Phloem and xylem tetrads alternate to form the roots. The stem epidermis has a single layer of cuticle covering it. Around the pith are six to seven collateral bundles that make up the vascular bundles. The secondary xylem has uniseriate xylem rays and unicellular pores, which have two to three cells each. Only the lower epidermis of the leaf contains the normal form of stomata. Two layers of

palisade mesophyll and four to six layers of spongy mesophyll are present (Zaini & Mustaffa, 2017)

One of the most notable features of *Parkia speciosa* Hassk is its seeds. About 15-18 seeds grow in elongated pods and contain a unique combination of volatile organic compounds that give them their characteristic smell (Zaini & Mustaffa, 2017). The pods are long and flat, resembling green beans, and can grow to be about 30-50 centimetres in length (Matgomokol K., 1980). Although the odour can be off-putting to some, it is beloved by those who appreciate the rich and savoury taste it imparts to dishes. The beans are used in various traditional recipes, such as sambal *petai*, and are prized for their umami flavour. They are often cooked with shrimp paste, chilies, and other ingredients to create a delightful, aromatic dish.

Apart from its culinary uses, *Parkia speciosa* Hassk has been utilized in traditional medicine for centuries. Various parts of the tree, including the leaves, roots, and bark, are believed to have medicinal properties. In traditional Southeast Asian medicine, the plant is used to treat ailments such as diabetes, hypertension, and digestive issues. While the scientific evidence supporting these claims is limited, the potential health benefits of *Parkia speciosa* Hassk are an area of ongoing research.

Additionally, the stink bean tree is not only important in human culture but also plays a vital ecological role in the tropical ecosystems where it grows. The tree's broad canopy provides shade and habitat for numerous species of wildlife. Its

nectar-rich flowers attract pollinators, including bees and butterflies, which contribute to the pollination of other plants in the ecosystem. The nitrogen-fixing properties of *Parkia speciosa* Hassk also benefit the surrounding vegetation by enriching the soil with essential nutrients.

Despite its ecological importance and cultural significance, *Parkia speciosa* Hassk faces various conservation challenges. Habitat loss and deforestation, driven by urbanization and agricultural expansion, threaten the species and its natural habitat. Furthermore, overharvesting of the beans for culinary use can negatively impact local populations of the tree. Conservation efforts, including protected areas and sustainable harvesting practices, are essential to ensure the long-term survival of this remarkable plant species.

2.1.2 Phytochemical composition of *Parkia speciosa* Hassk

Parkia speciosa Hassk possesses a rich phytochemical profile that contributes to its potential medicinal properties and ecological importance. The phytochemicals found in this remarkable tropical tree offer a numerous of benefits, making it a subject of interest for researchers in fields ranging from traditional medicine to biodiversity conservation.

Through phytochemical screening, pharmacologically active compounds were found mainly in the seeds of *Parkia speciosa* Hassk. Almost all parts of the plant revealed the presence of phenolic compounds (Aisha et al., 2012; Tangkanakul et al., 2005). They contain antioxidants like flavonoids and polyphenols, guarding against oxidative stress and reducing the risk of chronic diseases. The presence

of phytonutrients, such as saponins and tannins, adds to their allure by potentially offering anti-inflammatory and anti-cancer properties. Moreover, these beans are a calorie-conscious choice, making them an ideal component for those seeking weight management. Some of the key phytochemicals found in different parts of the tree are summarized in Table 2.1 (Chhikara et al., 2018).

Table 2.1: Health benefits of bioactive compounds in *Parkia speciosa* Hassk

Plant part	Component	Condition	Mechanism	Impact on health
Pod and seed	Flavonoids	Free radical scavenger	Scavenging and chelating activity	Antioxidative effects
Pods	Phenolics	Free radical scavenger	FRAP, TEAC, and DPPH assay	Antioxidative effects, impede genetic mutation and carcinogenesis
Empty pods	Methanolic extracts	Atherosclerosis, hypertension	Plasma nitric oxide loss prevention and reduction of vascular resistance	Lowers blood pressure and heart oxygen demand
Seeds	Lectins	Cancer	Incorporation of thymidine into human DNA	Anti-proliferative effect and effective nitrite trapping
Seeds	Protein extract	Laxative effect	Contraction of duodenum	Blood glucose level reduction
Seeds	Chloroform extract	Hypoglycaemic activity	United actions of β-sitosterol and stigmasterol	Blood glucose level reduction

The phytochemicals in *Parkia speciosa Hassk* includes:

1. Alkaloids

The seeds of *Parkia speciosa* Hassk contain alkaloids, which are known to have a wide range of biological activities (Chhikara et al., 2018). These compounds may contribute to the tree's medicinal potential, although further research is needed to explore their specific effects.

2. Flavonoids

Parkia speciosa Hassk is rich in various flavonoids, which are believed to play a role in protecting the tree against oxidative stress and may have health benefits including antioxidant, hepatoprotective, anti-inflammatory, antifungal, anti-diabetic effects (Tapas et al., 2008) as well as a lower chance of developing hypertension, hyperbilirubinemia, gastric lesions brought on by stress, hyperhomocysteinemia, cancer, and atherosclerosis (Zaini & Mustaffa, 2017). Flavonoids can scavenge superoxide and inhibit xanthine oxidase. Because they lower the levels of uric acid and superoxide in human tissues, they may therefore be a promising treatment for several diseases and disorders that affect humans, including ischemia and gout (Cos et al., 2000). The seeds have 20.3 mg RE/g DW of total flavonoid content (Zaini & Mustaffa, 2017) and the pod methanolic extract has 5.28 mg of flavonoid content (Ko et al., 2014). Their mode of action is based on scavenging or chelating mechanisms (Table 2.1). Flavonoids from *Parkia speciosa* Hassk seed extract, including luteolin, myricetin, kaempferol, and apigenin, were detected.

3. Terpenoids

Terpenoids are another class of phytochemicals present in *Parkia speciosa* Hassk These compounds are known for their potential antimicrobial and anti-inflammatory properties and are found in various parts of the tree except for the leaves (Liliwirianis, 2011). *Parkia speciosa* Hassk's primary non-fatty acid constituents were determined to be 3.42% β-stigmasterol, 2.29% campesterol, and 2.18% stigmasterol (Salman et al., 2006).

4. Phenolic compounds

Phenolic compounds are abundant in *Parkia speciosa* Hassk These compounds are known for their antioxidant properties and their potential role in traditional medicine for various health conditions. Polyphenolic chemicals, which are responsible for the synthesis of secondary metabolites during proper development, are found in plants (Stahl & Sies, 2003). Tryptophan, tyrosine, and proteins are the main building blocks to produce polyphenolic chemicals. Compacted forms of polyphenols include phenolic acid derivatives and flavonoid glycosides. The main polyphenolic components of stinky bean seeds include quercetin, ellagic acid, gallic acid, and catechin (Ko et al., 2014). It was concluded that the main antioxidant components are found in phenolic compounds. The phenolics' mode of action involves oxidation termination, whereby they scavenge free radicals and produce stabilised radicals (Rice-Evans et al., 1997).

5. Saponins

Saponins are glycosides that can be found in the seeds and other parts of the tree. They are known for their foaming properties and may have potential health benefits, such as anti-inflammatory and immune-boosting effects.

6. Amino acids

Amino acids, the building blocks of proteins, are also found in *Parkia speciosa* Hassk Some of these amino acids play essential roles in human health and nutrition.

2.1.3 Nutritional value of *Parkia speciosa* Hassk

Parkia speciosa Hassk, commonly known as the stink bean or *petai*, is revered for its distinct aroma and culinary uses and a valuable source of nutrition. This tropical tree, native to Southeast Asia, offers a unique combination of essential nutrients and bioactive compounds that contribute to its significance as a dietary staple and a potential source of health benefits. Table 2.2 summarizes the nutritional information of *Parkia speciosa* Hassk

Table 2.2: Nutritional information of *Parkia speciosa* Hassk

Component	Amount (per 100g edible portion)
Ash (g)	1.2-4.6
Protein (g)	6.0-27.5
Fat (g)	1.6-13.3
Carbohydrate (g)	13.2-52.9

Table 2.3: Continued

Crude fiber (g)	**1.7-2.0**
Energy (kcal)	91.0-441.5
Calcium (mg)	108.0-265.1
Iron (mg)	2.2-2.7
Phosphorus (mg)	115.0
Potassium (mg)	341.0
Magnesium (mg)	29.0
Copper (ppm)	36.7
Zinc (ppm)	8.2
Vitamin C (mg)	19.3
α-Tocopherol (mg)	4.15
Thiamin (mg)	0.28

Parkia speciosa Hassk seeds have a high concentration of carbohydrates (68.3–68.7%), proteins (6–27.5%), fibres (1.7–2.0%), lipids (1.6–13.3%), and minerals (0.5–0.8%) (Kamisah et al., 2013). *Parkia speciosa* Hassk seeds are an excellent source of plant-based protein, with approximately 6-27.5% protein by weight, making them an invaluable addition to vegetarian and vegan diets. These seeds are also rich in dietary fiber, promoting digestive health and blood sugar regulation. Furthermore, they are a source of essential vitamins like vitamin C, vitamin A, thiamine (B1), riboflavin (B2), and niacin (B3), all of which contribute to overall well-being. Petai seeds boast an impressive mineral profile, including potassium for blood pressure regulation and heart health, as well as significant amounts of phosphorus, magnesium, and iron. For every 100 g of the edible section of the plant, *Parkia speciosa* Hassk contains an abundance of minerals,

including calcium (108–265.1 mg), magnesium (29 mg), potassium (341 mg), phosphorous (115 mg), and iron (2.2–2.7 mg) (Kamisah et al., 2013).

The nutritional richness of *Parkia speciosa* Hassk seeds have contributed to their role as a dietary staple in the region, and they are often included in various traditional dishes, such as curries, salads, and stir-fries. In addition to their culinary value, the potential health benefits associated with their consumption have garnered the attention of researchers and health enthusiasts alike.

2.1.4 Effects of drying treatment on *Parkia speciosa* Hassk

Drying treatment plays a fundamental role in preserving and enhancing the storability quality of *Parkia speciosa* Hassk The drying process has a substantial impact on the aroma and flavour of *Parkia speciosa* Hassk beans.

Another advantage of the drying process is it removes moisture from the beans, inhibiting the growth of microorganisms and enzymes that can cause spoilage. This extends the shelf life of the beans, allowing them to be stored for an extended period without losing their nutritional value.

Drying process that are commonly applied on food products include:

1. Traditional drying methods

There are several methods of drying, and the choice of method can significantly impact the final product. Some of the traditional drying methods include sun drying, air drying, and smoke drying. These methods have been used for generations and are deeply embedded in the culinary traditions of Southeast Asia.

2. Convection drying

Technology has advanced to the point that a variety of drying methods are now available. Because it is so inexpensive, convection drying is one of the most popular drying techniques. In order to remove moisture from the food item, heated air is continuously circulated within the oven and used as a drying medium (Rahman & Perera, 2007). Hot air circulates at a speed of 0.5-5 m/s through food that is typically prepared to a thickness of 2-4 cm and arranged on a tray. The rate of dehydration may be excessive if the temperature rises beyond 70°C. The technique's modest maintenance cost and comparatively low cost of production and dehydrated goods having a longer shelf life through convective drying make it popular for manufacturing dried fruits and vegetables.

However, due to the irregular air flows, it is doubtful that the heating will be consistent throughout the oven. Furthermore, convection drying may have a detrimental impact on the food items' bioactive, nutritional, and sensory attributes. The first enzymatic breakdown of antioxidant molecules and the thermal degradation of phytochemical compounds have been linked to losses in phytochemical content and antioxidant capabilities (Chan et al., 2009; Chong & Lim, 2012). According to Gümüşay et al. (2015), fresh, vacuum-dried, and freeze-dried tomatoes and gingers had considerably higher total phenolic content (TPC) and ascorbic acid contents than tomatoes and gingers that had been convection oven-dried. Fruits such as kiwifruits (Maskan, 2001) and Mexican serviceberry fruit (Melgar-Almanza et al., 2015) are examined for their drying properties. Apart from the aspects of dehydration, the rehydration properties of carrot (Abbaspour-

Gilandeh et al., 2020), pumpkin (Rojas et al., 2020), and green pea (Kaveh & Abbaspour-Gilandeh, 2020) were documented.

3. Freeze drying and vacuum drying

Freeze drying is a dehydration process by the sublimation of a frozen product. The operations at low temperatures reduce microbial growth or impede a spoilage reaction to preserve the final product (Ratti, 2001). This method is suitable for foods that are sensitive to heat loss and nutritional value, giving rise to high-quality products with good recovery properties. The drying characteristics of cherry (Sanchez et al., 2015), stink bean powder (How & Siow, 2020), stink bean (Akbar et al., 2019) and acorn (Ahmadi et al., 2019) were investigated. In addition to dehydration, the rehydration of strawberry (Huang et al., 2009) and mussel (Tribuzi & Laurindo, 2016) were also characterized. Freeze drying is widely used to produce commercial rehydrated foods but has a high cost compared to conventional drying (Figiel & Michalska, 2016; Monteiro et al., 2015). The suitability of freeze-drying for producing stink bean powder has been supported by research conducted by How & Siow (2020), which determined that freeze-drying under vacuum conditions results in enhanced antioxidant capacities, a lighter color, and increased DPPH radical-scavenging activity and ferric reducing antioxidant power (FIC) ability. Furthermore, Karam et al. (2016) found that freeze-dried samples exhibited the lightest color compared to other drying methods, due to the absence of enzymatic and non-enzymatic browning reactions. Enzymatic browning is caused by the reaction between reducing sugars and amino acids, while non-enzymatic browning involves the degradation

of phenolic compounds and color pigments. Based on these findings, freeze-drying under vacuum conditions is concluded to be the preferred method for producing Parkia speciosa Hassk powder, as it maintains antioxidant capacities, preserves light color, and prevents undesirable browning reactions during storage.

While freeze drying involves freezing food material under reduced pressure conditions so that ice crystals can be sublimated into vapour, vacuum drying allows food products to be dried under reduced pressure conditions so that water can evaporate below boiling temperature (Rahman & Perera, 2007). Both vacuum and freeze drying make it possible to dry food ingredients without exposing them to high temperatures or high oxygen levels, making them ideal for goods that are readily oxidised and heat labile. Thus, it is possible to reduce the amount of heat-induced oxidation and degradation of bioactive compounds and nutraceutical components (Strumłło & Adamiec, 1996). According to a study, vacuum-oven-dried rosehips retain more phenolic components (25.1%) and antioxidant capacity (57.5%) than other methods (Quintero Ruiz et al., 2014). Research has also demonstrated that fresh and freeze-dried tomatoes did not significantly differ in terms of TPC or ascorbic acid concentration (Chang et al., 2006; Gümüşay et al., 2015). Furthermore, according to Karam et al., (2016), most of the time, the ascorbic acid retention level in freeze-dried products was reported to be greater than 60%.

4. Microwave vacuum drying

Due to its great energy efficiency, a notable reduction in drying time, and excellent quality of dehydrated products, microwave vacuum drying has drawn a lot of attention (Reyes et al., 2006). The resulting food products have excellent nutritional and sensory properties and minimal shrinking because microwave waves are used to spin the water molecules and create heat in a low-pressure environment (Barreto et al., 2019). Numerous goods, including blueberries (Zielinska & Michalska, 2016), pumpkin (Nawirska et al., 2009), herbs (Calín-Sánchez et al., 2015), potato cubes (Bondaruk et al., 2007), carrots (Nahimana & Zhang, 2011), and apples (Ando et al., 2019), have already been subjected to microwave hoover drying. Rice (Phukasmas & Songsermpong, 2019), turnip seed (Reyes et al., 2006), green bell pepper (V. Kumar et al., 2019), squid shreds (Pankyamma et al., 2019), shiitake mushroom (Kantrong et al., 2014), bird nest (Nisoa & Kerdtongmee, 2016), pumpkin (Monteiro et al., 2018), and button mushroom (Pei et al., 2014) were among the items dried using microwave vacuum drying and examined on their rehydration properties. Although microwave vacuum drying is a novel technique, its full potential for the commercial manufacturing of rehydrated foods has not yet been realised.

In conclusion, the investigation into *Parkia speciosa* Hassk has yielded valuable information on its physical properties and nutritional composition. This knowledge lays the groundwork for further explorations of this botanical entity for diverse applications, ranging from traditional medicine to nutritional supplementation.

2.2 Tablet formulation development and evaluation

Parkia speciosa Hassk is renowned for its high nutritional value. Formulating it into chewable tablets provides an accessible means for individuals to incorporate its overall health and nutritional benefits into their daily routine, especially for those who may encounter challenges in consuming it in its raw state. Tablets stand out as the most prevalent dosage form due to their simplicity in administration, cost-effectiveness in production, and aesthetic appeal (Pawar et al., 2014). They offer several advantages, including ease of administration, accurate dosing, and stability. Developing a tablet formulation is a complex and multidisciplinary process that requires a deep understanding of various scientific principles. The principles of tablet formulation development are crucial in ensuring the safety, efficacy, and quality of pharmaceutical tablets.

2.2.1 Physical and flowability properties of powder for tablet compaction

The formulation and compaction of tablets in the pharmaceutical and nutraceutical manufacturing centre are fundamentally dependent upon the physical and flowability properties of powders. The key properties are moisture content, powder density which includes both bulk and tapped, the powder particle size distribution, the angle of repose and finally the Carr's index and Hausner ratio (Deb et al., 2021; Kalman, 2021; Shah et al., 2008).

Moisture content emerges as a critical variable significantly affecting powder flow and compressibility. Studies by Faqih et al., (2007) and Wallack & King (1988) demonstrate that excessive moisture content can lead to agglomeration and decreased powder flow. Conversely, an optimal moisture level is essential for promoting interparticle bonding during compaction, thereby contributing to tablet hardness and integrity.

Powder density, encompassing both bulk density and tapped density, stands as a key determinant of powder flowability. Research by Amidon et al. (2009) and Patel et al. (2006) highlights the interaction between powder density and tablet mechanical properties. Achieving a delicate balance between bulk and tapped density is essential to attain optimal powder flow and compaction efficiency.

Particle size distribution emerges as a pivotal factor in powder behaviour. Studies conducted by Amidon et al. (2009) emphasise the importance of a narrow particle size distribution, revealing a positive correlation with improved tablet uniformity and dissolution rates. Fine powders with higher surface area and cohesiveness exhibit distinctive flow properties during compaction.

The angle of repose stands out as a fundamental parameter reflective of a powder's ability to flow freely. Research by Beakawi Al-Hashemi & Baghabra Al-Amoudi (2018), Bodhmage (2006), Kalman (2021), and Moravkar et al. (2020) accentuates the significance of a low angle of repose in ensuring optimal powder flow during compaction. Powders characterized by lower angles of repose

showcase enhanced interparticle movement and reduced friction, thereby contributing to improved tablet compression.

Finally, Carr's index and Hausner's ratio serve as widely employed indices to assess powder compressibility and flowability. Tan et al. (2015) highlight the importance of a lower Carr's Index as indicative of improved powder flow properties. Likewise, a Hausner Ratio close to 1 suggests good flowability, providing a crucial understanding of powder behavior during tablet compaction and aiding in the formulation of tablets with consistent quality (Dai et al., 2019; Mohan, 2012).

Table 2.4 shows the range of values that identifies the flow character of a powder through the depiction by the angle of repose, Carr's index and Hausner ratio (Maddiboyina et al., 2020).

Table 2.4: Flow character of powder for compaction of tablets

Flow character	Angle of repose	Carr's index	Hausner's ratio
Excellent	<20	<10	1.00-1.11
Good	20-30	11-15	1.12-1.18
Fair	-	16-20	1.19-1.25
Passable	30-34	21-25	1.26-1.34
Poor	-	26-31	1.35-1.45
Very Poor	>35	32-37	1.46-1.59

In conclusion, a deep understanding of the physical and flowability properties of powders is imperative for the successful compaction of tablet manufacturing. The interdependence of factors such as particle size distribution, angle of repose,

compressibility indices, moisture content, and powder density highlights the complexity of powder behaviour during compaction.

2.2.2 Principles of tablet formulation development

Tablet formulation development involves a series of steps that encompass the selection of active ingredients and excipients, and the development of a robust manufacturing process. The final product should meet the required specifications, including uniformity of content, disintegration, dissolution, and stability. This literature review section explores the fundamental principles underlying tablet formulation development, highlighting key considerations in the design and manufacturing of tablets.

2.2.2.1 Active ingredients selection

The first step in tablet formulation development is selecting the appropriate active ingredients. The pre-formulation stage involves the characterization of several aspects of the active ingredients including solubility, dissolution, permeability, polymorph/salt screening, stability (solid state and solution-state), ionization properties, particle size distribution, active ingredient-excipient compatibilities etc. (Chrzanowski, 2008).

2.2.2.2 Excipient selection

Excipients are inactive substances that facilitate the manufacture, stability, administration, delivery of the active ingredients, and other functionalities to the dosage form. Excipients are used to improve processing such as improving

powder flow (Abe et al., 2009; Gstirner & Pick, 1967), powder compactibility (Nokhodchi et al., 2007; Vromans & Lerk, 1988), enhance aesthetics (e.g. identification, branding etc. (Derganc et al., 2003)), optimize product performance (e.g. modified active ingredients-release (Dave et al., 2012; Williams et al., 2002)), and to facilitate patient compliance (e.g. taste masking (Cantor et al., 2015; Kharb et al., 2014; Li et al., 2014; Yuan et al., 2014)). They may constitute anywhere from 1 to 99 % of the total formulation mass. The selection of excipients is based on their compatibility with the active ingredients and their role in achieving the desired tablet characteristics**.**

There is a chance that the active ingredients and one or more excipients in a formulation will interact chemically or physically because of their close contact. Any such interactions could have a detrimental effect on the pharmaceutical and nutrceutical product's performance, stability, or physical characteristics (Crowley & Martini, 2001; McDaid et al., 2003). Selecting the right excipients is essential to preventing these side effects and to help create a strong, efficient formulation (Makai et al., 2008; Tiţa et al., 2011; Tita et al., 2013). Consequently, screening for excipient-active ingredient compatibility is acknowledged as a crucial step in the formulation creation process for a logical choice of excipients.

2.2.2.3 Formulation design

The formulation design involves determining the ratio of the active ingredients to excipients, which affects the tablet's physical and chemical properties. This includes considerations for tablet hardness, disintegration time, and dissolution

rate. Formulation development often requires an extensive series of experiments to optimize these parameters (Shah et al., 2014).

2.2.2.4 Granulation and compression

The next step involves the preparation of granules, which are then compressed into tablets. Granulation improves the flowability and compressibility of the formulation. During compression, the selection of appropriate equipment and compression forces is essential to ensure uniform tablet weight and hardness.

2.2.2.5 Quality by Design (QbD)

Quality by Design is a systematic approach to product development and manufacturing that focuses on understanding the sources of variability and ensuring quality throughout the product's life cycle. QbD principles are integral to tablet formulation development, as they help identify critical process parameters and attributes that influence tablet quality.

2.2.2.6 Tablet coating

In some cases, tablets are coated to improve taste, appearance, or active ingredients release characteristics. The choice of coating material, coating process, and coating thickness must be carefully considered to achieve the desired tablet properties. Examples of coating materials include talc, microcrystalline cellulose, glyceryl monostearate, stearic acid and magnesium stearate.

2.2.2.7 Analytical methods

Developing tablet formulations requires the use of various analytical methods to assess the quality and performance of the tablets. Techniques such as HPLC, UV spectroscopy, and dissolution testing are employed to ensure the tablets meet the required specifications.

2.2.2.8 Regulatory compliance

The development of tablet formulations is subject to strict regulatory guidelines and quality standards to ensure safety and efficacy. The manufacture of traditional medicines and health supplements depends on the quality of starting materials, manufacturing processes, and the facilities and personnel involved (Ya'akob et al., 2018). The cultivation of medicinal plants should adhere to Good Agricultural and Collection Practices (GACP) established by the World Health Organization (WHO) to ensure the quality of raw materials (WHO, 2003). Consistency, safety, and efficacy of the products are maintained through adherence to Good Manufacturing Practices (GMP). These guidelines mandate standardized procedures, robust quality control measures, and proper documentation throughout the manufacturing process (He et al., 2015). In Malaysia, the Ministry of Health oversees traditional and complementary medicines, the Ministry of Agriculture and Food Industries supervises herb management, and the Malaysian National Pharmaceutical Regulatory Agency (NPRA) regulates traditional and complementary medicine products (Park et al., 2022).

2.2.2.9 Scale-up and technology transfer

Transitioning from laboratory-scale formulation development to commercial manufacturing is a critical aspect of tablet development. The principles and methods used in the laboratory must be scaled up and transferred to larger production facilities without compromising product quality.

2.2.3 Excipients in tablet formulation

Tablets are one of the most common and convenient oral dosage forms for delivering pharmaceutical or neutraceutical active ingredients to patients. While the active ingredient is the key component responsible for the therapeutic effect, tablets would not be feasible without the use of excipients.

Excipients are essential in tablet formulation, playing a pivotal role in ensuring the success of pharmaceutical products. Researchers and formulators are exploring new excipients with enhanced functionality, such as improved taste-masking agents and disintegrants. Additionally, the development of excipients that are compatible with innovative active ingredient delivery systems, like orally disintegrating tablets and controlled-release formulations, is gaining attention. The selection of excipients is a delicate balance of compatibility, functionality, and regulatory compliance.

Excipients, often referred to as “inert” or “inactive” ingredients, are far from inconsequential. They are indispensable in pharmaceutical tablet formulation for several reasons:

1. Dosage form: Excipients provide the necessary bulk and consistency to create a tablet that can be conveniently handled, packaged, and administered.
2. Active ingredients stability: Some active ingredients are chemically unstable on their own. Excipients can protect them from degradation by acting as stabilizers or antioxidants.

2 Disintegration and dissolution: Excipients can influence the rate at which a tablet disintegrates and releases the active ingredients, directly impacting bioavailability and therapeutic effectiveness.

3 Taste masking: Excipients can be used to mask the unpleasant taste of certain active ingredients, improving patient compliance.

4 Colour, shape, and identification: Excipients can be used to shape the tablet and provide the necessary pigmentation for identification and branding.

The factors that influence this selection of the right excipients include:

1. Compatibility: Excipients must be compatible with the active ingredients, ensuring stability and efficacy.

2. Regulatory compliance: Excipients should comply with regulatory standards and guidelines to ensure safety and quality.

3. Functional role: Each excipient must serve a specific function in the tablet, whether it's binding, disintegration, or taste masking.

4. Physical and chemical properties: Excipient properties, such as particle size, density, and hygroscopicity, can impact tablet formulation and performance.

5. Cost: The cost of excipients can significantly affect the overall cost of tablet production.

6. Patient acceptance: Excipients used for taste masking or colouring should be acceptable to patients and not trigger allergies or sensitivities.

2.2.4 Role of excipients in tablet properties

Excipients come in various forms and serve multiple functions in tablet formulation.

Table 2.5 summarises the excipients used in tablet forms (Augsburger & Hoag, 2017; Pharmpedia, 2011).

Table 2.5: Excipients used in tablet forms

Excipient category	Function in formulation	Working principle	Example
Diluents	Fillers	Make up the bulk of solid unit dosage forms when active ingredients itself is inadequate to produce the bulk	Lactose, directly compressible starches, dextrose, sorbitol, microcrystalline cellulose, dibasic calcium phosphate dehydrate

Table 2.6: Continued

Binders and Adhesives	Impart cohesive qualities to powdered material	Improves free flow qualities by formulation of granules to desired hardness and size	Acacia, gelatin, starch paste, polyvinyl pyrrolidone, glucose, carboxylmethyl cellulose, providone.
Lubricants	Reduce inter-particular friction, prevent adhesion of tablet material to the surface of die and punches facilitate easy ejection of tablet from die cavity and improve the rate of flow tablet granulation	Interpose a film of low shear strength that interface between the tabletting mass and die wall	Talc, stearic acid, magnesium stearate, calcium stearate, polyethylene glycol, surfactants, vegetable oil.
Glidants	Improve flow characteristics of powder mixture	Added in dry state prior compression, it reduces friction between particles	Colloidal silicone dioxide (carbosil), asbestos free starch, corn starch.
Disintegrants	Facilitate breakup or disintegration after administration	Function by drawing water into the tablet, swelling it and causing the tablet to burst apart	Starches, clays, cellulose, cross linked to polymers, modified starches such as primogel and explotab, veegum HV.
Superdisintegrants	Improve disintegrant efficacy resulting in decreased use levels when compared to traditional disintegrants		Crosscarmalose, cross providone, sodium starch glycolate.
Coloring agents	Impart aesthetic appearance to dosage form, disguising off colour of active ingredients, product identification	-	FD and C, D and C dyes and lakes.
Flavors	Limited to chewable tablets/tablets intended to dissolve in mouth	Mask unpleasant taste	Spray dried and other flavours, syrups, etc.
Sweeteners	Impart sweet taste to the formulation; use is limited to chewable tablets		Mannitol, saccharin, etc.

Table 2.7: Continued

Sorbents	Moisture proofing	Limits the fluid sorbing, taking up of liquid or gas either by adsorption or absorption in dry state	Silica gel, activated carbon, clay, etc.
Coating materials	Protect tablet ingredients from deterioration by moisture, help swallowing unpleasant tasting tablet		Hydroxypropylmethyl cellulose (HPMC), synthetic polymers, shellac, corn protein zein, polysaccharides, capsules coated by gelatin, povidone, ethyl cellulose.
Plasticizers	For soft gelatin capsule preparation, gelatin-based suppositories, film-coated tablets, etc	Produce elasticity and flexibility to the coating materials in case of tablets, determine hardness of capsule shell in case of soft gelatin capsule and impart softness and resilience to suppositories	Castor oil, diacetylated monoglycerides, polyethylene glycol, polypropylene glycol, triacetin.

2.2.5 Types of excipients used in chewable tablets

Chewable tablets are a versatile and patient-friendly pharmaceutical dosage form that offers a convenient and palatable way to administer medications, particularly for those who may have difficulty swallowing traditional oral tablets or capsules and for those who dislike swallowing (Patil et al., 2012). While the active ingredient is the core therapeutic component, the success of chewable tablets largely depends on the careful selection and incorporation of excipients. These excipients

serve various essential roles, from enhancing the taste and texture to ensuring the tablet's stability and disintegration properties (Dahiya et al., 2015).

Table **2.8** shows the list of excipients used in the formulation of chewable tablets (Bhatt et al., 2021).

Table 2.8: Excipients used in the formulation of chewable tablets

Excipients	Functions	Examples
Diluents	Diluents are fillers used to make the required bulk of tablet	Lactose, microcrystalline cellulose, mannitol, etc.
Binders	Binders are used to impart cohesive qualities to powdered materials	Gelatin, glucose, acacia, ethyl cellulose, hydroxypropylmethyl cellulose, starch, etc.
Superdisintegrants	They facilitate tablet breaking when it comes in contact with water in the oral cavity/GIT	Croscaarmellose sodium, crospovisone, sodium starch glycolate, starch, etc.
Lubricants	These are added to prevent the adhesion of tablet material to the surface of dies and punches to reduce interparticulate friction	Magnesium stearate, talc, paraffin, sodium lauryl sulphate, etc.
Glidants	These are added to improve the flow characteristics of the powder mixture. Glidant minimize the friction between particles	Colloidal silicon dioxide (aerosil), corn starch, talc, etc.
Sweeteners	These are added to produce a palatable dosage form	Sucrose, saccharin, aspartame, etc.
Flavours	These are added to improve the taste of the dosage form	Peppermint, vanilla, orange, cinnamon, mango, cherry, menthol, etc.
Colours	These are added for a better appearance of the dosage form	Sunset yellow (supra), ferricoxide, etc.

2.2.6 Lactose-based excipient composition in chewable tablet formulation

Lactose is a disaccharide consisting of β-D-galactose β-(1-4)-linked to D-glucose (Portnoy & Barbano, 2021). It is the most important carbohydrate in mammalian milk and is obtained from bovine milk or whey through ultrafiltration and evaporation (Fox et al., 2015). The application of lactose in pharmaceuticals began in the early 19th century, with its commercialization starting in the late 1800s. The rapid development of the dairy processing industry led to the innovative idea of converting byproducts from cheese production into valuable commercial grades of lactose (Hebbink & Dickhoff, 2019).

Lactose plays a crucial role in the manufacture of tablets, being used in direct compression, wet granulation, and dry granulation tableting. The primary advantage of direct compression technology lies in its simplicity, requiring less equipment, fewer preparation steps, lower cost, and reduced energy consumption. In this study, direct compression technology was utilized to produce *Parkia speciosa* Hassk chewable tablets.

There are various types of lactose-based excipients used in tablet formulation. They are categorized by their granulation method and suitability for direct compression. The granulation types include milled, agglomerated, spray-dried, anhydrous, and co-processed. Under milled lactose, the products are GranuLac® 70, 80, 140, 200, 230, and SorboLac® 400. Agglomerated lactose products include Tabletose® 70, 80, and 100. Spray-dried lactose products include FlowLac® 90 and 100. The anhydrous category features DuraLac® H, while co-

processed lactose includes Cellactose® 80, MicroceLac® 100, StarLac®, CombiLac®, a sustained release option, RetaLac®, Reta M®, and a lactose-free variant. This classification helps in selecting the appropriate lactose-based excipient based on the desired granulation and compression requirements for tablet production (https://www.pharmaceutical-networking.com/meggle-lactose-based-excipients-for-direct-compression-dc-tableting/). In the present study, three types of lactose-based excipients were used: Tablettose® 80, FlowLac® 90, and MicroceLac® 100 (Chapter 3, Section 3.5.1).

In conclusion, the multi-layered considerations, and meticulous procedures integral to creating pharmaceutical tablets are required for the tablet formulation development and evaluation. The understandings gained allow for advancements in active ingredients delivery systems, emphasizing the importance of precision and quality control in the development of effective and reliable chewable tablet formulations.

2.3 Compaction behaviour and frictional characteristics

Comprehending the influence of compaction pressure, excipients, and excipient composition on the physical, nutritional, and mechanical attributes of *Parkia speciosa* Hassk chewable tablets are essential for enhancing the formulation process. The compaction behavior of pharmaceutical powders is a critical aspect of tablet manufacturing. Various factors contribute to the compaction behavior of materials, ranging from particle properties to manufacturing conditions. Other than the relationship between particle shape, size that emerged as a crucial

determinant of compaction characteristics, it also involves the rearrangement of powder particles under pressure, leading to the formation of a cohesive tablet (Dai et al., 2019; Patel et al., 2006) . This highlights the influence of compaction pressure on compaction behavior and frictional characteristics.

2.3.1 Compaction behaviour during tablet compaction

Compaction behaviour such as the plastic deformation reflected in the calculated plastic work under the force-displacement profile in the loading-unloading stages of the compaction process influences the final tablet's mechanical integrity (Shamsudin et al., 2014). The final tablet's mechanical integrity is important to ensure that the formed tablet can withstand the subsequent processing and handling throughout its cycle before consumption by the end user. The ease of pushing or extruding the tablet from the die cavity is a crucial measure of the die wall friction between the tablet and the die wall. Low die wall friction, and consequently low maximum ejection forces, are favored in the compaction process to minimize wear and reduce the required work (Abe et al., 2009).

Figure 2.2 illustrates a typical force-displacement profile for the compaction process, as described by Ragnarsson and Sjögren (1985). This profile is essential for understanding the relationship between the applied force and the resulting displacement during tablet formation, providing insights into the material behavior and compaction efficiency. Elastic work (Area C in Figure 2.2) refers to the energy required to deform a material elastically, meaning that it can return to its original shape after the applied force is removed. Plastic work (Area B in Figure 2.2), on

the other hand, involves the energy required to permanently deform a material, causing it to change shape even after the force is removed.

The influence of various factors on the elastic and plastic work during compaction has been studied in different contexts. For example, in the study by Vu et al. (2020), the compaction of granular materials made of elastic particles was investigated, and the influence of the coefficient of friction between the particles on the macroscopic and micro-structural behaviors of the system was discussed (Vu et al., 2020). Another study by An et al. (2021) proposed a viscoelastic-plastic dynamic compaction deformation formula for rockfill materials and analysed the effects of the number of roller passes and vibration frequency on the compaction process.

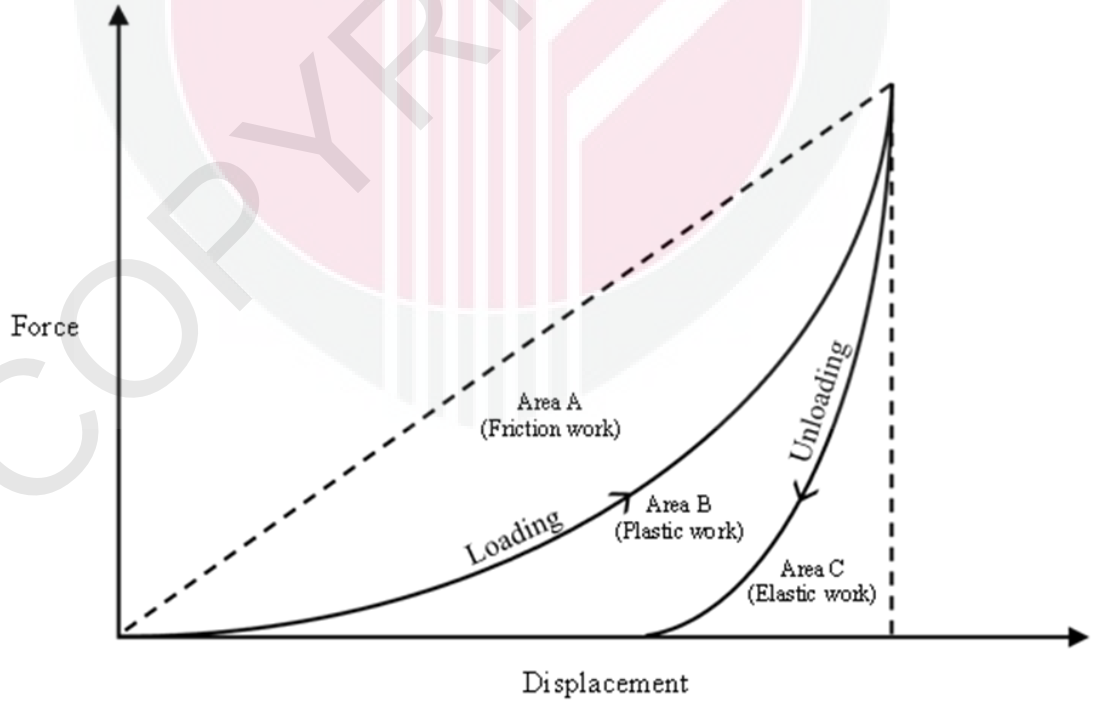

Figure 2.2: Typical representation of a force-displacement profile for compaction process (Source: Ragnarsson & Sjögren, 1985)

To further quantify the compaction process, the work-energy principle can be applied, which breaks down the total work done during compaction into its elastic and plastic components. The total work W_{total} performed during compaction is a combination of the elastic work $W_{elastic}$, where the material deforms but returns to its original shape, and the plastic work $W_{plastic}$, where permanent deformation occurs. This relationship is mathematically expressed as:

$$W_{total} = W_{elastic} + W_{plastic} \quad (2.1)$$

Where $W_{elastic}$ and $W_{plastic}$, are defined as the integrals of their respective force-displacement curves during the elastic and plastic deformation phases respectively, over the maximum displacement during compaction d_{max}.

$$W_{elastic} = \int_0^{d_{max}} F_{elastic}(d)dd \quad (2.2)$$

$$W_{plastic} = \int_0^{d_{max}} F_{plastic}(d)dd \quad (2.3)$$

2.3.2 Frictional characteristics during tablet ejection

Frictional characteristics refer to the interaction between particles in a granular material and their resistance to relative motion. Frictional characteristics during tablet ejection play a crucial role in pharmaceutical manufacturing, affecting tablet uniformity and the overall manufacturing efficiency. Studies by Abu-Khalil (1999) have investigated the impact of lubricants and glidants on inter-particulate friction,

demonstrating their significance in minimizing die-wall friction and improving tablet quality. The ability to control and optimize frictional behaviour is vital for ensuring uniform tablet production and consistent therapeutic efficacy.

The frictional behaviour during tablet ejection, specifically the ejection pressure and work, is influenced by various factors. The tablet ejection force is mainly governed by tablet diameter and thickness, compact-die wall friction coefficient, and residual die wall stress upon ejection (Mukri et al., 2021). The presence of less lubricant at the tablet-die wall interface due to the shorter time available for migration of lubricant can increase the ejection force (Uzondu et al., 2018). Croscarmellose sodium, an example for lubricant, increased tablet elastic recovery and lowered tablet ejection work, tensile strength, and dissolution time (Mohd Rosidi et al., 2021).

Researchers (Jamar et al., 2020; Ragnarsson & Sjögren, 1985; Yusof et al., 2010) employed various experimental methods to investigate frictional characteristics during tablet ejection. One common approach is the use of force-displacement profiles obtained during tablet compaction tests. Figure 2.3 shows a typical force-displacement profile obtained during tablet compaction test. These profiles offer an understanding of the punch's resistance as it compresses the powder blend. By analysing these profiles, researchers can gain a better understanding of the frictional behaviour and optimize compaction conditions. Another method involves using sensors to measure the forces acting on the tablet press components during compaction. By monitoring the forces, researchers can assess the impact of

friction on the compaction process and identify opportunities for friction reduction (Jamar et al., 2020; Ragnarsson & Sjögren, 1985; Yusof et al., 2010).

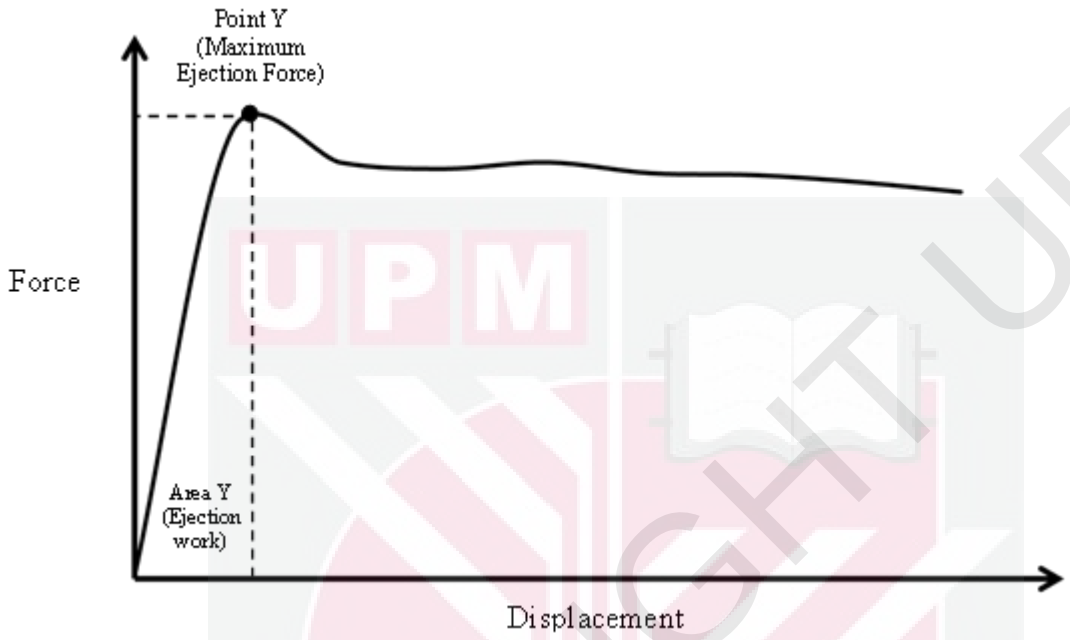

Figure 2.3: Typical force-displacement profile during ejection
(Source: Ragnarsson & Sjögren, 1985)

Frictional characteristics during tablet compaction have several critical implications for pharmaceutical manufacturing:

1. Quality control: Understanding and controlling friction during tablet compaction is essential for maintaining consistent tablet quality. Reducing frictional variation helps in achieving uniform tablet weight and hardness, ensuring that each tablet contains the correct amount of active ingredient.

2. Tooling design: Tooling components, such as punches and dies, play a vital role in determining frictional behaviour. Manufacturers can design tooling with

appropriate surface coatings and texturing to minimize friction, leading to improved tablet production efficiency.

3. Optimization of compaction parameters: The knowledge of frictional characteristics allows manufacturers to optimize compaction pressure, speed, and dwell time to achieve the desired tablet properties. By reducing friction, they can reduce the risk of tablet defects, such as capping and lamination.

4. Scale-up: Understanding frictional behaviour is crucial when scaling up tablet production from laboratory to industrial scale. Maintaining consistent frictional characteristics is vital to ensure that tablet quality is maintained during large-scale production.

Uzondu et al. (2018) mentioned that the properties of the granular material being compressed significantly affect frictional characteristics. Factors such as particle size, shape, surface roughness, and cohesiveness can influence interparticle interactions and, subsequently, friction. Smoother and more spherical particles tend to reduce friction, while irregularly shaped or rough particles can lead to increased friction.

Other than that, lubricants and glidants are commonly added to tablet formulations to reduce friction and improve the flow of powders. Lubricants, such as magnesium stearate, reduce friction between particles and the tablet press components, facilitating smooth compaction. Glidants, like colloidal silicon dioxide, enhance powder flow, minimizing interparticle friction. The type and

concentration of lubricants and glidants can significantly affect frictional characteristics (Abu-Khalil, 1999; Jamar et al., 2020).

On toolings, optimizing surface coatings and texturing is crucial for minimizing friction during tablet compaction. Additionally, the alignment and parallelism of tooling components play a key role in influencing frictional behaviour. The speed at which tablet compaction occurs is also critical, since higher speeds often lead to increased friction due to rapid compression, while slower speeds allow for more gradual compaction, reducing frictional resistance (Cunningham et al., 2004).

The moisture content of the granular material is a crucial consideration, acting as a binding agent that increases both interparticle adhesion and friction. Simultaneously, compaction pressure emerges as a pivotal factor influencing friction. While an increase in pressure typically results in greater friction due to enhanced interparticle forces, it is imperative to strike a balance. Avoiding over-compression is essential to prevent the formation of excessively hard tablets, which could exacerbate friction-related issues (Vu et al., 2020; Yusof et al., 2010).

2.3.3 Influence of compaction pressure on compaction behaviour and frictional characteristics

Compaction pressure, often expressed in terms of stress or pressure applied to the granular material during compaction, is a fundamental parameter in compaction processes. In tablet manufacturing, compaction pressure plays a crucial role in determining tablet properties such as hardness, friability, disintegration time, and dissolution rate.

Compaction pressure significantly influences the compaction behavior of powders during tablet formation. Studies have demonstrated that an increase in compaction pressure generally leads to greater particle rearrangement and interparticle forces (Cunningham et al., 2004; Liu & DeLo, 2001). This heightened pressure results in enhanced powder densification, contributing to the formation of tablets with increased hardness.

In the context of frictional characteristics, higher compaction pressures result in greater interparticle forces and, consequently, increased the frictional resistance during tablet ejection. The cohesive forces between powder particles become more pronounced, impacting the ease with which the tablet separates from the tooling. Conversely, lower compaction pressures reduce the intensity of these interactions, resulting in decreased friction (Yusof et al., 2010).

2.3.3.1 Effects on tablet properties

The quality and performance of tablets depend on various factors, including the compaction process. In tablet manufacturing, compaction pressure plays a pivotal role in determining tablet properties such as hardness, friability, disintegration time, and dissolution rate (Audu-Peter & Ibrahim, 2014). Understanding the relationship between compaction pressure and these tablet properties is essential for pharmaceutical and neutraceutical researchers and manufacturers to produce high-quality tablets that meet the desired performance and efficacy standards. Careful consideration of compaction pressure is crucial in optimizing tablet

formulations for specific active ingredients and therapeutic outcomes, ensuring patient or user safety and satisfaction.

Figure **2.4** illustrates the relationship between compression pressure, mechanical strength, and release properties of tablets, as proposed by Adeleye (2019). The schematic provides a visual representation of the dynamic relationship shaping key aspects of tablet formulation and performance.

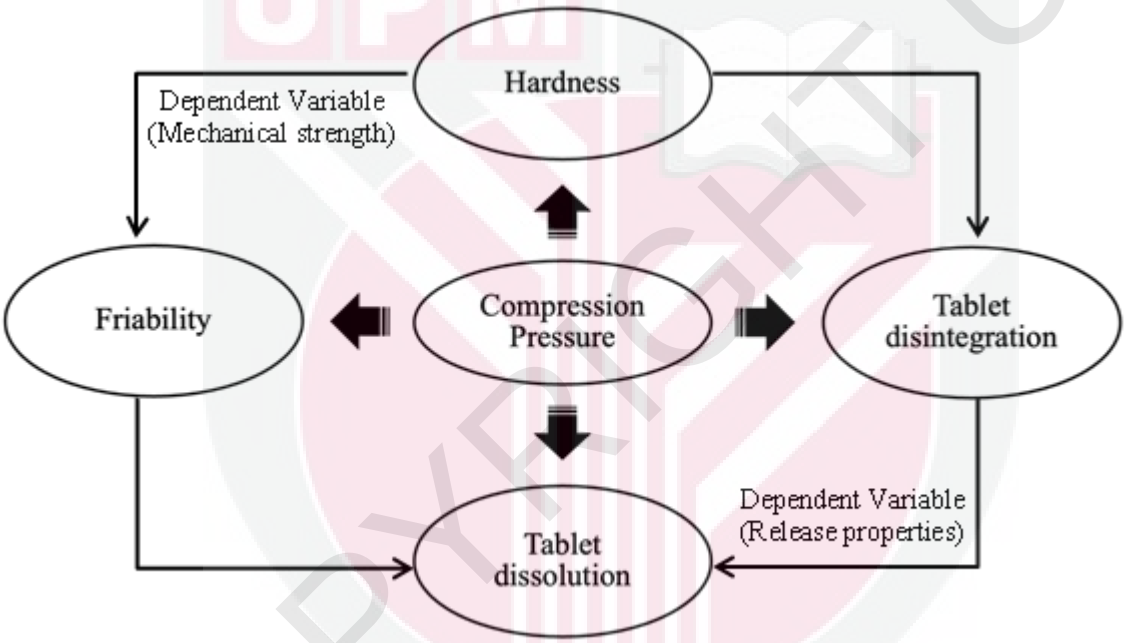

Figure 2.4: Schematic representation of the relationship between compression pressure, mechanical strength and release properties of the tablet (Source: Adeleye, 2019)

The influence that compaction characteristics and frictional properties has on tablet mechanical properties includes:

1. Tablet hardness

Tablet hardness or breaking strength is a measure of tablet strength. It is the force required to break a tablet from which tensile strength is determined. It assesses how strong a tablet must be to withstand breakage, crumbling or chipping under the conditions of storage, transportation, and handling (Odeku & Itiola, 2003). It generally depends on the type and concentration of binder in a formulation (Adeleye et al., 2015; Mulani et al., 2011), tablet height to diameter ratio and compression force (Haresh et al 2011; Adeleye et al 2015).

The relationship between compaction pressure and tablet hardness is often described as a linear or exponential function. Adequate tablet hardness is crucial to ensure the tablet's integrity throughout its shelf-life and patient use. However, excessive compaction pressure may lead to overly hard tablets that are difficult to disintegrate or dissolve. Therefore, it is important to strike a balance between achieving the desired hardness and avoiding over-compression.

2. Tablet friability

Tablet friability is a measure of the resistance of tablets to fracture. The test is generally used to assess the ability of tablets to withstand shock and abrasion, which will unavoidably be encountered during manufacturing, packaging, transportation, and handling (Khar, 2013). A high level of tablet friability is undesirable as it may lead to a loss of tablet mass and, consequently, dosing inaccuracies. Compaction pressure plays a significant role in tablet friability. Increased compaction pressure often results in reduced friability, as the tablet particles adhere more tightly due to increased interparticle bonding. Controlling

tablet friability is essential, as overly fragile tablets may not meet the pharmaceutical industry's quality standards. By adjusting the compaction pressure, it is possible to achieve the desired balance between tablet hardness and friability.

3. Tablet disintegration time

Tablet disintegration time is the first step towards tablet dissolution (Adeleye et al., 2019) and is a crucial parameter for active ingredients release. Disintegration time is defined as the time taken for a tablet to break down into smaller particles when exposed to a liquid medium. The disintegration time of tablets usually depends on formulation factors such as the nature, type and amount of active ingredients and the excipients used (internal variables), as well as on the actual tablet manufacturing conditions such as compression force, speed of compression and environmental conditions of the room where the compression is taking place (external variables) (Adeleye et al., 2019).

Often, disintegration time increases exponentially with an increase in compression pressure. Tablets made with high compression pressure exhibit low porosity with strong inter-particulate bond, thereby increasing the time required for penetration of water into the tablet, thus increasing the disintegration time (Adeleye et al., 2019). In tablets made with low compression pressure, there is large porosity, and the bond is weak, thereby decreasing the time required for penetration of water into the tablet, thus decreasing the disintegration time. (Mistry et al., 2014) reported that binder concentration has a direct relationship

with hardness and disintegration and an inverse relationship with friability. As the concentration of the binder increases, the hardness and disintegration times also increases, while the friability decreases.

Controlling disintegration time is essential to ensure that the active ingredient is released and absorbed in a timely and predictable manner. Therefore, the formulations must be carefully considered to achieve the desired disintegration profile for a given tablet formulation.

4. Tablet dissolution rate

Dissolution is a multistep process by which a solid active ingredient goes into solution in a solvent. This process involves the release of active ingredient molecules from the tablet surface with the formation of hydrated molecules at the solid-liquid interface, and the mass transport of the active ingredients molecules from the interphase to the bulk solution (Wang & Flanagan, 1999).

Dissolution is an important condition for the bioavailability of active ingredients. Tablet dissolution rate is the most important factor determining its absorption; it is the rate-limiting step in many formulations (Sharma et al., 2018). It is the rate at which the active ingredient dissolves in a liquid medium and becomes available for absorption by the body. Therefore, dissolution time indicates the time needed for the active ingredient to be absorbed and to induce a therapeutic effect.

Compaction pressure affects the tablet dissolution rate by influencing the tablet's internal structure, porosity, and surface area. Higher compaction pressures lead

to denser tablets with reduced porosity and surface area. As a result, tablets compressed at higher pressures tend to have slower dissolution rates. Conversely, tablets compressed at lower pressures exhibit faster dissolution. The choice of compaction pressure is essential in achieving the desired active ingredients release profile. The formulation needs to balance the tablet's mechanical properties, disintegration time, and dissolution rate to ensure that the active ingredient is delivered effectively.

2.3.3.2 Optimizing compaction pressure

Achieving the desired frictional characteristics during tablet compaction is essential for pharmaceutical manufacturers to maintain tablet quality and production efficiency. Optimizing compaction pressure involves striking a balance between the benefits and drawbacks associated with different pressure levels (Zhou et al., 2020).

Manufacturers must carefully control compaction pressure to ensure consistent tablet quality. Monitoring tablet weight uniformity, hardness, and the occurrence of defects like capping and lamination is vital for quality assurance.

Proper tooling design and maintenance also play a critical role in managing friction. Well-designed and well-maintained tooling components can reduce friction, enhance tablet quality, and extend the lifespan of tablet press equipment.

Pharmaceutical manufacturers should also consider various factors, including compaction speed, to optimize compaction pressure. This involves a thorough

understanding of the frictional characteristics under different conditions and the ability to adapt the compaction process accordingly.

In conclusion, the investigation of compaction behavior and frictional characteristics has unraveled the dynamics shaping tablet formation. This knowledge not only contributes to the refinement of tablet manufacturing processes but also emphasizes the significance of improving frictional forces for achieving consistent and desirable tablet properties.

2.4 Evaluation of mechanical characteristics in chewable tablets

Chewable tablets serve as a popular dosage form, particularly for pediatric and geriatric populations, as well as individuals with swallowing difficulties. The mechanical characteristics of these tablets play a crucial role in ensuring their efficacy, patient compliance, and overall therapeutic outcomes. This literature review aims to provide a comprehensive overview of the methods and techniques employed for evaluating the mechanical properties of chewable tablets.

Figure 2.5 summarizes the mechanical evaluation of chewable tablets including various physical and chemical parameters (Farheen & Bharadwaj, 2014; Fda et al., 2018; Jagdale et al., 2010). In this study the physical evaluation of the mechanical characteristics of *Parkia speciosa* Hassk chewable tablets were performed.

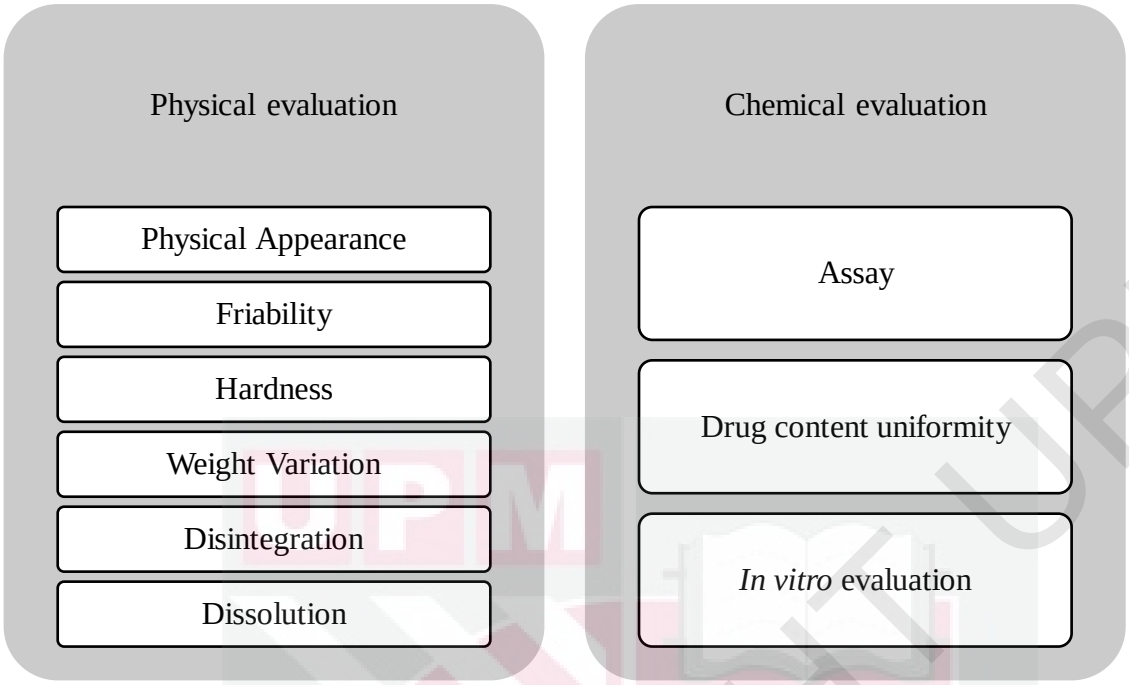

Figure 2.5: Physical and chemical evaluations of chewable tablets

2.4.1 Mechanical characteristics evaluation for tablet

In physical appearance evaluation, chewable tablets are assessed in terms of their size, shape, colour, taste, and odour. Patient acceptance of chewable tablets is significantly influenced by taste. Tastes can be related to active ingredients and additives, particularly sweeteners and flavourings. The tablet's dimensions can regulate its size and condition. Tablets should be uniform in both size and thickness between batches. A vernier calliper is used to measure a tablet's thickness and diameter.

According to the United States Pharmacopeia (USP) weight variation study by Bouin & Wierer (2014), the weight of 20 tablets is regulated by calculating the standard load and comparing the individual tablet load to normal (SahabUddin et

al., 2016). Table 2.6 shows the weight variation limit based on various pharmacopoeias in the United States, British and Indian (Agarwal et al., 2018).

Table 2.9: Weight variation limits as per various pharmacopoeias

USP	Limit	IP/BP
130 mg or less	± 10%	80 mg or less
130-324 mg	± 7.5%	80-250 mg
>324 mg	± 5%	>250 mg

2.4.1.1 Tablet strength and its industrial standard parameter

Chewable tablets should be hard enough to withstand the rigors of manufacturing, packaging, transportation, and distribution, but not so hard as to cause chewing problems. It can be measured by a few parameters and expressed in different units.

Tensile strength, a widely recognized industrial standard parameter, serves as a primary indicator of a tablet's mechanical robustness. This parameter is determined by measuring the breaking force of a tablet (Point X on Figure 2.6), carried out using a universal testing machine that generates the force-displacement profile of the tablet breaking process. Binders, such as microcrystalline cellulose, provide cohesive forces that enhance tensile strength by improving interparticle adhesion. However, excessive binder content can make the tablet brittle, negatively impacting tensile strength. Achieving the right balance between cohesive and adhesive forces is crucial to optimizing tensile strength.

The FDA guidance on chewable tablets recommends a breaking force upper limit of 12 kiloponds (kp), which is 117.68N when converted to the SI unit. As breaking force is dependent on tablet size, larger tablets (of similar composition) will have a higher breaking force. Adhering to this FDA guidance is imperative as it ensures that chewable tablets maintain their structural integrity during critical phases such as manufacturing, handling, and packaging. Tablets exceeding this threshold may be more prone to breakage or deformation, compromising their efficacy and patient compliance (Karalia et al., 2021; Nyamweya, 2020).

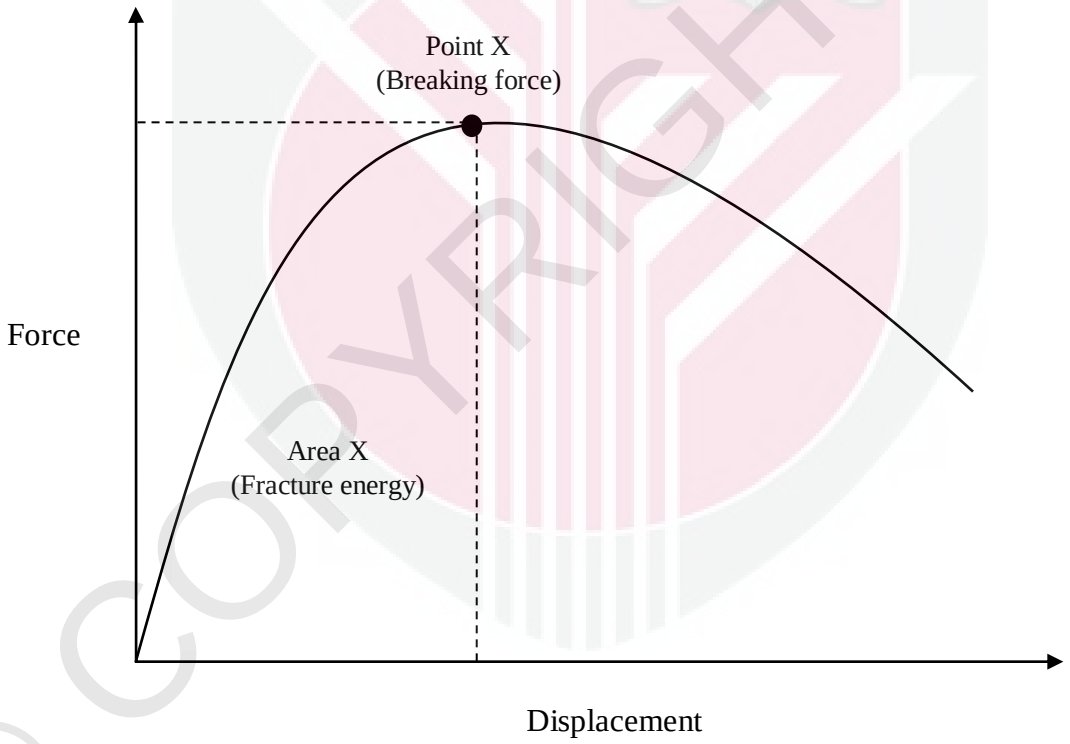

Figure 2.6: Force-displacement curve for evaluation of mechanical strength

Fracture energy is another valuable parameter in tablet strength evaluation. It quantifies the energy required to break a tablet from the area of curve below the breaking force point (Area X in Figure 2.6) and provides understandings into the tablet's resilience against mechanical forces. This parameter contributes additional information about the tablet's ability to withstand stresses beyond just force magnitude.

Friability is a critical factor in evaluating tablet strength as it measures a tablet's resistance to abrasion and impact. The industrial standard for a weight loss limit after being subjected to a 100-rpm rotating friabilator is 1% (Paul & Sun, 2017). This parameter becomes instrumental in ensuring the tablets remain intact during transportation and handling. Tablets with excessive friability may experience more significant wear and tear, potentially leading to issues such as chipping or breakage.

2.4.1.2 Release properties of chewable tablet

The release properties of chewable tablets stand as a critical determinant in achieving the intended therapeutic effects. Two fundamental aspects which are disintegration and dissolution, play important roles in shaping the overall active ingredient release profile and subsequent bioavailability.

Disintegration which is the initial step in the release process, involves the breakdown of the tablet into smaller particles. This is a crucial factor influencing the subsequent active ingredients release kinetics. Swift disintegration is particularly important for chewable tablets, as these formulations are designed for

oral consumption and should readily break down into easily ingestible fragments (Shakur Sheaikh et al., 2018).

Dissolution, the subsequent phase in the release process, measures the rate at which the active ingredients dissolve in gastrointestinal fluids. For chewable tablets, an industrial standard often mandates that the dissolution process should be completed within a specified time, commonly set at less than 1200 seconds (El-Gazayerly et al., 2004). This criterion ensures that the active ingredients are efficiently released and absorbed within a clinically relevant timeframe. Compliance with the specified dissolution time contributes to the predictability and consistency of therapeutic outcomes associated with chewable tablets.

Absorption from chewable tablets depends on the release of the active ingredient from the intact or chewed tablet. *In vitro* dissolution testing of chewable tablets should follow the principles of conventional Immediate Release (IR) tablet dissolution testing. For characterization of products under development, *in vitro* dissolution studies should be performed on intact tablets in at least four media which include water, pH 1.2 aqueous media, pH 4.5 buffered aqueous media and a buffered aqueous medium at pH 6.8 (Antil et al., 2023)

2.4.2 Relationship between excipients and tablet mechanical characteristics

Tablet excipients often account for a large portion of the total tablet mass, and so the excipients will typically influence the mechanical properties of the tablet (Maclean et al., 2022). The effects of excipients on tablet mechanical

characteristics, including tensile strength, fracture energy, friability, and dissolution time, are interconnected and demand a detailed approach to tablet formulation. Excipients like binders, disintegrants, and lubricants play important roles in shaping these properties, and their selection and concentration must be carefully considered to achieve tablets that are robust, durable, and effective. Striking the right balance between these mechanical characteristics is a challenging task for pharmaceutical formulators but is essential for ensuring the quality and efficacy of tablet medications (Jange et al., 2023).

1. Impact of binders:

Binders are critical excipients that provide cohesiveness to tablet formulations. Common binders, such as microcrystalline cellulose and starch, significantly affect tablet hardness and tensile strength. They provide cohesiveness to the tablet by promoting interparticle adhesion. Proper binder selection and concentration are essential for achieving the desired tablet hardness. Inadequate binder content can lead to low hardness, while an excess can result in overly hard and brittle tablets.

2. Role of disintegrants:

Disintegrants, including croscarmellose sodium and crospovidone, facilitate the rapid break-up of tablets upon exposure to moisture in the gastrointestinal tract. While they primarily impact tablet disintegration, their effects on tensile strength and friability should not be underestimated. The presence and concentration of

disintegrants can affect the overall mechanical properties of tablets by influencing tablet porosity and interparticle bonding.

3. Lubricants and their effects:

Lubricants, like magnesium stearate and talc, are essential for reducing friction during tablet compression and preventing sticking to the punches and dies. Their influence on tablet mechanical properties is predominantly seen in terms of tablet friability. Excessive lubricant use can lead to tablets with higher friability, making them prone to chipping or breaking.

4. Impact of fillers:

Fillers, also known as diluents, are used to increase the mass and volume of tablets, making them easier to handle and ensuring consistent tablet dimensions. While they do not directly influence hardness or tensile strength, the choice of filler can indirectly affect mechanical characteristics by altering tablet density and porosity.

Tablets are manufactured through a series of processes that involve mixing, granulation, and compression of active ingredients and excipients (Andrews, 2007). To ensure the production of high-quality tablets, it is necessary to optimize both the formulation and process variables. Traditional trial-and-error methods are insufficient (Bodea & Leucuta, 1997), requiring a shift towards more systematic and efficient strategies using Quality by Design or QbD (Apeji et al., 2022; Singh et al., 2011).

2.4.3 Effects of compaction pressure on tablet mechanical characteristics

Numerous studies have investigated the relationship between compaction pressure and tablet hardness which are the key mechanical properties influencing tablet strength and disintegration (Mitchell et al., 2017; Newton et al., 2011; Osei-Yeboah & Sun, 2015; Persson & Alderborn, 2018; Sinka et al., 2009). Higher compaction pressures generally result in tablets with greater hardness. This positive correlation is often attributed to increased particle rearrangement and reduced porosity, enhancing tablet mechanical integrity. However, there exists a delicate balance, as excessively high compaction pressures may lead to issues such as capping and lamination, compromising tablet quality.

Osei-Yeboah & Sun (2015) discovered the impact of compaction pressure on tablet friability that has been a subject of considerable interest. While increased compaction pressure tends to reduce tablet porosity and improve mechanical strength, it may simultaneously increase tablet friability due to internal stresses. This dichotomy highlights the importance of optimizing compaction pressure to achieve a balance between tablet strength and resistance to abrasion, ensuring the tablets withstand handling and transportation stresses.

The compaction pressure applied during tablet manufacturing significantly affects active ingredients release kinetics. The influence of compaction pressure on disintegration time were explored by Mitchell et al. (2017) a critical factor for chewable tablets. Research suggests that higher compaction pressures often lead to longer disintegration times. This paradoxical relationship is attributed to

increased tablet hardness hindering the disintegration process. Studies by Mitchell et al. (2017) and Zheng et al. (2022) have demonstrated that variations in compaction pressure impact the porosity and surface area of tablets, consequently influencing the rate and extent of active ingredient dissolution. Optimizing compaction pressure becomes essential to strike a balance between mechanical strength and active ingredients release, ensuring a controlled and predictable release profile for the chewable tablet.

In conclusion, through the exploration of the effects of excipients and compaction pressure on tablet mechanical characteristics, it is recognized that there are comprehensive roles these formulation components play in shaping the final product. Table 2.7 summarizes the effect of excipients in various powder mixtures. The knowledge gained not only informs current practices in nutriceutical formulation but also guides future endeavours in tailoring excipient choices for specific tablet requirements.

Table 2.7: Effect of excipients in various powder mixtures

Powder	Authors	Observed effect
Roselle	Shamjuddin et al., 2014	Increased sodium starch glycolate composition in the roselle tablet decreased the tensile strength and dissolution time of tablets but increased the porosity and the elastic recovery of tablets.

Table 2.7: Continued

Palm oil empty fruit bunch	**Radzali et al., 2018**	**Carboxymethyl cellulose (from palm oil empty fruit bunch) tablets exhibited lower plastic work as well as lower mechanical strength and longer disintegration time compared to microcrystalline cellulose tablet**
Lactose-sodium starch glycolate binary powder mixture	Yaakub et al., 2018	The addition of super disintegrant; SSG with lactose and acdisol with lactose; would enhance the mechanical strength of lactose based tablets, especially in the case of acdisol-lactose binary tablets.
Coffee powder	Jamar et al., 2020	The addition of the effervescent agents to the coffee mix tablet decreased the disintegration time but the addition of the lubricant increased the effervescent coffee mix tablet disintegration time.
Mannitol-cocoa powder mixtures	Mukri et al., 2021	The addition of mannitol improved the tablet's strength and shortened the disintegration time.

2.5 Chewing process

The chewing process, or mastication, is a coordinated activity involving mechanical forces and chemical processes whereby food is comminuted by occlusal surfaces and moistened by saliva to create a cohesive bolus of small particles suitable for swallowing (Abe et al., 2011). The mechanical component of masticatory function is the most critical because the cohesive force among food particles and subsequent digestive episodes depend on the particle size (van der Bilt, 2011). Optimal masticatory performance is influenced by intraoral characteristics, such as the number of occlusal pairs, size and shape of teeth, and soft tissue motility (Tei et al., 2005; van der Bilt, 2011) as well as by extraoral determinants, such as skeletal features, articular kinematics, and jaw muscle lines of action (Koolstra, 2003).

When chewing is done voluntarily, most of the process happens automatically, meaning that once mastication starts, minimal conscious effort is needed (S. Mistry & Hamdy, 2008). The central pattern generator produces the fundamental rhythmic activity of masticatory movements (Westberg & Kolta, 2011) and is constantly altered by peripheral inputs in response to variations in food texture and dental conditions (Lund, 2011). Saliva plays a pivotal role in moistening food and beginning enzymatic digestion, contributing to the sensory aspects of eating (Pedersen et al., 2018).

2.5.1 Importance of chewing process in chewable tablets

Chewable tablets are a widely used pharmaceutical dosage form known for their ease of administration and enhanced patient compliance, particularly in children and older adults. The ability to break down food is a skill acquired in early childhood (Le Révérend et al., 2014) which can be compromised under certain medical conditions such as swallowing difficulties (Loret, 2015) at a later stage in life (Devezeaux De Lavergne et al., 2021).

Figure **2.**7 summarizes the food oral processing during the lifespan.

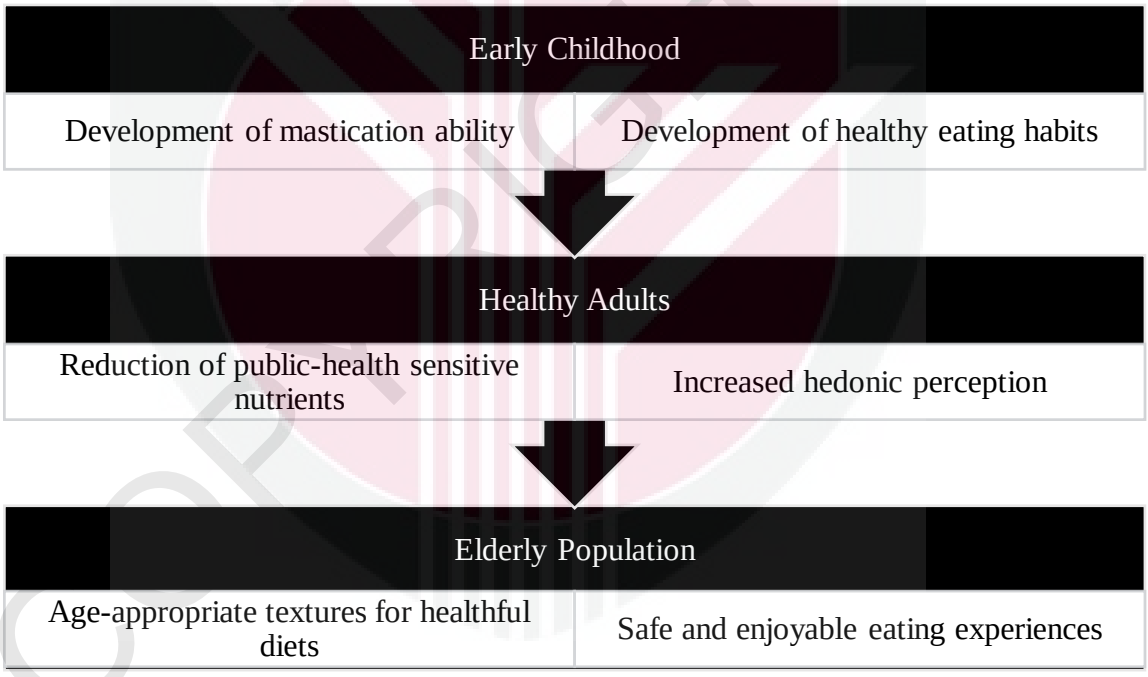

Figure 2.7: Food oral processing during the lifespan
(Source: Devezeaux De Lavergne et al., 2021)

In the context of chewable tablets, the importance of the chewing process becomes evident in several ways. Firstly, it significantly impacts active ingredient release and bioavailability. Chewable tablets are designed to disintegrate and

dissolve in the mouth rapidly, and the efficiency of this process is influenced by how the tablet interacts with the chewing process. Incomplete disintegration can reduce active ingredient release, potentially compromising therapeutic efficacy. Furthermore, the mechanical properties of the tablet, such as tensile strength, fracture energy, and friability, are critical in determining how well a tablet withstands the forces of mastication without compromising its effectiveness (Kuentz et al., 2005; Sun, 2009).

Furthermore, sensory attributes such as taste, texture, and flavor perception are crucial to the acceptance of chewable food products. These attributes are inherently linked to the chewing experience. The enjoyment of taste is influenced by how the food interacts with saliva during chewing (Sun-Waterhouse et al., 2021), and the texture must be appropriate for mastication, finding the right balance between hardness and friability. The effects of processing parameters on the mechanical properties of the food, such as compaction pressure, are particularly significant. Varying compaction pressure can impact plastic and elastic deformation, frictional work, maximum ejection pressure, and ejection work, all of which contribute to the product's overall texture and performance during chewing (Tye et al., 2005; Zou et al., 2019). Palatability and ease of consumption are vital for consumer satisfaction, especially when offering functional foods to children and older adults. A pleasant chewing experience encourages regular consumption, making it an attractive option for these specific age groups.

Chewable tablets are also relevant in paediatric and geriatric contexts, where the ability to chew may vary. Children may have different chewing patterns and abilities compared to adults, necessitating tailored formulations. In the geriatric population, age-related changes in dental health and salivary function can impact the chewing process. Formulations must consider these variations to ensure consistent supplement efficacy and safety.

2.5.2 Chewing modelling

Chewing modelling and the establishment of standard parameters are fundamental to our understanding of the complex biomechanical process of chewing. Researchers have employed various approaches to simulate and study chewing mechanics.

2.5.2.1 Techniques of chewing

Chewing techniques offer valuable insights and methods that can be applied to the development of chewable tablets, providing innovative approaches in the pharmaceutical industry. These techniques include a variety of methods, such as computational simulations, laboratory testing, and sensory evaluations, all of which are crucial in enhancing the formulation and performance of chewable tablets.

Laboratory testing involves experimental studies conducted in controlled environments, replicating the chewing process and its impact on chewable tablets (Brown et al., 2011). These experiments can assess factors like disintegration

time, mechanical resistance, dissolution rate, and taste masking effectiveness. Chewing simulators are also employed to mimic the oral environment, allowing researchers to evaluate how different formulations and excipients affect tablet behavior. However, no existing chewing simulator fully replicates human masticatory movements and forces under the specific humidity and pH conditions of the oral cavity. A simulator that could encompass these characteristics would be instrumental in standardizing trials related to simulated mastication (Soriano-Valero et al., 2020). The findings from these laboratory tests are essential in refining the physical and chemical properties of chewable tablets.

2.5.2.2 Subject with normal occlusal criteria for chewing techniques

Ensuring the accuracy and reliability of chewing techniques necessitates specific inclusion criteria related to normal occlusion and associated factors (How, 2021; How et al., 2021; Proeschel, 2006). The ideal candidate for participation in this study must exhibit a combination of anatomical, physiological, and health-related characteristics to contribute to a comprehensive understanding of the natural chewing process as listed in Table 2.8.

Table 2.8: Inclusion criteria for chewing dynamics study

	Inclusion criteria	Reason
1	Complete set of post-canine teeth (possession of eight premolars and molars)	Ensures accurate modeling of chewing dynamics
2	Absence of pain or discomfort during chewing	Signifies a healthy and functional masticatory system
3	No history of serious jaw injuries	Ensures no underlying structural issues compromising occlusal function
4	No current orthodontic interventions (subjects should not be wearing braces)	Focuses on the natural interaction of teeth
5	No issues with dry mouth or salivary flow	Ensures proper lubrication and bolus formation during chewing
6	No denture wear	Ensures natural tooth interactions in the modeling process
7	Not on medications affecting saliva flow (Excludes medications like oxybutynin or amitriptyline)	Ensures proper lubrication and bolus formation during chewing
8	Absence of mouth disorders, tooth decay, and gum disease	Ensures oral structure integrity and overall health
9	Absence of tooth grinding or excessive clenching	Ensures accurate forces and dynamics during mastication
10	Overall good health	Ensures the well-being of participants
11	Absence of blood-borne infectious diseases	Ensures the safety of both participants and the research team

By meticulously adhering to the above inclusion criteria, the study aims to employ a subject that embodies normal occlusion and associated factors, encouraging a comprehensive and accurate representation of the natural chewing process in the context of modelling.

2.5.3 Utilizing chewing techniques to select the best tablet formulation

Utilizing chewing techniques to select the best tablet formulation is a sophisticated approach that aims to develop the design of chewable tablet formulation by considering the complex and highly individualized process of chewing behaviour. This approach is especially relevant in the development of pharmaceuticals, nutraceuticals, or even confectionery products, where sensory and nutritional outcomes are critical for consumer satisfaction and product efficacy.

Chewing behaviour varies widely among individuals due to a combination of physiological, anatomical, psychological, and behavioural factors. These factors can include gender, age, dental status, saliva flow rate, muscle strength, facial anatomy, personality type, emotion, cognitive processes, and learned patterns. The mechanical properties of the tablet, influenced by the effects of compaction pressure, play a significant role in determining the optimal formulation. High compaction pressure may increase tensile strength and decrease friability, but it could also extend dissolution time, impacting the bioavailability of active ingredients (Fell & Newton, 1970; Podczeck et al., 2006).

It’s important to note that selecting the best tablet formulation using chewing techniques is often an iterative process. Further adjustments may be necessary

based on the feedback and data collected during the testing phase. Incorporating chewing technique efficiency into the evaluation process not only allows for a standardized and systematic method of assessing the quality of *Parkia speciosa* Hassk chewable tablets but also contributes to the progress of development and evaluation methodologies for such tablets. By understanding the interplay between compaction pressure and mechanical properties, researchers can better tailor formulations to ensure optimal performance in real-world chewing conditions (Rowe et al., 2012).

While the current study has provided valuable insights into the development of chewable tablets, particularly those containing Parkia speciosa Hassk, it is important to recognize that there is a noticeable gap in research regarding the use of plant-based ingredients in chewing techniques, particularly in the context of Malaysian products

As we conclude our exploration of the chewing process, it is acknowledged that it is an important part in the efficacy of chewable tablets. The understandings gained contribute to the ongoing efforts in formulating medications that align with the natural processes of mastication, ensuring optimal active ingredients release and absorption.

CHAPTER 3

METHODOLOGY

3.1 Experimental design

Figure 3.1 illustrates the experimental design in this study. The flow is structured based on the four objectives of this research which involved: (1) analysing the physical and nutritional properties, (2) evaluating the effects of compaction pressure, types of excipients, and excipient composition on the tablet's compaction behaviour, (3) assessing the impact of these factors on the tablet's mechanical characteristics, and (4) selecting the best formulation using chewing techniques.

The analysis was divided into two phases: pre-compaction and post-compaction. In the pre-compaction phase, the physical, chemical, and nutritional properties of *Parkia speciosa* Hassk were examined. In the post-compaction phase, the focus shifted to studying the compaction behaviour, mechanical integrity, and chewing efficiency which were later used in selecting the best tablet formulation. The study design section illustrates a clear roadmap of the investigation conducted in this study (Figure 3.1).

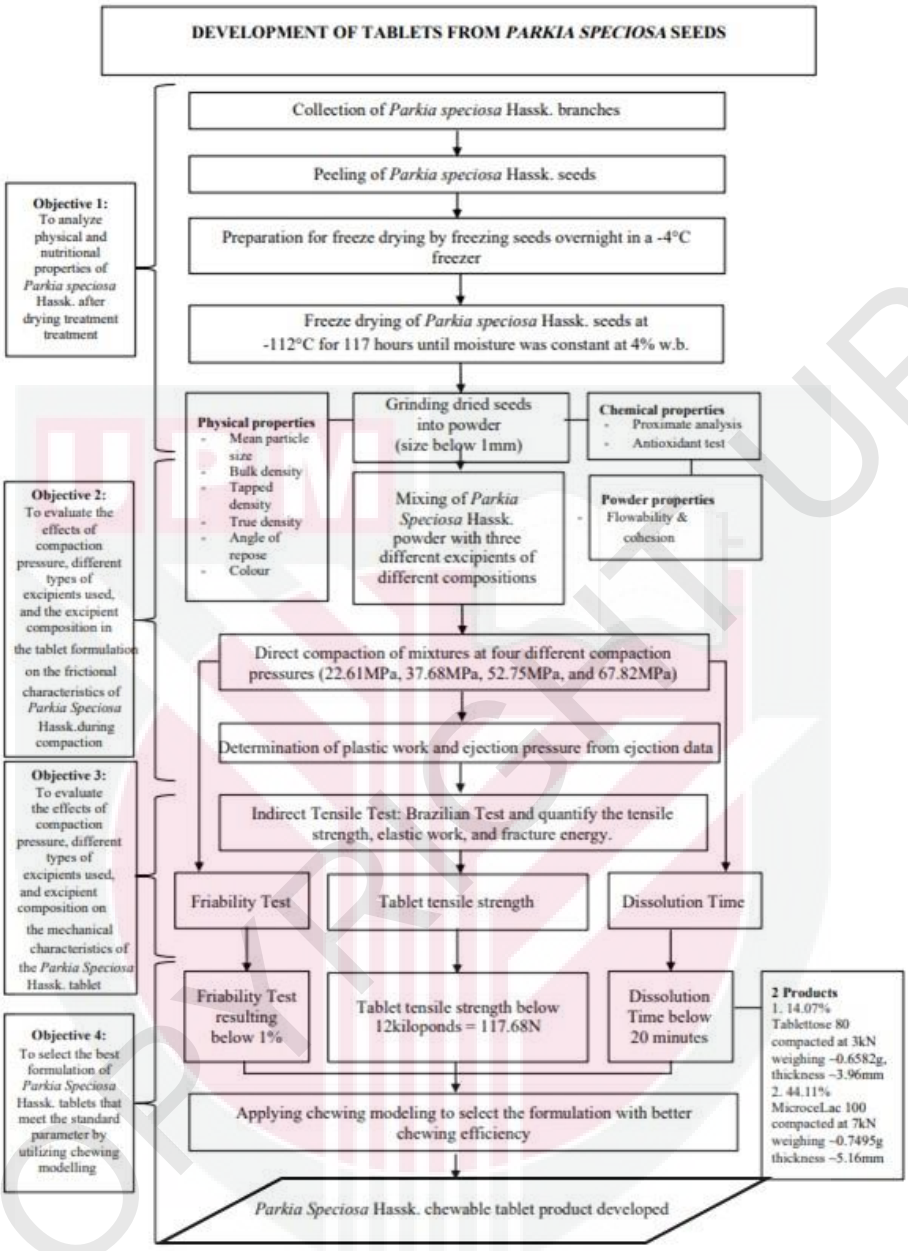

Figure 3.1: Overview of the experimental design

3.2 Materials

In this section, the materials selected for the study are introduced. The study mainly used 18 branches of *Parkia speciosa* Hassk as the chewable tablet active pharmaceutical ingredient (API), which were sourced from a local farmer in Nilai, Negeri Sembilan, who is involved in land ownership and cultivation of *Parkia speciosa* Hassk Three types of lactose-based excipients were used as binders in this study, namely agglomerated lactose (13005001 Tablettose® 80, Lot No.:104311321), spray-dried lactose (13005215 FlowLac® 90, Lot No.: L101533321), and microcrystalline cellulose (13008272 MicroceLac® 100, Lot No.: L103155221), which were obtained from MEGGLE Pharma (Wasserburg, Germany). Magnesium stearate (Bioventures Enterprise, Klang, Selangor) which was obtained from the Malaysian Agricultural Research and Development Institute (MARDI) was used as the lubricant in the formulation

The materials section concludes with a comprehensive overview of the chosen components and their significance in the context of the study's objectives. This section ensures transparency in material selection, setting the stage for the controlled experimentation and analysis that follows.

3.3 Sample preparation and drying treatment

This section delves into the details of preparing *Parkia speciosa* Hassk samples and subjecting them to drying treatments. The methodology was designed to preserve the integrity of the samples while facilitating the analysis of their physical

and nutritional properties. The rationale behind the chosen drying techniques and their implications for subsequent investigations are outlined.

3.3.1 Extraction and freezing of *Parkia speciosa* Hassk seeds

The *Parkia speciosa* Hassk used in the study consisted of 18 branches as seen in Figure 3.2, which were detached into 102 strips. During the peeling process, which involved removing the outer husk from the beans, a total of 1122 seeds were obtained from the branches. The peeling procedure involved several steps, starting with the use of a knife to make a longitudinal incision along one side of the pod, allowing for easy removal of the beans from their husks. Figure 3.3 shows the seeds obtained after peeling. It is worth noting that the seed coating was retained, as it contains the highest antioxidant capacity, as demonstrated by a study conducted by Kamisah et al. (2013).

Figure 3.2: A Bunch of Freshly Harvested *Parkia speciosa* Hassk

Figure 3.3: *Parkia speciosa* Hassk seeds after the peeling process

Since the peeling process of *Parkia speciosa* Hassk seeds can be time-consuming; a method was used to prevent browning and maintain the quality of the peeled seeds. After peeling, the seeds were placed in a vacuum storage bag to minimize exposure to oxygen, which can accelerate browning reactions. The sealed bags prevented oxygen from reaching the peeled seeds, slowing down the enzymatic reactions responsible for browning (Beltrán et al., 2005).

To further preserve the integrity of the seeds, they were then placed in a freezer set at a temperature of -4°C (Marefati et al., 2013). This freezing process helped solidify and firm up the seeds, effectively maintaining their structure and cellular integrity. Freezing also played a crucial role in slowing down enzymatic reactions, including the undesirable discoloration caused by browning (Ioannou, 2013.; Liang et al., 2015). By inhibiting these reactions, the freezing process helped minimize the loss of colour and extend the shelf life of the final freeze-dried product.

3.3.2 Freeze-drying of *Parkia speciosa* Hassk seeds

Based on the research conducted by How & Siow, (2020), it was determined that freeze-drying under vacuum conditions is the most suitable drying method for producing stink bean powder. The study found that vacuum drying resulted in enhanced antioxidant capacities, a lighter colour, and exhibited increased 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical-scavenging activity and ferric reducing antioxidant power (FIC) ability.

Further support for the suitability of freeze-drying can be found in the study by Karam et al. (2016), their research compared the colour changes of stink bean powder subjected to different drying methods, including freeze-drying, convection drying, and vacuum drying, after 25 days of storage at 75% relative humidity (RH). The findings revealed that freeze-dried samples had the lightest colour compared to the other drying methods. This is attributed to the absence of enzymatic and non-enzymatic browning reactions that typically occur during storage. Enzymatic browning is caused by the reaction between reducing sugars and amino acids, while non-enzymatic browning involves the degradation of phenolic compounds and colour pigments.

Based on these findings, it can be concluded that freeze-drying under vacuum conditions is the preferred method for producing *Parkia speciosa* Hassk powder. This drying technique not only maintains the antioxidant capacities of the powder but also preserves its light colour and prevents undesirable browning reactions during storage.

The freeze-drying process of *Parkia speciosa* Hassk was conducted after the peeled seeds were completely frozen, they were spread evenly on the trays and placed in the freezing chamber of the freeze dryer (Labogene ScanVac, Hadsten, Denmark) as shown in Figure 3.4, which was connected to a rotary vane pump (model RZ 2.5, VacuuBrand, Wertheim, Germany).

Figure 3.4: ScanVac freeze dryer used for freeze-drying the *Parkia speciosa* Hassk seeds

In the study conducted by How & Siow (2020), the freeze-drying process for drying 200g of *Parkia speciosa* Hassk seeds involved subjecting them to a temperature of -85°C at 0.100 mBar for 48 hours. This process was carried out until a constant weight was achieved, indicating a moisture content of approximately 5%. In the current research, a larger quantity of 1.2kg of seeds was dried using a freeze-dryer by subjecting them to A lower freezing temperature of -112°at a pressure of 0.5 mbar for 117 hours until a constant weight was attained, indicating a moisture content of around 5%.

As this section concludes, it leaves a clear understanding of the methodology employed in preparing the freeze-dried *Parkia speciosa* Hassk samples. The meticulous attention to sample preservation and the rationale behind the chosen

drying treatments set the stage for the subsequent analyses, ensuring that the results obtained accurately reflect the characteristics of the dried samples.

3.3.3 Grinding of *Parkia speciosa* Hassk seeds

After freeze-drying, the dried stink beans were subjected to a grinding process to obtain a fine powder suitable for further analysis. Grinding is a critical step in the preparation of plant materials, as it significantly influences the particle size distribution, which in turn affects the material's subsequent processing and analysis. The particle size and homogeneity of the ground material can impact the accuracy and reproducibility of analytical results, especially in studies involving physical, chemical, and sensory properties of the material.

For this study, the dried stink beans were ground using a grinder (model MX-AC210S, Panasonic, Malaysia). This model was selected due to its robust grinding capabilities, ensuring uniform particle size and consistency. The grinding process was conducted in batches to avoid overheating and potential degradation of the sample's bioactive components. The material was ground to a fine powder, which was then passed through a 0.6 mm mesh sieve to ensure uniformity in particle size. This sieving step is crucial as it removes larger, unground particles that could affect the subsequent analyses.

The sieved powder samples were carefully collected and transferred into amber bottles. Amber bottles were chosen for their ability to protect the samples from light, which could cause photodegradation of sensitive compounds in the stink bean powder. To maintain the integrity of the samples, the bottles were stored in

desiccators containing silica gels at room temperature (25°C). The desiccators provided a moisture-free environment, crucial for preventing the absorption of ambient moisture, which could lead to clumping and affect the quality of the powder. This storage method ensured that the samples remained in optimal condition for subsequent analyses.

The grinding process, combined with proper storage conditions, was designed to preserve the physical and chemical properties of the stink bean powder, making it suitable for detailed analysis and processing into *Parkia speciosa* Hassk chewable tablets.

3.4 Physical and nutritional analysis of *Parkia speciosa* Hassk

This section focuses on the methodology for analysing the physical and nutritional properties of *Parkia speciosa* Hassk post-drying treatment. The techniques employed in this phase aimed to provide a comprehensive understanding of the changes in colour, aroma, taste, and nutritional content. The methodologies selected were tailored to obtain meaningful information on the evolving characteristics of the dried *Parkia speciosa* Hassk samples.

3.4.1 Physical properties analysis

This section explains the physical properties analysis of freeze-dried *Parkia speciosa* Hassk which are particle size distribution, density, angle of repose and flowability.

3.4.1.1 Particle size distribution

The particle size distribution of ground *Parkia speciosa* Hassk powder was determined using a sieve analysis method with specific sieve sizes. The analysis was performed using a vibratory sieve shaker (model AS200, Retsch, Germany) shown in Figure 3.5 at an amplitude of 2 mm. A method of determining particle size distribution, which is a part of quality control referred to Kumar et al. (2013), which also mentioned that d90, which is the cumulative 90% of the size distribution should be above 500µm. Hence, the following sieve mesh strainer with aperture sizes were used: 1000µm, 500µm, 250µm, and 100µm.

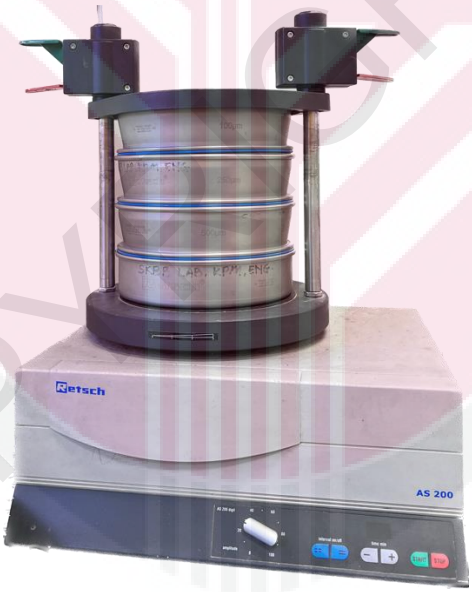

Figure 3.5: Sieve shaker used for sieve analysis in determining particle size distribution

All powder samples of *Parkia speciosa* Hassk was placed on the top sieve (500µm). The sieve stack was then assembled and securely attached to the sieve shaker. The sieve shaker was set to operate at an amplitude of 30, which refers

to the intensity of shaking. This amplitude helps to ensure efficient particle separation. The sexperiment was conducted until all powders passed through the first sieve. The powder with a size larger than 1000µm underwent additional grinding.

After the shaking process, the mesh sieves were carefully removed from the sieve shaker, and the retained particles on each sieve were collected. The particles on each sieve were weighed individually to determine the amount of material retained.

The mean particle size was calculated by analysing the particle size distribution across the different sieve sizes. The mass of the retained particles on each sieve were used to calculate the percentage of particles retained at each sieve size. A graph plot of cumulative percentage against sieve mesh aperture based on the data obtained from the sieve analysis was then used to obtain the percentile values at 10% (d10), 50% (d50), which is also the median aperture value, and 90% (d90) (ICUMSA Method GS1-20 (2005) - ICUMSA, 2005).

3.4.1.2 Density

In the realm of industrial processes and material property investigations, density stands as a fundamental parameter, defined as the total mass divided by the total volume. Expressed in kilograms per square meter in SI units, density holds significance in characterizing various materials. Specifically, within the domain of powders, different types of density are recognized, including bulk density, tapped density, apparent density, and true density. This study aims to calculate three

primary types of density which are true density, bulk density, and tapped density, to enhance our understanding of the material properties and facilitate comprehensive analyses.

The true density of *Parkia speciosa* Hassk powder was determined using a helium pycnometer (model AccuPyc II 1340, Pycnometer, Georgia, USA) as shown in Figure 3.6. The instrument operates based on the principle of gas displacement. This method is preferred over liquid-based approaches due to its enhanced accuracy and ease of use. Helium gas, chosen for its inert nature and smaller atom size compared to mercury and air components, efficiently penetrates smaller pores and interstitial spaces (Gabaude et al., 1999; Michrafyet et al., 2007).

Figure 3.6: Gas Pycnometer used for measuring true density

The test involved measuring approximately 1g of the *Parkia speciosa* Hassk powder sample in three replicates. The helium pycnometer ensures precision by excluding voids, and the rapid movement of gas ensures thorough filling of void and pore spaces.

The true density of the sample was determined by analysing the pressure change resulting from the introduction of the gas into the sample chamber. The instrument provided the true density value based on the displacement of gas by the sample.

Bulk density, representing the ratio of sample mass to its volume, including interparticular voids, was determined using the graduated cylinder method utilising a setup of measuring cylinder and an analytical balance (model PX224, OHAUS, New Jersey, USA) as shown in Figure 3.7. This method, as described by Fini et al. (2008) and Yaakub et al. (2018), provides an accurate assessment of the overall density of the powder, considering the space between particles.

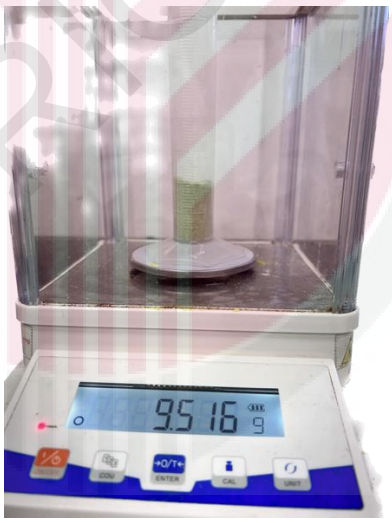

Figure 3.7: The graduated cylinder method cylinder in determining bulk density

A suitable quantity of the *Parkia speciosa* Hassk powder was carefully poured into a 50ml tarred graduated measuring cylinder. The volume was then read directly from the cylinder and substituted into the bulk density equation:

$$\text{Bulk density} = \frac{\text{Mass of sample (g)}}{\text{Occupied volume (ml)}} \quad (3.1)$$

Tapped density, indicative of bulk density after tapping the container containing samples, was determined using a micromeritics tapped density analyzer (model 1360, GeoPyc, U.S.A.) as shown in Figure 3.8. The instrument utilizes an envelope method combined with tapping to determine the tapped density of the sample.

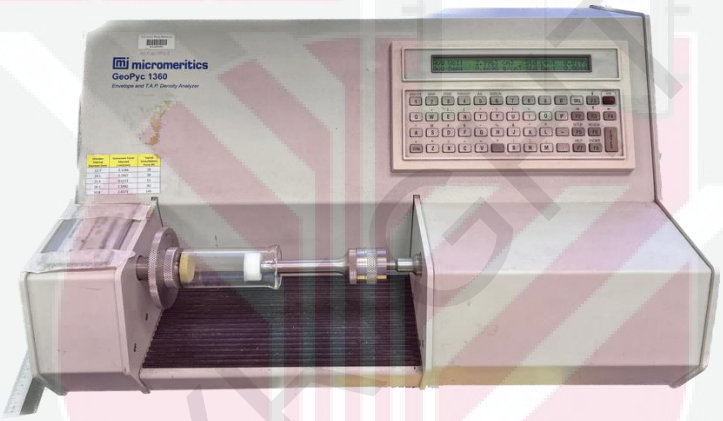

Figure 3.8: Tapped density analyser

Exactly 2 ± 0.001g of *Parkia speciosa* Hassk powder was inserted into a cylindrical chamber with a 50.8mm internal diameter and covered using a piston tip (Guerin et al. 1999). A consolidation force of 145N, adjusted according to a conversion factor of 2.0373cm^3/mm, was applied to the sample. Tapping the container ensures closer packing of particles, affecting the overall density.

The instrument performed a series of taps on the sample, and the volume of the sample was measured after each tap until a constant volume was achieved. The

tapped density was calculated by dividing the mass of the sample by its tapped volume.

This comprehensive density measurement methodology for *Parkia speciosa* Hassk powder provides understanding of its true density, bulk density, and tapped density, employing accurate and widely accepted techniques to ensure reliable results.

3.4.1.3 Angle of repose

The angle of repose of *Parkia speciosa* Hassk was determined using the method described by Al-Hashemi & Al-Amoudi (2018). A flat, clean, and dry surface was prepared, and a funnel with 10cm diameter was fixed at 9cm above the surface using a retort stand as shown in Figure 3.9.

Figure 3.9: The setup for measuring the angle of repose of *Parkia speciosa* Hassk powder using a retort stand and a filter funnel

Each sample of *Parkia speciosa* Hassk was gently poured through the funnel onto the surface, forming a cone-shaped pile. The height of the cone-shaped pile and the diameter of the base were measured using a ruler or calliper. The angle of repose was calculated using the formula:

$$\text{Angle of repose} = \tan^{-1}\frac{h}{r} \qquad (3.2)$$

where

h is the height of the cone-shaped pile

r is the radius of the base of the pile.

To ensure accurate results, the experiment was repeated three times, and the average angle of repose was calculated. It is important to note that the angle of repose provides information about the flowability and cohesiveness of the sample, with steeper angles indicating poor flowability and lower angles indicating better flowability.

3.4.1.4 Flowability

To calculate the flowability parameters based on Sutton et al. (2017), the values of Carr's index and Hausner ratio were used where it utilizes the density values of the *Parkia speciosa* Hassk samples. These parameters indicate the powder's ability to flow and its cohesiveness.

Carr's index, also known as the compressibility index, is calculated using the following formula:

$$\text{Carr's index} = \left[\frac{(\text{Tapped density} - \text{Bulk density})}{\text{Tapped density}}\right] \times 100 \qquad (3.3)$$

The tapped density refers to the density of the powder after it has undergone a specified tapping or consolidation process, while the bulk density represents the density of the unpacked powder.

Hausner ratio, on the other hand, is calculated as the ratio of the tapped density to the bulk density:

$$\text{Hausner ratio} = \frac{\text{Tapped density}}{\text{Bulk density}} \qquad (3.4)$$

Both Carr's index and Hausner ratio provide understandings into the flowability of the powder. A higher Carr's index value indicates poorer flowability, while a lower value suggests better flowability. Similarly, a higher Hausner ratio indicates poor flowability and increased cohesiveness, whereas a lower ratio indicates better flowability.

3.4.2 Nutritional composition analysis

3.4.2.1 Total ash

Total ash content in *Parkia speciosa* Hassk was determined according to the official method described in the Association of Official Agricultural Chemists (AOAC International, 2023).

The method involves the complete incineration of a specified amount of *Parkia speciosa* Hassk powder to obtain the total ash content. The sample was first prepared by accurately weighing 5g of representative sample portion and placing it in a previously ignited, cooled in a desiccator, and weighed crucible promptly upon reaching room temperature. The crucible with the sample was then placed in a furnace set at approximately 550°C reaching a dull red heat until a light grey ash was obtained, and a constant weight was achieved.

During the incineration process, the organic matter in the *Parkia speciosa* Hassk powder was oxidized, leaving behind the inorganic residues, which constitute the total ash. After this process, the ash was allowed to cool in a desiccator and promptly reweighed upon reaching room temperature. A reignited CaO serves as

a suitable drying agent for the desiccator throughout this procedure, ensuring accurate and reliable measurements of the total ash content in *Parkia speciosa* Hassk powder. The difference in weight before and after incineration represents the total ash content of the sample.

The Association of Official Agricultural Chemists (AOAC International, 2023) provides detailed instructions and guidelines for the accurate determination of total ash content in various agricultural and food products. By following this method, the total ash content of *Parkia speciosa* Hassk can be determined, providing information about the inorganic mineral content in the sample.

3.4.2.2 Protein

The protein content in the *Parkia speciosa* Hassk sample was analyzed using the method described by Mæhre et al. (2018). This method is widely recognized for its accuracy and reliability in determining protein content in various food and agricultural samples.

In the analysis, approximately 2 grams of powder samples were carefully weighed and placed in a 250 mL digestion tube. Catalyst tablets, sulfuric acid, and hydrogen peroxide were sequentially added to initiate the digestion process. The tubes were subsequently heated in a block digestor at 410°C for about 45 minutes under controlled conditions to prevent intense reactions. After cooling, water was added, and steam distillation was carried out using sodium thiosulfate in a sodium hydroxide ($NaOH–Na_2S_2O_3$) solution to collect liberated ammonia. The resulting

ammonia was titrated with 0.2M hydrochloric acid (HCl), and the volumes of acid required for both test portions and blanks were meticulously recorded.

The protein content of the *Parkia speciosa* Hassk sample was calculated based on the absorbance readings and the corresponding protein concentrations from the standard curve. The final protein content was expressed as a percentage or gram per unit weight of the sample.

$$\text{Protein, \%} = (V_A - V_B) \times 1.4007 \times M \times 6.25 / \text{g test portion} \quad (3.5)$$

where,

V_A and V_B = volume of standard acid required for the test portion and blank,

1.4007 = milliequivalent weight of N × 100(%);

M = molarity of standardized acid; and

6.25 = protein factor for *Parkia speciosa* Hassk powder (16% N).

This comprehensive and systematic approach ensures the reliability and accuracy of the protein determination process, crucial for assessing the nutritional composition of *Parkia speciosa* Hassk powder.

3.4.2.3 Total fat

The analysis of total fat content in the *Parkia speciosa* Hassk sample was performed using the Soxhlet extraction method (AOAC, 2023). This method is

widely recognized and accepted for the determination of fat content in various food and agricultural samples.

Total fat encompasses triglycerides, phospholipids, wax esters, sterols, and minor non-fatty materials. The Soxhlet extraction technique was chosen over acid hydrolysis in this instance. In Soxhlet extraction, crude fat, including free fat, was determined without hydrolysis. The procedure involves the use of petroleum ether as the solvent. Sample preparation is crucial, involving representative and homogenous portions from both edible and non-edible sections, considering water content, and ensuring a defined "0" point for accurate measurements. The Soxhlet extraction requires dried samples, and results may vary based on reflux rate and extraction time.

After extraction, the determination involves weighing the residue, drying to a constant weight, and cautious attention to prevent increased fat weight due to oxidation during prolonged heating. This meticulous approach ensures reliable results in assessing the total fat content in *Parkia speciosa* Hassk powder.

The total fat content in the *Parkia speciosa* Hassk sample was calculated by dividing the weight of the extracted fat by the initial weight of the sample and multiplying it by 100. This provided the fat content as a percentage or gram per unit weight of the sample.

$$\text{Total Fat} = \frac{\text{Weight of extracted fat}}{\text{Weight of initial sample}} \times 100 \qquad (3.6)$$

3.4.2.4 Carbohydrate

The analysis of carbohydrate content in the *Parkia speciosa* Hassk sample was analysed according to the Promerance Food Analysis method (Pomeranz & Meloan, 1978). The carbohydrate content was determined by difference, which means that it was calculated by subtracting the sum of the other measured components (such as protein, fat, moisture, ash) from the total mass of the sample. Carbohydrates were considered as the residual portion remaining after accounting for the known components.

Carbohydrate = Mass of sample – (Sum of protein, fat, moisture & ash) (3.7)

The Promerance Food Analysis method provided a comprehensive approach that helped in the determination of the carbohydrate content in the *Parkia speciosa* Hassk sample. By utilizing the principles outlined in the book, accurate and reliable information about the carbohydrate composition of the sample was obtained, contributing to a better understanding of its nutritional profile and potential applications in the food industry.

3.4.2.5 Energy

The calculation of energy content in the *Parkia speciosa* Hassk sample was analysed using the method described by Mohd Ali et al. (2023). To calculate the energy content, the sample's composition data, including the amounts of protein, fat, and carbohydrate, were obtained through specific analysis methods, that were mentioned earlier.

Using the known energy conversion factors for protein, fat, and carbohydrate, the energy contribution from each component was determined. These conversion factors represent the energy yield per gram of each macronutrient, accounting for the different energy densities associated with protein, fat, and carbohydrate. The energy content of the *Parkia speciosa* Hassk sample was then calculated by summing up the energy contributions from protein, fat, and carbohydrate. This calculation provided an estimate of the total energy content in the sample.

Energy = Sum of protein energy + fat energy + carbohydrate energy (3.8)

The approach described in Pearson's book, which incorporates energy conversion factors and composition data, allowed for the determination of the energy content of the *Parkia speciosa* Hassk sample.

3.4.3 Moisture content analysis

The moisture analysis for *Parkia speciosa* Hassk powder using a moisture analyser (model MX-50, A & D, Japan) shown in Figure 3.10 and involved determining the percentage of moisture content expressed on a wet basis (w.b).

Figure 3.10: Moisture analyzer used for determining the percentage of moisture content in *Parkia speciosa* Hassk powder

The methodology, as adapted from Razak et al. (2020), employed the moisture analyser, which utilizes thermo-gravimetric principles to assess the weight loss of the sample during the drying process. The sample was subjected to constant temperature drying at 105˚C. This temperature was carefully selected to ensure effective moisture removal without causing undesirable alterations to the sample. The moisture analyser provided a controlled environment for the drying process, allowing accurate measurement based on the weight loss observed as the sample underwent heating.

The results obtained from this moisture analysis contribute important information about the moisture content of *Parkia speciosa* Hassk powder, essential for assessing its stability, quality, and potential applications in various contexts, as outlined in the study by Razak et al. (2020).

3.4.4 Antioxidant capacity analysis

3.4.4.1 2,2-diphenyl-1-picrylhydrazyl (DPPH)

The DPPH assay was performed according to the method described by Wu et al. (2006). The assay was employed to determine the percentage inhibition of the *Parkia speciosa* Hassk sample (Wu et al., 2006).

A 0.1 ml aliquot of the acetone extract was mixed with 3.9 ml of 80% ethanolic 0.6 mM DPPH solution. Following the methodology described by Cai et al. (2003), the tubes were vortexed for 15 seconds and allowed to stand for 180 minutes. After incubation, the absorbance of the mixture was measured at 515 nm using a UV–Vis spectrophotometer (Hewlett Packard, Palo Alto, CA). This procedure, adapted from Cai et al. (2003), ensured that most tested compounds reacted completely within the 180-minute timeframe. Ethanol (80%) was used as a blank solution, and the DPPH solution without test samples served as the control. All tests were conducted in triplicate. The antioxidant activity of the *Parkia speciosa* Hassk powder was expressed in % inhibition of DPPH absorbance, calculated as:

$$\% \text{ Inhibition} = \left[\frac{(\text{Absorbance control} - \text{Absorbance sample})}{\text{Absorbance control}}\right] \times 100 \qquad (3.9)$$

3.4.4.2 Ferric Reducing Antioxidant Power (FRAP)

The FRAP assay was performed according to the method described by Wu et al. (2006). The assay was employed to determine the antioxidant capacity of the *Parkia speciosa* Hassk sample (Wu et al., 2006).

In the determination of FRAP in *Parkia speciosa* Hassk powder, the procedure followed the DPPH assay principles. A 0.1 ml aliquot of the acetone extract, as prepared previously, was mixed with a solution containing ferric-tripyridyltriazine (FRAP reagent). The tubes were vortexed and incubated for 30 min in a water bath. Subsequently, the absorbance of the reaction mixture was measured at 593 nm wavelength using a UV–Vis spectrophotometer (Hewlett Packard, Palo Alto, CA).

The FRAP assay measures the ferric-reducing ability of antioxidants, and the antioxidant power of the *Parkia speciosa* Hassk powder was expressed as mg/ml vitamin C equivalence. The results were calculated based on standard curves established using vitamin C as a reference standard.

3.4.4.3 Total polyphenol

The total polyphenol content of the *Parkia speciosa* Hassk sample was analyzed using a modified Folin-Ciocalteu method described by Wolfe et al. (2003). A 125 µl aliquot of a known dilution of the extract was placed in a test tube, followed by the addition of 0.5 ml of Folin–Ciocalteu's reagent. The tubes were vortexed for 15 seconds and then allowed to stand for 6 minutes at 20°C.

Subsequently, 1.25 ml of 7% sodium carbonate solution was added to the test tubes, and the mixture was diluted to 3 ml with distilled, de-ionized water. The colour development process spanned 90 minutes, after which the absorbance was measured at 760 nm using a UV–V spectrophotometer (model 8452, Hewlett Packard, Palo Alto, CA). The measurements were compared to a standard curve generated from prepared gallic acid solutions, and the results were expressed as gallic acid equivalents in milligrams. Triplicate determinations were performed for each sample, and the data presented later represent the means of three measurements.

The closure of this section marks the conclusion of the analytical methodologies applied to assess the physical and nutritional attributes. As the analysis progresses, the acquired data will illuminate the impact of the drying treatment on *Parkia speciosa* Hassk, setting the stage for subsequent stages in tablet formulation and mechanical characterization.

3.5 Tablet formulation development

The formulation development phase is introduced with a focus on the methodology employed in crafting the *Parkia speciosa* Hassk chewable tablets. This section elucidates the rationale behind the selection of compaction pressures, excipients, and their compositions. The aim is to comprehensively evaluate the compaction behaviour and subsequent mechanical characteristics of the tablets.

3.5.1 Selection of excipients

The excipients selected for the chewable tablet formulation method were agglomerated lactose - Tablettose® 80 (Meggle, GmbH, Germany), spray-dried lactose - FlowLac® 90 (Meggle, GmbH, Germany), and microcrystalline cellulose - MicroceLac® 100 (Meggle, GmbH, Germany). Figure 3.11 shows the 1kg packs of excipients used for tablet formulation.

Figure 3.11 1kg packs of excipients used for tablet formulation

Table 3.1: Excipients Descriptions

Excipient	Description
Tablettose® 80 (Agglomerated lactose)	Excipient Tablettose® 80, agglomerated lactose was chosen as an excipient due to its unique manufacturing process. It is produced through a continuous spray agglomeration process where water is used as a binder. Fine milled lactose particles are fluidized, and water is sprayed onto them, creating liquid bridges that form agglomerated lactose. This excipient is specifically designed for direct compression, offering the combined advantages of flowability from coarse lactose crystals and good compressibility from fine milled lactose.
FlowLac® 90 (Spray-dried lactose)	Excipient FlowLac® 90, spray-dried lactose was selected based on its production method. It is created by spray-drying a suspension of fine milled alpha-lactose monohydrate crystals in a lactose solution. During spray-drying, water is rapidly removed, resulting in the formation of both amorphous, non-crystalline lactose and crystalline lactose. The amorphous content, kept at a stable level, provides better tabletting properties. Spray-dried lactose has a spherical agglomerate shape consisting of small alpha-lactose monohydrate crystals bound by amorphous lactose.
MicroceLac® 100 (Microcrystalline cellulose)	Excipient MicroceLac® 100, microcrystalline cellulose (MCC) was included as an excipient due to its well-established properties. Both lactose and MCC are commonly used as diluents and binders in oral dosage formulations. In an effort to achieve synergistic effects such as improved tablet hardness and adherence capacity, a co-processed excipient was developed by combining lactose and MCC through the spray-drying process. This co-processed excipient maintains the individual chemical identities of 75% alpha-lactose monohydrate and 25% MCC, providing the capability for direct compression due to its favourable flowability and compactibility.

The selection of these excipients was based on their specific characteristics and the desired properties for chewable tablet formulation. Agglomerated lactose and spray-dried lactose offer improved flowability and compressibility, while the combination of lactose and MCC in the co-processed excipient provides enhanced tablet hardness and adherence capacity. By using these excipients in the formulation, the aim was to achieve a chewable tablet with optimal characteristics for patient acceptability and ease of administration.

3.5.2 Excipient composition

The variations of excipient compositions used in this research were determined based on the maximum daily exposure (MDE) of lactose monohydrate (www.fda.gov/Drugs/InformationOnDrugs/ucm113978.htm).

The MDE for lactose monohydrate was determined to be 1185mg. Considering that three maximum units of *Parkia speciosa* Hassk chewable tablets were taken daily, the maximum lactose monohydrate content would be 394.67mg. Since the constant dosage of *Parkia speciosa* Hassk was set at 500mg, the maximum composition of excipient could be 44.11%.

Based on these calculations, four different excipient compositions were established: 14.07%, 29.41%, and 44.11%. These compositions represent the different amounts of excipient used in the formulation of the *Parkia speciosa* Hassk chewable tablets. The purpose of varying the excipient compositions was to evaluate the impact of different excipient levels on the characteristics and performance of the chewable tablets.

3.5.3 Compaction pressure

The variations of compaction pressure used in this research were determined based on previous studies and the desired tablet characteristics. The universal testing machine (Model 5566, Instron, Canton Ma, U.S.A.) was utilized for tablet compaction, using a 13 mm Evacuable Pellet Die (GS03000, Specac, UK) positioned between the compression platen, which are the designated accessories for compression testing, as shown in Figure 3.12. The machine had a maximum allowable force of 9 kN and a minimum of 3 kN.

Figure 3.12: Instron 5566 compression platens as a compression accessory for compression

By subjecting the tablets to a 13mm die, the maximum compaction pressure achievable was calculated to be 67.82 MPa, while the lowest compaction pressure was determined to be 22.61 MPa. These values were derived from the specifications of the machine and die setup used in the research. Study by Hamidi et al. (2019) indicated a range of compaction pressures from 15 MPa to 74 MPa for chewable binary tablet mixtures. This range was chosen to comprehensively assess the compaction behaviour and mechanical characteristics of the tablets.

Additional studies by Adiba et al. (2011), Morris et al. (1996), and Wu et al. (2006) provided an understanding of acceptable compaction forces and loads required for tablet formation, which were converted to MPa. These references supported the selection of compaction pressures and aided in establishing the appropriate range.

Furthermore, a study by Shamjuddin et al. (2014) utilized a universal testing machine (Model 5566, Instron, Canton Ma, U.S.A.) with applied loads of 5 kN, 15 kN, 55 kN, and 95 kN. Converting these loads to pressures and considering the crosshead speed of 0.1 mm/s mentioned in Mohammed et al. (2006), the corresponding compaction pressures of 22.61 MPa, 37.68 MPa, 52.75 MPa, and 67.82 MPa were determined.

By considering these references and the technical specifications of the equipment used, the compaction pressures were carefully selected to evaluate the compaction behaviour and mechanical characteristics of the chewable tablets with different excipient compositions.

In conclusion, this section provides a clear understanding of the tablet formulation process, facilitating subsequent evaluations. The choices made in compaction pressure, excipient types, and compositions are essential to clarify the aspects of *Parkia speciosa* Hassk chewable tablets, offering an understanding of their mechanical attributes.

3.6 Mixing *Parkia speciosa* Hassk powder with excipients

The preparation of *Parkia speciosa* Hassk chewable tablets began with the precise mixing of the *Parkia speciosa* Hassk powder with three distinct types of excipients: Tablettose® 80, FlowLac® 90, and MicroceLac® 100. These excipients were chosen due to their well-documented functionality in tablet formulation, and they were incorporated at varying compositions of 14.07%, 29.41%, and 44.11%. The dry powder rotator (Model 099A RD9912, Glas-Col, USA) was employed for the mixing process, ensuring uniform distribution of the excipients throughout the *Parkia speciosa* Hassk powder.

The process began by accurately weighing 500 mg of *Parkia speciosa* Hassk powder for each tablet dose. The excipients were then carefully measured and added according to the predetermined percentages to ensure consistency across all tablet formulations. To maintain accuracy and uniformity, each powder mixture was prepared individually, with each tablet dose being placed in its own small mixing jar.

Once the powders were placed in the jars, all the jars were securely taped together to prevent any movement or spillage during the mixing process. These jars were then loaded into the rotator's mixing chamber, which was filled to 70% of its capacity. This ensured that the powders had enough space to tumble freely, promoting thorough mixing. The jars were tumbled at a controlled rotation speed of 30 rpm for 30 minutes. This duration was selected based on preliminary trials to ensure optimal mixing without causing segregation of the powder components.

The mixing process was a critical step in the tablet manufacturing process, as it ensured the homogeneity of the powder blend, which is essential for producing tablets with consistent weight, content uniformity, and mechanical properties. The thorough mixing achieved by the dry powder rotator allowed for a uniform distribution of the excipients, which is crucial for the subsequent compaction process.

After the mixing was completed, the homogeneous powder blends were then subjected to direct compaction. This step involved compressing the mixed powders into tablets using a range of compaction pressures—22.61 MPa, 37.68 MPa, 52.75 MPa, and 67.82 MPa. The direct compaction process was carefully controlled to ensure that the tablets produced were of consistent quality, with uniform hardness, disintegration time, and other critical parameters. The mixed powders' uniformity played a significant role in achieving these outcomes, highlighting the importance of the mixing process in the overall tablet manufacturing procedure.

3.7 Evaluation of compaction and frictional characteristics during ejection

This section addresses the methodology employed in assessing the compaction and frictional characteristics during the ejection of *Parkia speciosa* Hassk chewable tablets. The focus here is on understanding the forces at play during tablet compaction and ejection, offering an understanding of optimizing formulations, ensuring manufacturing consistency, and gaining a deeper understanding of material behaviour during compaction processes.

The evaluation of compaction and frictional characteristics during ejection involved the use of compacted *Parkia speciosa* Hassk chewable tablets mixed with three different types of excipients (Tablettose® 80, FlowLac® 90, and MicroceLac® 100) at various compositions (14.07%, 29.41%, and 44.11%). The tablets were compressed at different compaction pressures (22.61 MPa, 37.68 MPa, 52.75 MPa, and 67.82 MPa) using a universal testing machine (Model 5566, Instron, Canton Ma, U.S.A.). The ejection process was conducted using an ejection force of 9kN (corresponding to an ejection pressure of 67.82 MPa) at a speed of 0.1 mm/s, as mentioned by Mohammed et al. (2006).

During the compaction and ejection process, the force-displacement profile was generated to capture the behaviour of the tablets. The properties, including maximum ejection pressure, plastic and elastic work, and friction work, were analysed from the force-displacement data (Alderborn & Nyström, 1996).

3.7.1 Plastic and elastic work

Tablet compaction studies provide a comprehensive approach to unravelling the mechanical behaviour of powders during compression. By delving into the force-displacement profiles obtained during compaction, the fundamental processes of elastic and plastic deformation, particle rearrangement, and the impact of pressure on the material were gained. It also allows for a detailed exploration of how tablets respond to mechanical forces, focusing on crucial aspects such as tablet strength, deformability, and the energy dynamics involved in the compaction process.

Plastic work referred to the energy required for the permanent deformation of the tablets, while elastic work represented the energy stored and recovered during ejection. Elastic work is determined by calculating the area under the force-displacement curve during the elastic phase, which represents the energy stored in the tablets while plastic work was calculated by subtracting the elastic work from the total work (area under the force-displacement curve).

Elastic work, plastic work, and total work were calculated following a calculation proposed by Antikainen and Yliruusi (2003), Antikainen (2003) and Patel et al. (2007). Calculations were made using MATLAB from the force and displacement data obtained during the compaction process.

For elastic work calculation, it was computed by integrating this force per unit displacement array over the compaction phase using the 'trapz' function. This value represents the energy stored and recovered as elastic deformation during compaction.

$$\text{Elastic Work } (W_e) = \int_{h_f}^{h_t} P_{unloading}\, dh \qquad (3.10)$$

where

W_e = elastic work

h_t= maximum displacement

h_f= final displacement

$P_{unloading}$= reaction pressure during unloading

While for plastic work,

$$\text{Plastic Work } (W_p) = \int_{h_{f(loading)}}^{h_t} P_{loading}\, dh \tag{3.11}$$

where

W_p = plastic work

h_t= maximum displacement

h_f= final displacement after loading

$P_{loading}$= reaction pressure during loading

The elastic and plastic work is also correlated by total work as follows:

$$\text{Total Work } (W_t) = W_e + W_p \tag{3.12}$$

where

W_t = total work

W_e = elastic work

W_p = plastic work

3.7.2 Frictional characteristics during ejection

The process of ejecting the tablet from the die after compaction involves complex dynamics influenced by frictional forces within the tablet and the die wall. The maximum ejection pressure and the work required for ejection depend on the shear forces at the interface of the compact surface and the die wall. Frictional interactions during ejection can result in challenges like capping or laminating of compacts and radial expansion.

3.7.2.1 Maximum ejection pressure

The maximum ejection pressure represented the peak force experienced during ejection, indicating the resistance encountered by the tablets. It is the highest value observed in the force-displacement profile. The maximum ejection pressure was determined using the maximum force and its corresponding displacement, as shown in

Figure **2.3**. This was done by dividing the maximum force by the corresponding displacement (Hölzer and Sjögren, 1977). The resulting value represents the maximum pressure exerted on the tablets during ejection. The maximum ejection pressure, automatically recorded by the software connected to a universal testing machine (Model 5566, Instron, Canton Ma, U.S.A.), is crucial for assessing friction and lubrication effects.

3.7.2.2 Ejection work

The assessment of ejection work serves as the final component in conducting a comprehensive mechanical energy evaluation of compact formation. The energy required to eject the tablet from the die is represented by ejection work, a mechanical energy derived from the force-displacement measurements, which was simply calculated by the integral of applied force, F, over a distance, dX (DeCrosta et al., 2001).

$$\text{Ejection Work } (W_{ejection}) = \int F dX \tag{3.13}$$

Studies conducted by Ketolainen et al. (1993) suggest a direct relationship between the rise in compaction force and an increase in ejection work.

3.8 Indirect tensile strength test

The indirect tensile test, also known as the Brazilian test, was conducted to evaluate the strength properties of compacted *Parkia speciosa* Hassk chewable tablets mixed with different types of excipients (Tablettose® 80, FlowLac® 90, and MicroceLac® 100) at varying compositions (14.07%, 29.41%, and 44.11%) and compaction pressures (22.61 MPa, 37.68 MPa, 52.75 MPa, and 67.82 MPa).

The test was performed using a universal testing machine (Model 5566, Instron, Canton Ma, U.S.A.). The compacted tablets were placed between two parallel loading platens or supports. The lower platen was fixed, while the upper platen was movable and connected to a force sensor. The test was initiated by applying a diametral compressive force to the tablets. The force was set at a constant value

of 9kN. The loading was applied at a controlled speed of 0.1 mm/s, as specified in Mohammed et al. (2006).

During the test, the force exerted on the tablets and the corresponding displacement or deformation were recorded using the equipment's data acquisition system. The test continued until the tablets fractured.

3.8.1 Tensile strength

After completing the test, the maximum force at failure was determined from the recorded data. This force represented the tensile strength of the tablets in the diametral direction. The indirect tensile strength was then calculated using the formula:

$$\text{Tensile strength} = (2 * \text{breaking force}) / (\pi * \text{diameter}) \qquad (3.14)$$

where the diameter is the measured diameter of the tablets after 24 hours of compaction.

3.8.2 Fracture energy

Determining the fracture energy from the indirect tensile test described previously, the force-displacement data obtained from the compression equipment was processed using MATLAB. The data was imported and smoothed to eliminate any noise or irregularities. The displacement value corresponding to the maximum force, which indicated the point of fracture, was identified. Then, the area under

the force-displacement curve was calculated using numerical integration methods which is the trapezoidal rule. This area represented the fracture energy of the tablets, quantifying their ability to absorb energy before breaking. The fracture energy was expressed in units of force times displacement, N·m.

3.8.3 Dissolution time test

The tablet dissolution test was conducted using a dissolution tester (model PT-DT70, Pharma Test, Hainburg, Germany) shown in Figure 3.13 equipped with a paddle blade rotating at a speed of 50 rpm. The test was performed in water at a pH of 7.44 and a temperature of 28.2°C to mimic physiological conditions as Smith and Tang (2017) discuss that physiological conditions, particularly in the human gastrointestinal tract, often range from a pH of 6.8 to 7.4 and a temperature of around 37°C, though ambient laboratory conditions (28-30°C) are also used in certain in vitro studies for simplicity. Additionally, previous studies, such as those by (Saifullah et al., 2016) have utilized distilled water for the dissolution testing of chewable tablets to simulate these conditions.

Figure 3.13: Dissolution tester used to measure the dissolution time

The dissolution tester was prepared by filling the dissolution vessel with the dissolution medium, which in this case was water at the specified pH and temperature. The tablet under evaluation was carefully placed into the dissolution vessel, ensuring that it was fully immersed in the medium. The dissolution vessel was securely attached to the dissolution tester, and the paddle blade was positioned inside the vessel, ensuring it did not come into contact with the tablet. The dissolution test was initiated, and the paddle blade began rotating at a constant speed of 50 rpm. The rotation of the paddle blade created a stirring motion within the dissolution medium, facilitating the release of the tablet's active ingredients.

The tablet dissolution process was continuously monitored until complete disintegration and breakdown of the tablet occurred. This was dewasined by visually observing the dissolution medium and confirming that no solid particles

or remnants of the tablet were present. The tablet dissolution time was recorded as the duration it took for the tablet to fully disintegrate and dissolve in the dissolution medium. The time was measured in minutes or hours, depending on the specific requirements of the study.

The dissolution test is a critical component of this research on Parkia speciosa Hassk chewable tablets, as it directly influences the tablet's effectiveness and consumer acceptability. This test is essential for assessing the drug release profile, ensuring that the active ingredients are released quickly and efficiently for absorption in the body. Additionally, the dissolution test ensures consistency and uniformity across different batches of tablets, which is crucial for maintaining therapeutic efficacy. Given the use of various excipients such as Tablettose® 80, FlowLac® 90, and MicroceLac® 100 in different compositions, the dissolution test helps determine how these excipients affect the dissolution rate of the active ingredients, allowing for the optimization of the tablet formulation. Furthermore, dissolution testing serves as a predictive tool for the tablet's behavior in vivo, providing insights into its bioavailability and therapeutic effectiveness. The test also ensures compliance with regulatory standards, demonstrating that the tablet meets the necessary quality requirements. Ultimately, the results of the dissolution test guide formulation optimization, enabling researchers to make necessary adjustments to improve the dissolution characteristics and, consequently, the overall quality and efficacy of the chewable tablets.

3.8.4 Friability test

The tablet friability test was conducted to evaluate the resistance of tablets to abrasion and breakage that normally happen during handling and transportation. The test was performed using an automated friabilator (Model DF-3, Distek, New Jersey, USA, Figure 3.14), following the method described by the United States Pharmacopeia (USP, 2006).

Figure 3.14: Friability tester for tablet friability test

One tablet at a time was weighed and placed in the friability testing apparatus, ensuring it was positioned centrally in the drum. A total of 10 tablets were tested for each cycle. The drum was then secured in the friability tester, and the test was initiated. The drum inside the tester rotated at a speed of 25 revolutions per minute (rpm) for a total of 4 minutes, resulting in 100 revolutions. During this rotation, the

tablets underwent repeated impacts and collisions with the drum walls and other tablets, simulating real-world handling conditions. After the completion of the test, the tablets were carefully removed from the drum, and any loose or broken fragments were collected. The tablets were gently cleaned to remove any adhering particles.

The tablets, along with any fragments collected, were reweighed to determine the amount of weight loss due to abrasion and breakage. The friability was calculated as a percentage by comparing the weight loss with the initial tablet weight.

$$\text{Friability} = \frac{\text{final weight} - \text{initial weight}}{\text{initial weight}} \times 100 \quad (3.15)$$

The closure of this section sets the stage for subsequent mechanical evaluations by providing an understanding of the compaction and frictional aspects during tablet ejection. The acquired data in this phase contributes to a comprehensive understanding of the tablet's manufacturing dynamics.

3.9 Modelling of chewing process and selection of the best tablet formulation

In this phase, the methodology for evaluating the mechanical characteristics of *Parkia speciosa* Hassk chewable tablets were introduced. The focus was on assessing the impacts of compaction pressure, excipient types, and compositions on the tablets' mechanical attributes. Additionally, the establishment of standard parameters for evaluation were detailed out. In order to measure the chewing

efficiency and utilize it as a tool for selecting the best tablet formulation, a method based on the thesis by How (2021) was employed. The study focused on developing a mechanistic chewing model that utilized selection and breakage processes to predict changes in the particle size distribution of the bolus during chewing. The model implementation involved the discretization of a population balance.

3.9.1 Chewing efficiency

To evaluate chewing efficiency and aid in selecting the optimal tablet formulation, the study utilized a methodology adapted from How (2021). This approach focused on modeling the mechanical aspects of chewing and its impact on bolus formation.

Initially, the occlusal area was measured using chewing gum. Subjects were selected based on specific criteria detailed in section 2.5.2.2 to ensure normal occlusion and reliable chewing techniques. The ideal participants had a complete set of post-canine teeth, no history of jaw injuries, no current orthodontic interventions, and did not wear dentures or take medications affecting saliva flow. They were also free from oral disorders and in good overall health. These criteria ensured that the subjects' chewing dynamics closely represented natural conditions, providing accurate data for the study.

The subjects were instructed to chew a piece of gum on their preferred side of the mouth and bite down on it in a single action. A high-resolution image of the chewed gum was captured using a digital compact camera (PowerShot G7x Mark II, Canon, Tokyo, Japan). Image analysis was performed using ImageJ software, which involved converting the images into binary format to isolate the gum's occlusal surface. The software's measurement tools were then used to determine the projected occlusal area, approximating the gum's contact surface with the teeth.

Following this, the chewing of tablets was conducted to assess their efficiency. Two different tablet formulations were used, and each subject chewed both formulations, noting the number of chews and the duration of the chewing process. The subjects continued until they felt the tablets were adequately broken down for swallowing. This data, including the number of chews and the duration, was recorded to analyze the distribution of bolus sizes.

The comparison of bolus sizes and chewing parameters allowed for the evaluation of the mechanical performance of each tablet formulation. This phase aimed to develop mechanistic models to predict changes in particle size distribution during chewing and to identify the formulation with the most desirable chewing efficiency. The results from this analysis were used to guide the selection of the best tablet formulation based on its performance in the chewing process.

3.9.2 Chewing performance

To assess the chewing performance, the subject repeated the chewing process at 25%, 50%, 75%, and 100% of the initial number of chews. After each chewing stage, the chewed tablet was spat onto a petri dish. The subject then gargled 30 mL of mineral water and spat it onto the same dish to ensure the collection of any remaining tablet bolus. The collected bolus was subsequently dissolved in glycerol to separate them. Moisture content and particle size were determined using the loss on drying method (Ileleji et al., 2010), where the particles were subjected to a 105°C oven until fully dry and left for 3 days. Image analysis using ImageJ software was performed to obtain the mean distribution of bolus size by converting the captured images into binary format, setting a threshold to isolate the bolus particles, and then using the software's measurement tools to calculate the area and size distribution of each bolus. This process allowed for precise quantification and statistical analysis of the bolus sizes, ensuring accurate and reproducible results in the assessment of particle size distribution.

By employing this method, the study aimed to explore the development of mechanistic models for chewing and its potential applications in food design. The investigation of chewing efficiency, as well as the analysis chewing performance, provided understandings for the selection of optimal tablet formulations and enhanced control over mechanical outcomes and sensory attributes.

In conclusion, Chapter 3 of this study meticulously outlines the methodology employed to investigate the properties and applications of *Parkia speciosa* Hassk

seeds in tablet formulation. The experimental design was carefully structured to include a comprehensive approach to sample preparation and drying treatments, specifically focusing on extraction, freezing, and freeze-drying processes. Detailed physical and nutritional analyses were conducted to evaluate the seeds' properties, including their antioxidant capacity and moisture content. The development of tablet formulations involved selecting suitable excipients, optimizing their composition, and determining appropriate compaction pressures. Furthermore, the evaluation of compaction and frictional characteristics during ejection, along with various mechanical tests such as indirect tensile strength, dissolution time, and friability, provided critical insights into the tablet's performance. The final part of the study included observing the chewing process to select the best tablet formulation based on efficiency and performance. This thorough methodological framework ensures the reliability and validity of the research findings, contributing significantly to the field of pharmaceutical sciences.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Physical and nutritional properties of freeze-dried *Parkia speciosa* Hassk

The first objective of this study was to conduct a comprehensive analysis of the physical and nutritional properties of *Parkia speciosa* Hassk after undergoing a freeze-drying treatment. These properties play a vital role in understanding the composition and quality of the plant material. Physical attributes, including size, density, and colour, offer understandings into the material's external characteristics. Furthermore, the proximate analysis, which encompasses the determination of total ash, protein, fat, and carbohydrate content, allows us to delve into the nutritional values of *Parkia speciosa* Hassk Additionally, the study evaluates its antioxidant potential using DPPH and FRAP assays, providing insight into its capacity to combat oxidative stress. The results in this section will provide a fundamental understanding of the raw material and its suitability for chewable tablet formulation.

4.1.1 Physical properties of freeze-dried *Parkia speciosa* Hassk and excipients

Table 4.1 summarizes the physical properties of *Parkia speciosa* Hassk following a freeze-drying treatment for tablet compaction.

Table 4.1: Physical properties of freeze-dried *Parkia speciosa* Hassk

Property	Value
Particle size distribution (µm)	3.2
Bulk density (g/cm^3)	0.4758
Tapped density (g/cm^3)	0.6698
True density (g/cm^3)	1.3384

The particle size distribution, at 3.2 µm, indicates the presence of fine particles, contributing to desirable flowability and content uniformity in tablet formulation. The bulk density of 0.4758 g/cm^3 suggested that the powder contains void spaces, influencing its flowability. However, the higher tapped density (0.6698 g/cm^3) signifies that the powder can be effectively compacted into tablets. The true density, considerably higher at 1.3384 g/cm^3, suggests the presence of interstitial spaces between particles. These physical properties collectively suggest that the dried *Parkia speciosa* Hassk powder was well-suited for tablet compaction, with its fine particle size and favourable tapped density.

Tablettose® 80 is an agglomerated alpha lactose monohydrate with a particle size distribution such that less than 63 microns accounts for no more than 20% of the material, less than 180 microns represents 40-75%, less than 400 microns is at least 85%, and less than 630 microns makes up at least 97%. It has a bulk density of 0.62 g/ml and a tapped density of 0.77 g/ml.

FlowLac® 90 is a spray-dried lactose excipient with a particle size distribution where less than 32 microns constitutes no more than 5% of the material, less than

100 microns represents 25-40%, and less than 200 microns is at least 85%. Its bulk density is 0.56 g/ml, and its tapped density is 0.67 g/ml.

MicroceLac® 100 is a co-processed excipient containing 75% lactose monohydrate and 25% microcrystalline cellulose. Its particle size distribution includes less than 32 microns making up no more than 15%, less than 160 microns representing 45-70%, and less than 250 microns at least 90%. The bulk density of MicroceLac® 100 is 0.46 g/ml, with a tapped density of 0.58 g/ml.

4.1.2 Flowability properties of freeze-dried *Parkia speciosa* Hassk

The relationship between particle size and flowability of freeze-dried *Parkia speciosa* Hassk powder can be better understood by examining various parameters as summarized in Table 4.2.

Table 4.2: Flowability properties of *Parkia speciosa* Hassk powder and excipients

Property	*Parkia speciosa* Hassk	Tablettose® 80	FlowLac® 90	MicroceLac® 100
Angle of repose	22.44° (Good)	11.5°(Excellent)	8.9°(Excellent)	9.7° (Excellent)
Carr's index	28.96% (Poor)	19.48% (Fair)	16.42% (Fair)	20.69%(Passable)
Hausner ratio	1.41 (Poor)	1.24 (Fair)	1.20 (Fair)	1.26 (Passable)

The angle of repose is an important parameter that indicates the flowability of a powder. In this study, the angle of repose was 22.44 degrees. This relatively low angle of repose indicates good flowability, suggesting that the *Parkia speciosa* Hassk powder can move freely, which is advantageous for the compaction of chewable tablets.

Carr's index and the Hausner ratio are additional parameters used to evaluate powder flowability. Carr's index measures the compressibility of a powder, where a lower value indicates better flow properties. In this study, Carr's index was 28.96%, which is considered moderately high and classified as 'poor' flowability (Maddiboyina et al., 2020). This suggests that the powder may not flow as freely as required without the assistance of additional materials. Similarly, the Hausner ratio, calculated by dividing the tapped density by the bulk density, further assesses flowability. A Hausner ratio close to 1 signifies good flow properties, but the ratio for *Parkia speciosa* Hassk was 1.41. This higher value indicates poor flowability, suggesting that the powder might experience difficulty flowing without external aids (Suhag et al., 2024).

The particle size of Parkia speciosa Hassk powder contributes to its potential for good flowability, as indicated by its fine particles. However, practical flowability assessments reveal that the powder has moderate to poor flowability according to Carr’s index and Hausner ratio. This suggests that while the powder can form a stable pile (angle of repose), it may encounter difficulties in actual compaction and processing without the addition of flow-enhancing excipients or agents. Thus, optimizing the formulation with suitable excipients will be essential to ensure

smooth processing and compaction of Parkia speciosa Hassk into chewable tablets.

4.1.3 Nutritional properties of freeze-dried *Parkia speciosa* Hassk

The nutrient composition of freeze-dried *Parkia speciosa* Hassk seeds is summarized in Table 4.3. The nutritional properties encompass a range of aspects, from macronutrients to antioxidant capacity, offering meaningful observations into the potential health benefits and culinary applications of this versatile ingredient.

Table 4.3: Nutrient composition of freeze-dried *Parkia speciosa Hassk*

Component	Composition (per 100 g)
Total Ash (g)	3.6
Protein (g)	15.5
Total Fat – Soxhlet (g)	7.0
Carbohydrate (g)	67
Energy (kcal)	393
DPPH (% inhibition)	80.28
FRAP (mg/ml Vit C equivalence)	5.99
Total Polyphenol (GAE) (mg/g)	86.67

Total ash is a measure of the residual inorganic material left behind when organic matter is completely incinerated or burned at a high temperature. Often used as a quality control parameter, it helps ensure that the plant material or powder is free from contaminants, such as soil, sand, or other impurities. As expected, the value of total ash remains within the range of 1.2 to 4.6 g per 100 g. The high protein content of 15.5 g per 100 g is especially significant, making *Parkia*

speciosa Hassk a valuable protein source, particularly in regions where access to animal protein may be limited. Additionally, the moderate fat content (7.0 g per 100 g) and carbohydrate content (67 g per 100 g) provide a well-rounded nutritional package suitable for diverse dietary preferences. The observed results show that the energy value of 393 kcal per 100 g aligns with previous data from Kamisah et al. (2013), indicating consistency in energy content. However, the carbohydrate value being higher in this study suggests potential variations in the sample composition or differences in measurement methodologies. Factors such as geographical location, cultivation practices, or sample processing techniques could contribute to these discrepancies (Ghasemzadeh et al., 2018). Such variations are common in food composition studies and highlight the need for standardized protocols to ensure comparability across different studies.

The tablets' antioxidant properties namely 1,1-diphenyl-2-picrylhydrazyl (DPPH) inhibition and ferric ion antioxidant potential (FRAP) were evaluated in the study (Table 4.3). The DPPH radical-scavenging assay was done to measure the ability of the compound to donate hydrogen to the DPPH radical. In this study, the DPPH inhibition rate of 80.28% indicates that *Parkia speciosa* Hassk has a high capacity to scavenge free radicals. The FRAP assay was done to determine the antioxidant activity of a compound by measuring its redox property to reduce the ferric ion by single electron donation. The FRAP value in this study was 5.99 mg/ml of vitamin C equivalence. This indicates that *Parkia speciosa* Hassk is capable of reducing ferric ions and, by extension, neutralizing free radicals. The total polyphenol content assay commonly uses gallic acid as a standard and was found to be 86.67

mg/g. These values emphasize the potential of *Parkia speciosa* Hassk to combat oxidative stress in the body, contributing to overall health (Hayati Azizul, 2019; Izzah Ahmad et al., 2019; Kamisah et al., 2013; Ko et al., 2014). The antioxidant content and activity of *Parkia speciosa* Hassk is considered high amongst edible plants (Ali et al., 2011; Maisuthisakul et al., 2008; Wong et al., 2006) especially its TPC.

4.2 Effects of compaction pressure on tablet compaction behaviour

The second objective of this research was to investigate the influence of compaction pressure on the compaction behaviour of *Parkia speciosa* Hassk chewable tablets. The compaction process is a critical step in tablet manufacturing and understanding how varying compaction pressures impact this process is crucial. In this section, we will explore how different levels of compaction pressure affect the tablet's plastic work, elastic work, ejection pressure, and ejection work. By examining these compaction parameters, we can gain understandings into the tablet's ability to withstand mechanical forces and its suitability for chewable tablet applications.

4.2.1 Plastic work during the compaction process

The plastic work value was obtained during the loading stage of the compaction process. It represents the apparent work done during the loading stage, where the particulate materials are compacted into tablet form (Alderborn & Nyström, 1996). This work encompasses the energy expended in deforming the tablet material and overcoming interparticulate forces, which are largely influenced by

friction at various interfaces. An understanding of the relationship between compaction pressure and plastic work is instrumental in optimizing tablet formulations and compaction processes.

Table 4.4 and Figure 4.1 summarize the plastic work of *Parkia speciosa* Hassk chewable tablet following different compaction pressures. The data reveals the influence of different excipients (Tablettose® 80, FlowLac® 90, and MicroceLac® 100) and their compositions (14.07%, 29.41%, and 44.11%) on the plastic work required during compaction at varying pressures (22.61MPa, 37.68MPa, 52.75MPa, and 67.82MPa). A closer examination of the data shows that both excipient type and composition significantly affect the plastic work. For instance, the use of Tablettose® 80 at 44.11% composition requires the highest plastic work, indicating a higher energy demand during compaction. Higher compaction pressures may reduce porosity, but they can also increase the energy expended in the process, thereby affecting tablet quality.

Figure 4.1 shows that plastic work increases with rising compaction pressure for all excipients tested. This trend indicates that as pressure increases, more energy is required to compact the tablet, reflecting a greater deformation and densification of the particulate material. For instance, Tablettose® 80 at 44.11% composition shows the highest plastic work values across all pressures, suggesting a substantial energy requirement during compaction. This is consistent with studies such as Jamar et al. (2020), which noted that increased compaction pressure in coffee powder also led to higher plastic work due to greater particle deformation and inter-particle bonding. Similarly, Radzali et al.

(2018) and Yaakub et al. (2018) observed that higher compaction pressures resulted in increased plastic work for various powders, aligning with the trend seen in this study.

Table 4.4: Plastic work of *Parkia speciosa* Hassk chewable tablet at different compaction pressures

Excipient	Composition of excipient	Compaction pressure (MPa)	*Plastic work (kJ)
Control	0%	22.61	22.61 ± 1.50
		37.68	90.06 ± 2.10
		52.75	148.23 ± 3.00
		67.82	278.06 ± 4.50
Tablettose® 80	14.07%	22.61	41.15 ± 1.70
		37.68	113.04 ± 2.40
		52.75	175.66 ± 3.50
		67.82	250.26 ± 4.70
	29.41%	22.61	48.61 ± 1.80
		37.68	125.85 ± 2.60
		52.75	225.77 ± 3.80
		67.82	310.62 ± 4.90
	44.11%	22.61	57.43 ± 2.00
		37.68	157.50 ± 3.00
		52.75	289.60 ± 4.20
		67.82	438.12 ± 5.50

Table 4.4: Continued

FlowLac® 90	14.07%	22.61	18.09 ± 1.20
		37.68	48.23 ± 1.80
		52.75	100.23 ± 2.70
		67.82	172.26 ± 3.90
	29.41%	22.61	18.54 ± 1.30
		37.68	71.22 ± 2.00
		52.75	141.90 ± 3.10
		67.82	300.44 ± 4.40
	44.11%	22.61	49.29 ± 1.90
		37.68	120.58 ± 2.80
		52.75	199.92 ± 3.60
		67.82	306.55 ± 4.80
MicroceLac® 100	14.07%	22.61	45.90 ± 1.60
		37.68	43.71 ± 1.70
		52.75	100.75 ± 2.50
		67.82	301.12 ± 4.20
	29.41%	22.61	54.04 ± 1.90
		37.68	66.69 ± 2.30
		52.75	129.24 ± 3.20
		67.82	213.63 ± 3.90
	44.11%	22.61	68.51 ± 2.10
		37.68	116.43 ± 3.00
		52.75	184.10 ± 3.70
		67.82	257.72 ± 4.50

*Values are mean ± SD

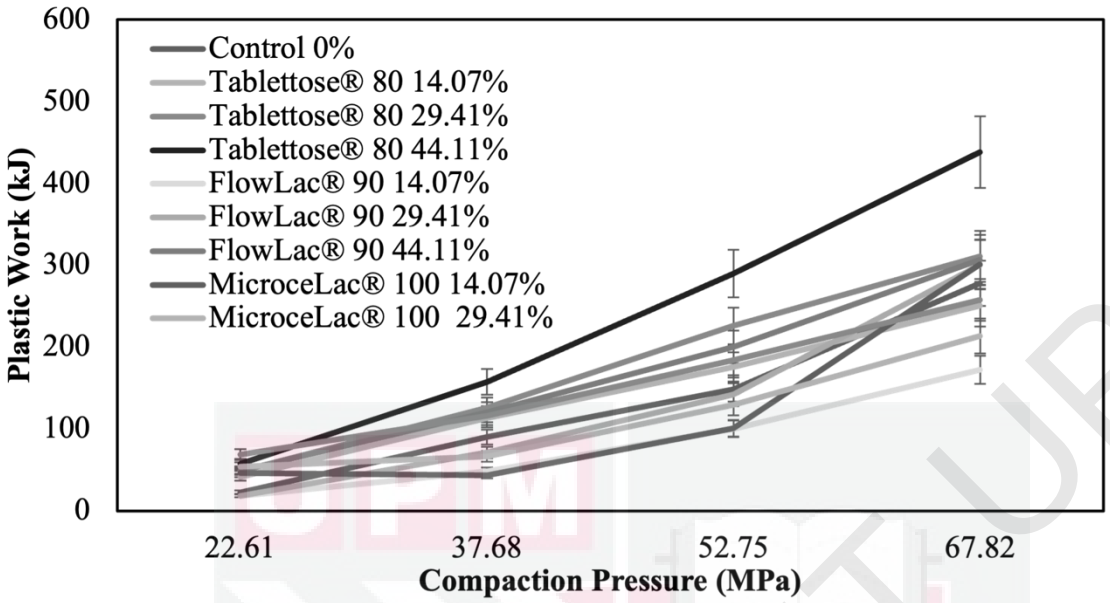

Figure 4.1: Plastic work of *Parkia speciosa* Hassk chewable tablet at different compaction pressures

The plastic work generally increased with increasing values of the compaction pressure used to compact *Parkia speciosa* Hassk chewable tablet. When higher compaction pressures are applied, the particle bed undergoes greater deformation, resulting in stronger inter-particulate bonds and a more coherent and mechanically robust tablet. This phenomenon can be explained by the increased contact area between particles, leading to better particle rearrangement and densification.

A similar trend has been observed in the compaction of other materials. For instance, in the compaction of coffee powder, increased compaction pressure also led to increased plastic work, resulting in tablets with greater tensile strength and cohesion. This is attributed to the permanent deformation and interlocking of coffee particles under higher pressures (Jamar et al., 2020).

Carboxymethylcellulose powder exhibits a comparable behavior; higher compaction pressures enhance plastic deformation, which in turn improves the integrity and mechanical strength of the resulting tablets (Radzali et al., 2018).

Similarly, a lactose-sodium starch glycolate binary powder mixture showed increased plastic work with higher compaction pressures, leading to stronger tablets due to enhanced particle bonding (Yaakub et al., 2018). The same effect was noted in the compaction of stevia and sweet potato powders, where higher pressures resulted in tablets with superior mechanical properties (Shamsudin et al., 2012). In a recent study by Mukri et al. (2021), mannitol-cocoa powder mixtures also followed this trend, with increased compaction pressure leading to increased plastic deformation and stronger, more coherent tablets.

4.2.2 Elastic work during the compaction process

Elastic work is an often-overlooked parameter that provides understanding of the energy expended during the tablet's deformation. Understanding the elastic work required for tablet deformation is crucial in optimizing tablet formulations and production processes, as it directly impacts the tablet's mechanical performance.

Table 4.5 and Figure 4.2 summarize the elastic work of *Parkia speciosa* Hassk chewable tablet following different compaction pressures. The data reveals the influence of different excipients (Tablettose® 80, FlowLac® 90, and MicroceLac® 100) and their compositions (14.07%, 29.41%, and 44.11%) on the elastic work required during compaction at varying pressures (22.61MPa, 37.68MPa, 52.75MPa, and 67.82MPa). A closer examination of the data shows that both

excipient type and composition significantly affect the elastic work values. For instance, Tablettose® 80 at 44.11% composition requires the highest elastic work, indicating a higher energy demand during compaction. In contrast, FlowLac® 90 at 14.07% composition requires the lowest elastic work. The higher elastic work observed at lower compaction pressures for MicroceLac® 100 at 14.07% and 29.41% compositions requires further research with a larger sample size and detailed analysis.

Figure 4.2 shows the elastic work data, which also generally increases with compaction pressure. However, there are notable fluctuations in the data, especially for MicroceLac® 100, where the elastic work values at different compositions and pressures exhibit irregular patterns. For example, at a 14.07% composition, the elastic work decreases with increasing pressure, contrary to the expected trend. This inconsistency suggests that the material's response to pressure is not uniform across different excipients and compositions. Studies by Jamar et al. (2020) reported that elastic work should increase with pressure, indicating that the observed deviations may be due to experimental or material-specific factors that require further investigation. The observed fluctuations in elastic work may also reflect differences in how each excipient and its concentration affect the recoverable energy during compaction, impacting the final tablet's mechanical performance.

Table 4.5: Elastic work of *Parkia speciosa* Hassk chewable tablet at different compaction pressures

Excipient	Composition of excipient	Compaction pressure (MPa)	*Elastic work (kJ)
Control	0%	22.61	1.81 ± 0.18
		37.68	2.39 ± 0.24
		52.75	2.81 ± 0.28
		67.82	4.10 ± 0.41
Tablettose® 80	14.07%	22.61	1.82 ± 0.18
		37.68	3.00 ± 0.30
		52.75	3.33 ± 0.33
		67.82	3.69 ± 0.37
	29.41%	22.61	2.15 ± 0.22
		37.68	3.34 ± 0.33
		52.75	4.28 ± 0.43
		67.82	4.58 ± 0.46
	44.11%	22.61	2.54 ± 0.25
		37.68	4.18 ± 0.42
		52.75	5.49 ± 0.55
		67.82	6.46 ± 0.65

Table 4.5: Continued

	14.07%	**22.61**	**0.80 ± 0.08**
		37.68	1.28 ± 0.13
		52.75	1.90 ± 0.19
		67.82	2.54 ± 0.25
FlowLac® 90	29.41%	22.61	0.82 ± 0.08
		37.68	1.89 ± 0.19
		52.75	2.69 ± 0.27
		67.82	4.43 ± 0.44
	44.11%	22.61	2.18 ± 0.22
		37.68	3.20 ± 0.32
		52.75	3.79 ± 0.38
		67.82	4.52 ± 0.45
MicroceLac® 100	14.07%	22.61	2.03 ± 0.20
		37.68	1.16 ± 012
		52.75	1.91 ± 0.19
		67.82	4.44 ± 0.44
	29.41%	22.61	2.39 ± 0.24
		37.68	1.77 ± 0.18
		52.75	2.45 ± 0.25
		67.82	3.15 ± 0.32
	44.11%	22.61	3.03 ± 0.30
		37.68	3.09 ± 0.31
		52.75	3.49 ± 0.35
		67.82	3.80 ± 0.38

*Values are mean ± SD

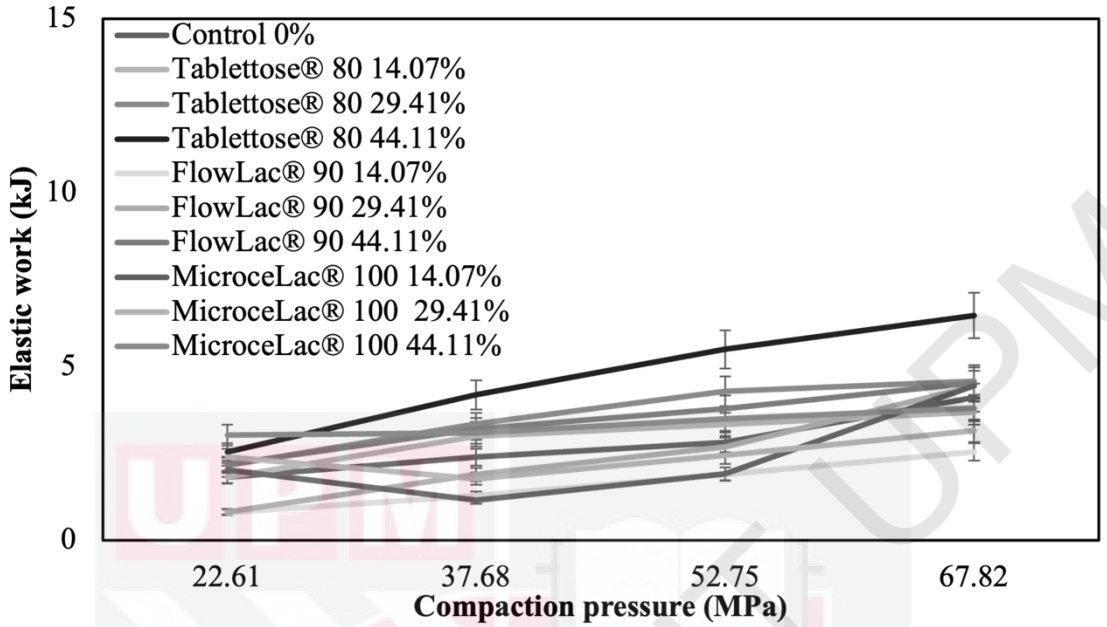

Figure 4.2: Elastic work of *Parkia speciosa* Hassk chewable tablet at different compaction pressures.

The elastic work, which refers to the recoverable energy stored during the compaction process, generally increases with higher compaction pressures. This trend was observed in the compaction of *Parkia speciosa* Hassk chewable tablets. When higher compaction pressures are applied, the particle bed undergoes greater elastic deformation. Upon decompression, the stored elastic energy can cause the particles to rebound, which may affect the tablet's final properties.

A study on coffee powder compaction by Jamar et al. (2020) also reported an increase in elastic work with higher compaction pressures. This was attributed to the increased resistance to deformation as the particles were more densely packed, leading to higher elastic recovery upon pressure release. Similarly, Radzali et al. (2018) found that carboxymethylcellulose powder exhibited higher

elastic recovery at greater compaction pressures, which affected the tablet's structural integrity.

Another study by Yaakub et al. (2018) on a lactose-sodium starch glycolate binary powder mixture demonstrated that higher compaction pressures led to greater elastic deformation, which in turn influenced the tablet's mechanical strength and disintegration properties. Additionally, a study by Shamsudin et al. (2012) on stevia and sweet potato powders indicated that higher compaction pressures increased the elastic work, affecting the tablet's robustness and dissolution rate.

Recently, Mukri et al. (2021) investigated mannitol-cocoa powder mixtures and found that the elastic work increased with compaction pressure, which had implications for the tablet's durability and release profile. These studies collectively highlight that higher compaction pressures lead to increased elastic deformation, affecting the final characteristics of the tablets.

These findings carry substantial implications for pharmaceutical tablet formulation and production. The choice of excipient and its composition can influence the mechanical behaviour of tablets during compaction. Manufacturers can use this information to optimize tablet formulations, ensuring they meet the desired specifications for hardness, disintegration, and dissolution. Moreover, a deeper understanding of the compaction behaviour can lead to improved tablet quality, reducing the risk of defects such as capping, lamination, or insufficient hardness.

4.2.3 Frictional characteristics

Frictional forces within the tablet compaction process are multifaceted and exert influence at several stages of tablet production. These forces come into play during powder filling, die filling, compression, and, notably, tablet ejection. When it comes to ejection, in particular, the friction between the tablet and the die wall, as well as between the tablet and the punch face, can determine the ease and success of tablet removal from the compression tooling. The characteristics of this friction are crucial, as excessive friction may lead to tablet sticking, capping, lamination, and other quality issues. Conversely, insufficient friction might result in tablets being ejected prematurely, causing damage or imperfections.

4.2.3.1 Maximum ejection pressure

Ejection pressure, on the other hand, is the force required to overcome the frictional resistance that impedes tablet release from the compression tooling. The ejection phase is crucial in ensuring the uniformity and integrity of the tablets. Compaction pressure can significantly impact ejection pressure, as higher pressures might lead to greater interfacial friction, which, in turn, necessitates a higher ejection force. Balancing this force with the tablet's strength and the frictional characteristics becomes a critical consideration in tablet production. Table 4.6 and Figure 4.3 summarize the maximum ejection pressure of *Parkia speciosa* Hassk chewable tablet following different compaction pressures. The data reveals the influence of different excipients (Tablettose® 80, FlowLac® 90, and MicroceLac® 100) and their compositions (14.07%, 29.41%, and 44.11%) on

the ejection pressure required during compaction at varying pressures (22.61MPa, 37.68MPa, 52.75MPa, and 67.82MPa). A closer examination of the data shows that both excipient type and composition significantly affect the maximum ejection pressure values. For instance, Tablettose® 80 at 44.11% composition requires the highest maximum ejection pressure, indicating a higher energy demand during compaction. While FlowLac® 90 at 29.4% composition required the lowest maximum ejection pressure. The inconsistencies of ejection pressure data observed at lower compaction pressures for certain formulations require further research with a larger sample size and detailed analysis.

The maximum ejection pressure needed to extrude the tablet from the die was used as the friction indicator in this work. The maximum ejection pressure was the highest force recorded when ejecting the tablet from the die divided by the cross-sectional area of the tablet (Mukri et al., 2021). A trend of increasing maximum pressure with the compaction pressure was also found in previous studies such as in the lactose-sodium starch glycolate tablets (Yaakub et al., 2018) and urea tablets (Shamsudin et al., 2019)

Table 4.6: Maximum ejection pressure of *Parkia speciosa* Hassk chewable tablet at different compaction pressures

Excipient	Composition of excipient	Compaction pressure (MPa)	*Ejection pressure (Pa)
Control	0%	22.61	0.034 ± 0.003
		37.68	0.031 ± 0.003
		52.75	0.082 ± 0.008
		67.82	0.117 ± 0.001

Table 4.6: Continued

Tablettose® 80	14.07%	22.61	0.032 ± 0.003
		37.68	0.129 ± 0.001
		52.75	0.132 ± 0.001
		67.82	0.028 ± 0.003
	29.41%	22.61	0.154 ± 0.015
		37.68	0.045 ± 0.005
		52.75	0.060 ± 0.006
		67.82	0.041 ± 0.004
	44.11%	22.61	0.073 ± 0.007
		37.68	0.234 ± 0.023
		52.75	0.069 ± 0.007
		67.82	0.095 ± 0.010
FlowLac® 90	14.07%	22.61	0.007 ± 0.001
		37.68	0.118 ± 0.012
		52.75	0.115 ± 0.012
		67.82	0.108 ± 0.011
	29.41%	22.61	0.038 ± 0.004
		37.68	0.013 ± 0.001
		52.75	0.017 ± 0.002
		67.82	0.034 ± 0.003
	44.11%	22.61	0.074 ± 0.007
		37.68	0.017 ± 0.002
		52.75	0.024 ± 0.002
		67.82	0.114 ± 0.011

Table 4.6: Continued

	14.07%	**22.61**	**0.059 ± 0.006**
		37.68	0.009 ± 0.001
		52.75	0.060 ± 0.006
		67.82	0.078 ± 0.008
MicroceLac® 100	29.41%	22.61	0.052 ± 0.005
		37.68	0.046 ± 0.005
		52.75	0.080 ± 0.008
		67.82	0.095 ± 0.010
	44.11%	22.61	0.045 ± 0.005
		37.68	0.041 ± 0.004
		52.75	0.012 ± 0.001
		67.82	0.019 ± 0.002

*Values are mean ± SD

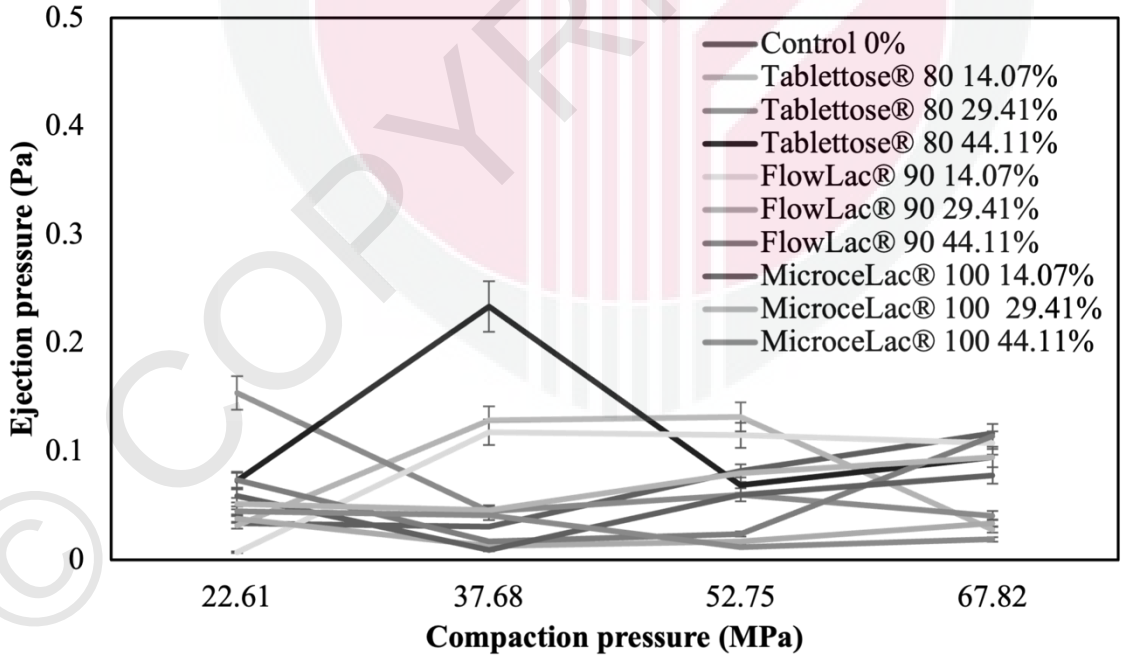

Figure 4.3: Maximum ejection pressure of *Parkia speciosa* Hassk chewable tablet at different compaction pressures

4.2.3.2 Ejection work

Table 4.7 and Figure 4.4 present an overview of the tablet ejection work for *Parkia speciosa* Hassk under varying compaction pressures. The data illustrates how different excipients (Tablettose® 80, FlowLac® 90, and MicroceLac® 100) and their compositions (14.07%, 29.41%, and 44.11%) influence the ejection work required during compaction at pressures ranging from 22.61MPa to 67.82MPa. Analysis of the results highlights that both the type of excipient and its proportion significantly impact the ejection pressure values. Generally, as the compaction pressure increases, so does the ejection work for producing chewable tablets from *Parkia speciosa* Hassk. However, tablets formulated with Tablettose® 80 at 44.11% composition required the highest ejection work, indicating greater energy demand during compaction. The higher ejection work and ejection pressure observed for Tablettose® 80 at 44.11% composition can be attributed to its hygroscopic nature, which causes the particles to bind more strongly together during compaction. This increased cohesiveness leads to greater resistance during the tablet's ejection from the die, thereby requiring more energy. Additionally, the higher percentage of Tablettose® 80 may have caused enhanced densification of the tablet, increasing friction between the tablet and die walls, further contributing to the elevated ejection work.

Other formulations show relatively constant ejection work except for Tablettose® 80 at 44.11% and 14.07% compositions, as well as FlowLac® 90 at 14.07% composition, where fluctuations in the measured ejection works were obtained. These fluctuations could be attributed to variations in the physical properties of

these excipients at different compositions. The tablet stored elastic energies caused the tablet to expand diametrically onto the die walls during ejecting (Anuar & Briscoe, 2009, 2010). This would then give rise to the resistance to tablet motion due to frictional effects between the tablet and the die wall surfaces.

Table 4.7: Ejection work of *Parkia speciosa* Hassk chewable tablet at different compaction pressures

Excipient	Composition of excipient	Compaction pressure (MPa)	*Ejection work (J)
Control	0%	22.61	0.21 ± 0.02
		37.68	0.20 ± 0.02
		52.75	0.49 ± 0.05
		67.82	0.73 ± 0.07
Tablettose® 80	14.07%	22.61	0.20 ± 0.02
		37.68	0.80 ± 0.08
		52.75	0.81 ± 0.08
		67.82	0.18 ± 0.02
	29.41%	22.61	0.95 ± 0.10
		37.68	0.28 ± 0.03
		52.75	0.38 ± 0.04
		67.82	0.26 ± 0.03
	44.11%	22.61	0.46 ± 0.05
		37.68	7.01 ± 0.70
		52.75	0.43 ± 0.04
		67.82	0.59 ± 0.06

Table 4.7: Continued

FlowLac® 90	14.07%	22.61	0.04 ± 0.01
		37.68	1.47 ± 0.15
		52.75	0.75 ± 0.08
		67.82	1.99 ± 0.20
	29.41%	22.61	0.24 ± 0.02
		37.68	0.08 ± 0.01
		52.75	0.11 ± 0.01
		67.82	0.21 ± 0.02
	44.11%	22.61	0.46 ± 0.05
		37.68	0.11 ± 0.01
		52.75	0.15 ± 0.02
		67.82	0.70 ± 0.07
MicroceLac® 100	14.07%	22.61	0.37 ± 0.04
		37.68	0.51 ± 0.05
		52.75	0.37 ± 0.04
		67.82	0.49 ± 0.05
	29.41%	22.61	0.33 ± 0.03
		37.68	0.29 ± 0.03
		52.75	0.49 ± 0.05
		67.82	0.59 ± 0.06
	44.11%	22.61	0.29 ± 0.03
		37.68	0.26 ± 0.03
		52.75	0.08 ± 0.01
		67.82	0.12 ± 0.01

*Values are mean ± SD

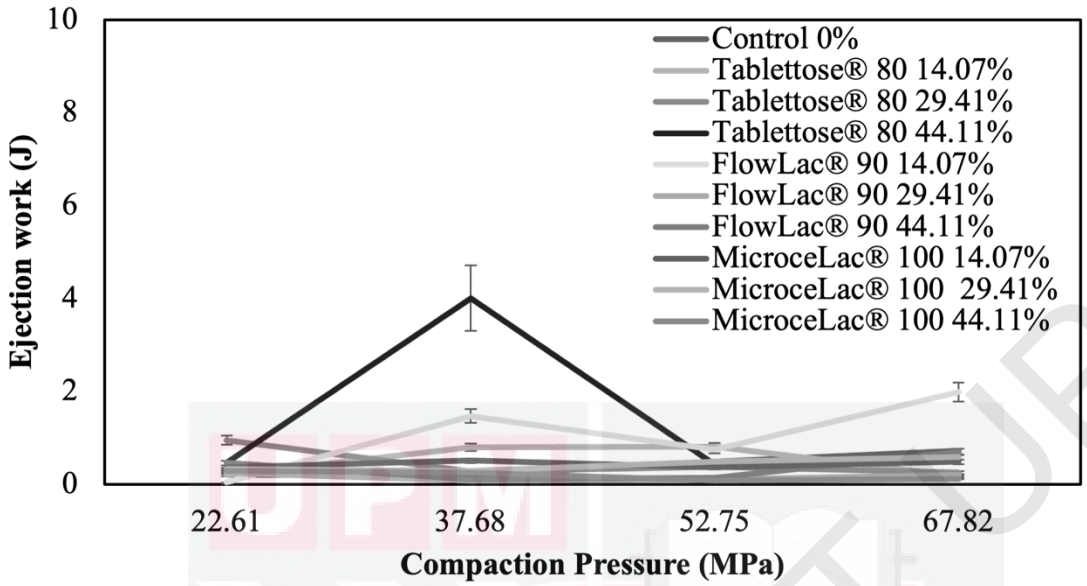

Figure 4.4: Ejection work of *Parkia speciosa* Hassk chewable tablet at different compaction pressures

4.3 Effects of compaction pressure on tablet mechanical characteristics

The third objective directs our attention toward assessing the effects of compaction pressure on the mechanical characteristics of *Parkia speciosa* Hassk chewable tablets. Mechanical attributes, including tensile strength, fracture energy, friability, and dissolution time, are vital indicators of tablet performance and quality. This section will provide understandings into the relationship between compaction pressure and the mechanical characteristics of tablets. The tensile strength, elastic work, and fracture energy assessed after 24 hours of direct compaction; it is aimed to provide a comprehensive understanding of how pharmaceutical and nutraceutical manufacturers can balance the need for robust tablets with the requirements of effective medication delivery. This knowledge will, in turn, contribute to the production of pharmaceutical and nutraceutical tablets

that meet the highest standards of quality, ensuring the health and well-being of patients and consumers worldwide.

The process of tablet compaction, where powdered ingredients are transformed into solid tablets under the influence of compaction pressure, is a delicate and meticulously controlled operation. The pressure applied during compaction can significantly impact the mechanical properties of the tablet. Higher pressures are known to reduce porosity, increasing the density and strength of the tablet. However, this increased strength must be balanced against other mechanical characteristics, as excessively strong tablets may become brittle, impacting their ability to disintegrate and release their contents.

4.3.1 Tensile strength

Tablets must possess a suitable mechanical strength to avoid crumbling or breaking when handling, while ensuring an appropriate disintegration after administration. Tensile strength is a critical indicator of a tablet's resistance to mechanical stresses, reflecting its ability to withstand both internal and external forces. It is an essential attribute that affects the tablet's handling, packaging, and, most importantly, its ability to disintegrate and release the active ingredient effectively once ingested. Accordingly, the tablet tensile strength is an essential parameter to consider (Pai et al., 2013; Shang et al., 2013; Wu & Seville, 2009) and is therefore standardly tested during the manufacturing process (Bouin & Wierer, 2014).

Table 4.8 and Figure 4.5 summarize the tablet tensile strength of *Parkia speciosa* Hassk following different compaction pressures. The data reveals the influence of different excipients (Tablettose® 80, FlowLac® 90, and MicroceLac® 100) and their compositions (14.07%, 29.41%, and 44.11%) on the tables tensile strength required during compaction at varying pressures (22.61MPa, 37.68MPa, 52.75MPa, and 67.82MPa). The tablets tensile strength increased resulting in relatively stronger tablets when the compaction pressure increased from 37.68 MPa to 67.82 MPa as shown by the MicroceLac® 100 at 44.11% composition (Mukri et al., 2021).

At higher compaction pressure of 52.75MPa, MicroceLac® 100 at 29.41%, Tablettose® 80 at 29.41% and 44.11% as well as control tablets exhibited relatively constant tensile strength values. Meanwhile, fluctuations in the tensile strength values were observed for the FlowLac® 90 at 44.11%, Tablettose® 80 at 44.11%, and MicroceLac® 100 at 14.07% and 29.41% tablets while an approximately linear increase was portrayed by the MicroceLac® 100 at 44.11% tablets. Notably, MicroceLac® 100 at 44.11% produced the strongest tablets overall, contrasting with FlowLac® 90 at 14.07%, which consistently showed the weakest tablet strength across all compaction pressures tested. The findings indicate that excipient composition plays a crucial role in determining tablet tensile strength across varying compaction pressures. The observed fluctuations in tensile strength highlight the complex interplay between excipient properties and compaction conditions. Further investigation is needed to elucidate the specific mechanisms behind these fluctuations, which could include differences in particle

size distribution, binding properties, and interparticle forces influencing tablet cohesion and mechanical integrity (Van Veen et al 2000).

Table 4.8: Tensile strength of *Parkia speciosa* Hassk chewable tablet at different compaction pressures

Excipient	Composition of excipient	Compaction pressure (MPa)	*Tensile strength (MPa)
Control	0%	22.61	0.1710 ± 0.0150
		37.68	0.1684 ± 0.0140
		52.75	0.1867 ± 0.0160
		67.82	0.1828 ± 0.0150
Tablettose® 80	14.07%	22.61	0.1580 ± 0.0130
		37.68	0.2081 ± 0.0170
		52.75	0.1931 ± 0.0160
		67.82	0.1832 ± 0.0150
	29.41%	22.61	0.1558 ± 0.0130
		37.68	0.2064 ± 0.0170
		52.75	0.2259 ± 0.0190
		67.82	0.1992 ± 0.0160
	44.11%	22.61	0.1275 ± 0.0100
		37.68	0.2087 ± 0.0170
		52.75	0.3163 ± 0.0250
		67.82	0.1883 ± 0.0150

Table 4.8: Continued

	14.07%	**22.61**	**0.1595 ± 0.0130**
		37.68	0.1557 ± 0.0130
		52.75	0.1589 ± 0.0130
		67.82	0.1413 ± 0.0110
FlowLac® 90	29.41%	22.61	0.2054 ± 0.0170
		37.68	0.2449 ± 0.0200
		52.75	0.2430 ± 0.0200
		67.82	0.2286 ± 0.0180
	44.11%	22.61	0.2257 ± 0.0180
		37.68	0.3085 ± 0.0250
		52.75	0.2086 ± 0.0170
		67.82	0.2815 ± 0.0230
MicroceLac® 100	14.07%	22.61	0.2103 ± 0.0170
		37.68	0.1658 ± 0.0130
		52.75	0.1486 ± 0.0120
		67.82	0.2718 ± 0.0220
	29.41%	22.61	0.1669 ± 0.0130
		37.68	0.1349 ± 0.0110
		52.75	0.2349 ± 0.0190
		67.82	0.2035 ± 0.0160
	44.11%	22.61	0.2405 ± 0.0190
		37.68	0.3367 ± 0.0270
		52.75	0.3846 ± 0.0310
		67.82	0.3669 ± 0.0290

*Values are mean ± SD

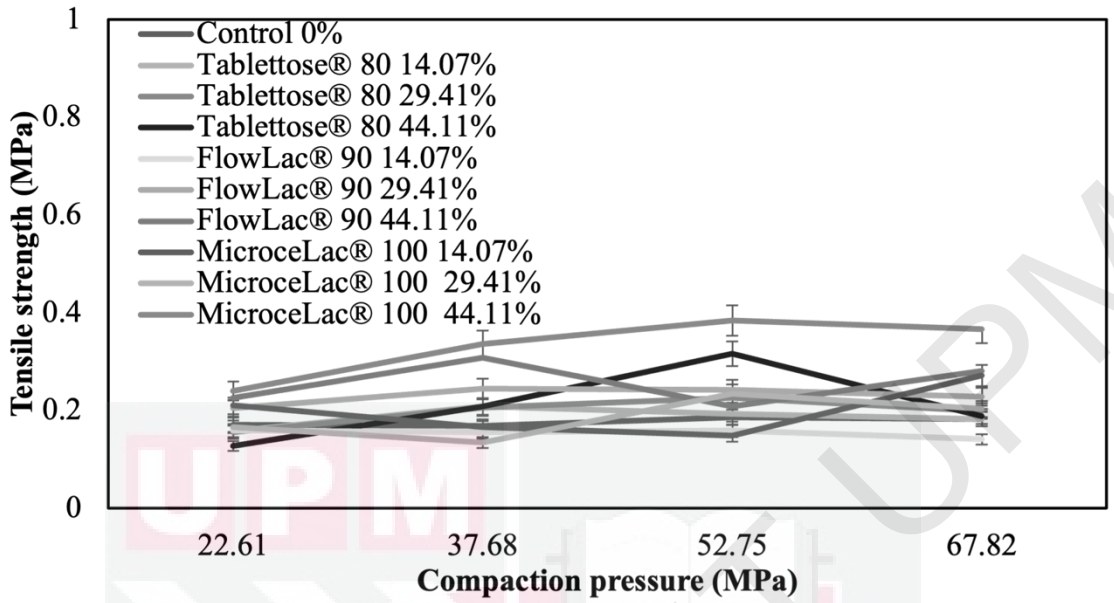

Figure 4.5: Tensile strength of *Parkia speciosa* Hassk chewable tablet at different compaction pressures

4.3.2 Fracture energy

Fracture energy, as assessed through the Brazilian test, is an essential aspect of tablet behaviour. This parameter reveals the energy absorbed by the tablet as it fractures, offering critical understandings into the tablet's mechanical integrity and its ability to withstand external forces and environmental factors.

Table 4.9 and Figure 4.6 summarize the tablet fracture energy of *Parkia speciosa* Hassk following different compaction pressures. The data reveals the influence of different excipients (Tablettose® 80, FlowLac® 90, and MicroceLac® 100) and their compositions (14.07%, 29.41%, and 44.11%) on the tablet fracture energy required during compaction at varying pressures (22.61MPa, 37.68MPa, 52.75MPa, and 67.82MPa). The tablet fracture energy increased with increasing

compaction pressure resulting in relatively stronger tablets as shown by the MicroceLac® 100 at 44.11% composition tablet.

At higher compaction pressure of 67.82MPa, MicroceLac® 100 at 44.11% and FlowLac® 90 at 44.11% composition tablets exhibit the highest fracture energy value. In contrast, the weakest tablet was observed in the control tablet at all the compaction pressures. Thus, indicating that the excipients contribute to stronger tablet.

Table 4.9: Fracture energy of *Parkia speciosa* Hassk chewable tablet at different compaction pressures

Excipient	Composition of excipient	Compaction pressure (MPa)	*Fracture energy (J)
Control	0%	22.61	1.35 ± 0.12
		37.68	1.98 ± 0.15
		52.75	2.18 ± 0.17
		67.82	0.87 ± 0.08
Tablettose® 80	14.07%	22.61	2.52 ± 0.21
		37.68	1.95 ± 0.16
		52.75	2.51 ± 0.20
		67.82	1.94 ± 0.16
	29.41%	22.61	2.57 ± 0.22
		37.68	2.26 ± 0.19
		52.75	3.22 ± 0.26
		67.82	1.98 ± 0.16
	44.11%	22.61	1.40 ± 0.11
		37.68	4.34 ± 0.35
		52.75	3.24 ± 0.26
		67.82	2.33 ± 0.19

Table 4.9: Continued

	14.07%	**22.61**	**2.33 ± 0.19**
		37.68	2.72 ± 0.22
		52.75	2.74 ± 0.22
		67.82	2.76 ± 0.22
FlowLac® 90	29.41%	22.61	2.98 ± 0.24
		37.68	5.35 ± 0.43
		52.75	3.90 ± 0.31
		67.82	2.70 ± 0.22
	44.11%	22.61	3.33 ± 0.27
		37.68	4.91 ± 0.39
		52.75	2.14 ± 0.17
		67.82	5.89 ± 0.47
MicroceLac® 100	14.07%	22.61	2.97 ± 0.24
		37.68	3.05 ± 0.25
		52.75	1.86 ± 0.15
		67.82	3.80 ± 0.30
	29.41%	22.61	1.88 ± 0.15
		37.68	4.29 ± 0.34
		52.75	4.19 ± 0.34
		67.82	3.03 ± 0.24
	44.11%	22.61	3.54 ± 0.28
		37.68	3.34 ± 0.27
		52.75	7.21 ± 0.58
		67.82	5.76 ± 0.46

*Values are mean ± SD

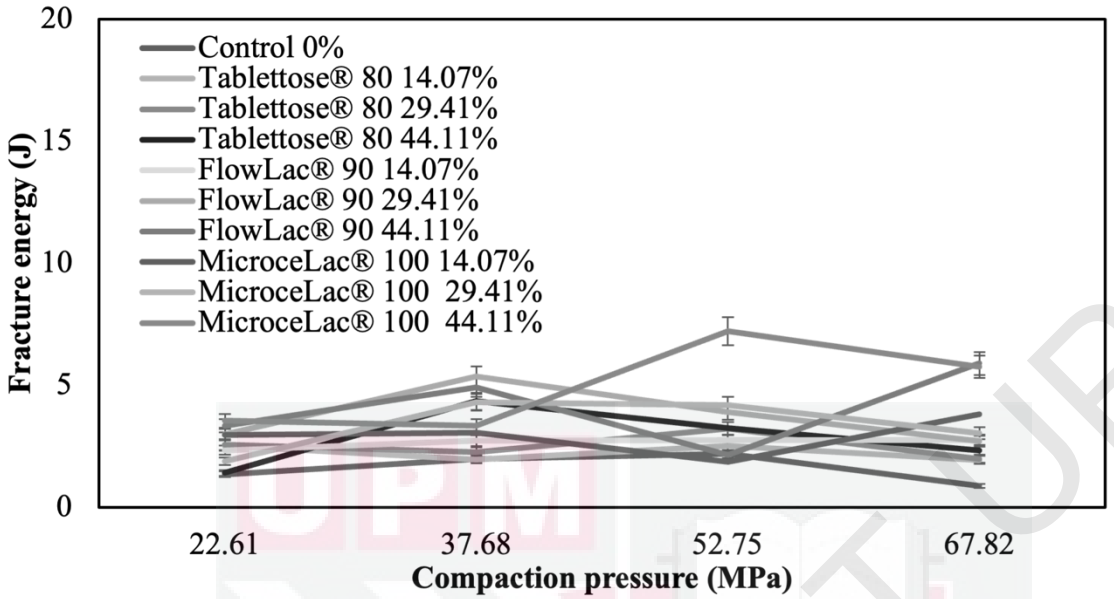

Figure 4.6: Fracture energy of *Parkia speciosa* Hassk chewable tablet at different compaction pressures

4.3.3 Friability

Friability can be affected by the material properties, the tablet's mechanical strength, and the tablet's internal structure (Paul & Sun, 2017). Tablets composed of brittle materials exhibit higher friability than those made of plastic materials under identical compression pressures. Tablets with high mechanical strength and low porosity (ε) generally demonstrate lower friability levels.

Table 4.10 and Figure 4.7 summarize the tablet friability of *Parkia speciosa* Hassk following different compaction pressures. The data reveals the influence of different excipients (Tablettose® 80, FlowLac® 90, and MicroceLac® 100) and their compositions (14.07%, 29.41%, and 44.11%) on the tablet friability required during compaction at varying pressures (22.61MPa, 37.68MPa, 52.75MPa, and 67.82MPa). The tablet friability increased when exceeded compaction pressure

of 37.68MPa as shown by control and FlowLac® 90 at 44.11% composition tablets. Other tablets showed relatively constant friability with increasing compaction pressures. MicoceLac® 100 tablets at all compositions showed friability of less than 1% which matched the acceptable range (Oshi, 2013). Additional research with new parameters may be necessary to uncover the precise mechanisms contributing to variations in the friability of specific formulations (Zhao et al., 2022).

Table 4.10: Friability of *Parkia speciosa* Hassk chewable tablet at different compaction pressures

Excipient	Composition of excipient	Compaction pressure (MPa)	*Friability (%)
Control	0%	22.61	0.55 ± 0.05
		37.68	1.42 ± 0.10
		52.75	2.98 ± 0.15
		67.82	1.54 ± 0.08
Tablettose® 80	14.07%	22.61	0.76 ± 0.07
		37.68	0.72 ± 0.06
		52.75	0.81 ± 0.07
		67.82	0.71 ± 0.06
	29.41%	22.61	0.52 ± 0.04
		37.68	0.72 ± 0.06
		52.75	1.05 ± 0.09
		67.82	0.61 ± 0.05
	44.11%	22.61	1.26 ± 0.10
		37.68	0.66 ± 0.05
		52.75	1.14 ± 0.09
		67.82	0.44 ± 0.11

Table 4.10: Continued

FlowLac® 90	14.07%	22.61	0.97 ± 0.08
		37.68	0.93 ± 0.07
		52.75	1.01 ± 0.09
		67.82	1.36 ± 0.11
	29.41%	22.61	2.51 ± 0.20
		37.68	1.46 ± 0.12
		52.75	1.32 ± 0.11
		67.82	1.70 ± 0.14
	44.11%	22.61	0.84 ± 0.07
		37.68	0.71 ± 0.06
		52.75	1.80 ± 0.15
		67.82	1.86 ± 0.15
MicroceLac® 100	14.07%	22.61	0.76 ± 0.06
		37.68	0.88 ± 0.07
		52.75	0.81 ± 0.07
		67.82	0.91 ± 0.08
	29.41%	22.61	0.50 ± 0.04
		37.68	0.43 ± 0.03
		52.75	0.67 ± 0.05
		67.82	0.97 ± 0.08
	44.11%	22.61	0.27 ± 0.02
		37.68	0.44 ± 0.04
		52.75	0.55 ± 0.05
		67.82	0.57 ± 0.05

5*Values are mean ± SD

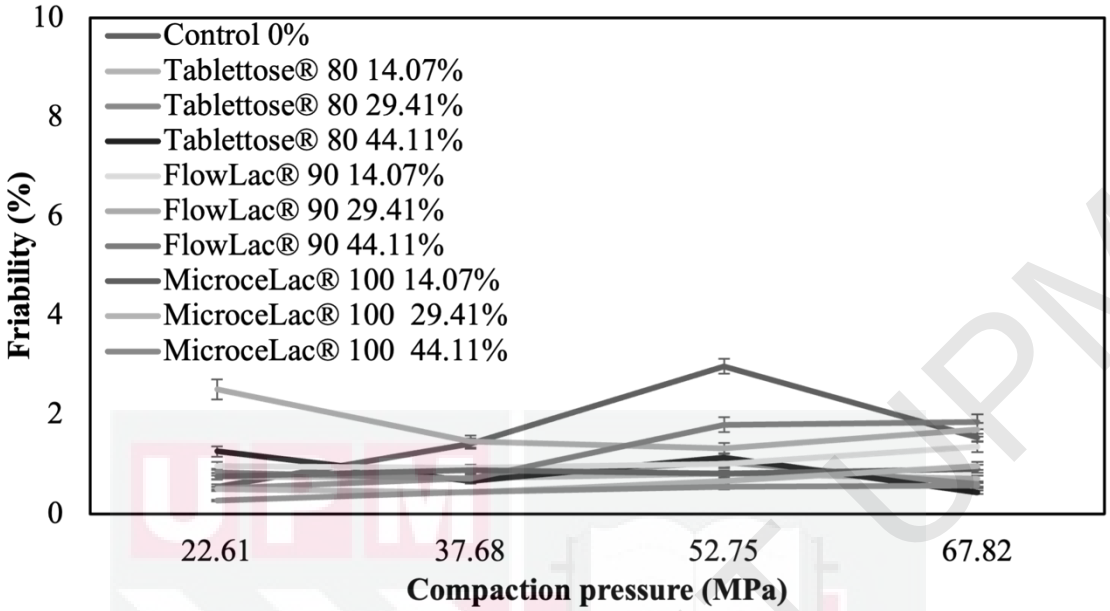

Figure 4.7: Friability of *Parkia speciosa* Hassk chewable tablet at different compaction pressures

4.3.4 Dissolution time

In tablet manufacturing, direct compression is an advanced technique for the development of many active ingredients into solid dosage forms and its formulation and process variables play a crucial role in the product's quality (Khan & Rhodes, 1976). The dissolution rate and solubility of a new active ingredient candidate are crucial factors that influence an active ingredient's tendency to supersaturate and thus, its bioavailability. Therefore, an understanding of dissolution behaviour is necessary during the tablet developmental stage.

Table 4.11 and Figure 4.8 summarize the tablet dissolution time of *Parkia speciosa* Hassk following different compaction pressures. The data reveals the influence of different excipients (Tablettose® 80, FlowLac® 90, and MicroceLac® 100) and their compositions (14.07%, 29.41%, and 44.11%) on the tablet dissolution time required during compaction at varying pressures (22.61MPa, 37.68MPa, 52.75MPa, and 67.82MPa). The tablet dissolution times were lowest for the control tablet and lower for Tablettose® 80 at 44.11% and MicroceLac® 100 at 29.41%, and MicroceLac® 100 at 44.11% at 37.68MPa and 52.75MPa compaction pressure, respectively. Other tablets showed relatively constant dissolution time with increasing compaction pressures. In line with other previous studies, there was no effect of compression pressure on the dissolution rate of solid materials has been reported. Iranloye & Parrott (1978) suggested that compression pressure did not influence the dissolution rate of compressed disks of crystalline salicylic acid, aspirin and mixtures of aspirin and salicylic acid. In addition, Velasco et al. (1999) reported that there is no relationship between compression pressure and the dissolution profiles of diclofenac sodium from matrix tablets. Löbmann et al. (2014), however, found that compression pressure can influence the intrinsic dissolution time of pure amorphous indomethacin, whereas crystalline indomethacin and a glass solution of indomethacin–poly(vinylpyrrolidone) were only marginally influenced by different compression pressures.

Table 4.11: Dissolution time of *Parkia speciosa* Hassk chewable tablet at different compaction pressures

Excipient	Composition of excipient	Compaction pressure (MPa)	*Dissolution time (s)
Control	0%	22.61	1238 ± 45
		37.68	1211 ± 42
		52.75	1184 ± 40
		67.82	1204 ± 41
Tablettose® 80	14.07%	22.61	1023 ± 38
		37.68	1394 ± 52
		52.75	1676 ± 61
		67.82	1302 ± 48
	29.41%	22.61	1242 ± 44
		37.68	1426 ± 51
		52.75	1384 ± 49
		67.82	1409 ± 50
	44.11%	22.61	1480 ± 52
		37.68	1048 ± 37
		52.75	1689 ± 62
		67.82	1112 ± 41

Table 4.11: Continued

FlowLac® 90	14.07%	22.61	1735 ± 64
		37.68	1577 ± 58
		52.75	1568 ± 58
		67.82	1561 ± 57
	29.41%	22.61	1844 ± 68
		37.68	1855 ± 69
		52.75	1711 ± 63
		67.82	1355 ± 50
	44.11%	22.61	1849 ± 68
		37.68	1978 ± 73
		52.75	1965 ± 72
		67.82	1577 ± 58
MicroceLac® 100	14.07%	22.61	1713 ± 63
		37.68	1724 ± 63
		52.75	1654 ± 60
		67.82	1666 ± 61
	29.41%	22.61	1711 ± 63
		37.68	1315 ± 48
		52.75	1669 ± 61
		67.82	1653 ± 60
	44.11%	22.61	1653 ± 60
		37.68	1643 ± 60
		52.75	1078 ± 39
		67.82	1776 ± 65

*Values are mean ± SD

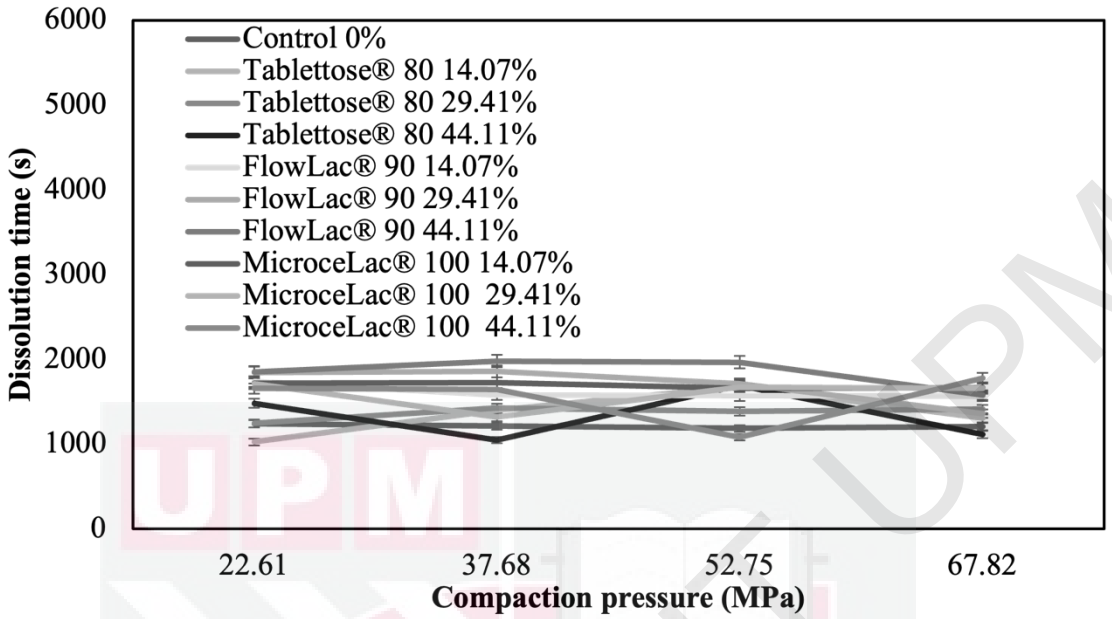

Figure 4.8: Dissolution time of *Parkia speciosa* Hassk chewable tablet at different compaction pressures

4.4 Selection of tablet formulation based on mechanical strength standards

Approaching the final objective, the aim was to identify the most suitable tablet formulation for *Parkia speciosa* Hassk chewable tablets that align with established standards governing chewable tablet properties.

The selection of the best tablet formulation was based on a comprehensive evaluation of mechanical strength parameters, including tensile strength, friability, and dissolution time. During an extensive investigation into the mechanical attributes of these tablets (A and B), which encompass the application of various excipients, including Tablettose® 80, FlowLac® 90, and MicroceLac® 100, a wide spectrum of compositions ranging from 0% to 44.11%, and a variation of compaction pressures spanning from 22.61MPa to 67.82MPa, two specific

formulations consistently stood out for their mechanical characteristics. These formulations are Tablet A, characterized by 14.07% Tablettose® 80 and compacted at 22.61MPa, and Tablet B, comprising 44.11% MicroceLac® 100 and compacted at 52.75MPa. Table 4.12 shows the formulations and their respective mechanical attributes for Tablet A and Tablet B.

Table 4.12: Mechanical properties of Tablet A and Tablet B

	Tablet A	Tablet B	Standard
Excipient type	Tablettose® 80	MicroceLac 100	
Composition	14.07%	44.11%	
Compaction pressure	22.61 MPa	52.75 MPa	
Tensile strength	0.1580 MPa	0.3846 MPa	<117.68MPa
Friability	0.71%	0.44%	< 1%
Dissolution time	1023s	1078s	<1100s

The tensile strength of these formulations, which is crucial for assessing the tablet's ability to withstand axial loads without fracturing, aligns with the standard parameters of less than 117.6798N (Karalia et al., 2021). Additionally, these formulations maintain low levels of friability, below the 1% threshold (Paul & Sun, 2017), which is essential for tablet durability during handling and transport. Furthermore, their dissolution times fall within the required limit of 1200 seconds (El-Gazayerly et al., 2004), ensuring effective active ingredients release.

The excipient Tablettose® 80 (an agglomerated alpha lactose monohydrate) and MicroceLac® 100 (an additional 25% ratio of microcrystalline cellulose) have

shown superior performance compared to FlowLac® 90. The agglomeration process employed in the production of Tablettose® 80 contributes to the formation of larger, more cohesive particles. This characteristic is likely responsible for enhancing the compressibility and binding properties of Tablettose® 80 (Ilić et al., 2009), resulting in higher tensile strength, lower friability, and appropriate dissolution times. The composition of Tablettose® 80 in Tablet A was 14.07%, the lowest from the variation of compositions. Importantly, it is observed that a higher composition of Tablettose® 80 in comparison to Tablet A results in longer dissolution times, with a difference of 100-400 seconds, since larger, more cohesive particles of Tablettose® 80(Grote & Kleinebudde, 2019) can lead to slower disintegration and active ingredients release. When Tablettose® 80 is present in higher compositions, these characteristics can become more pronounced, resulting in longer dissolution times. The lower compaction pressure used for Tablet A (22.61MPa) appears to be associated with a more favourable dissolution time, while still maintaining acceptable friability levels. This can be explained that a lower compaction pressure may result in a less dense tablet structure with more porous regions (Adolfsson & Nyström, 1996), which can allow for faster penetration of dissolution media, leading to quicker disintegration and active ingredients release.

On the other hand, FlowLac® 90, a spray-dried excipient, demonstrates less consistent mechanical attributes across the examined formulations. The use of spray-dried lactose excipients, known for their production of hollow particles (Pilcer et al., 2012), can significantly impact the compressibility, flow properties,

and compactibility of tablets, potentially leading to a less resilient tablet structure. This is evident in the variability in tensile strength, friability, and dissolution times observed in tablets containing FlowLac® 90. While it can still meet the desired standards in some cases, its performance is less reliable compared to Tablettose® 80 and MicroceLac® 100.

MicroceLac® 100, a co-processed excipient which includes a 25% ratio of microcrystalline cellulose, exhibits notably stable mechanical attributes across various formulations. The addition of microcrystalline cellulose, known for its binding and disintegrating properties (Reier & Shangraw, 1966), likely contributes to the cohesive nature of the tablets. The presence of microcrystalline cellulose provides added structural support and ensures the integrity of the tablets. The high composition of MicroceLac® 100 in Tablet B, along with its unique composition, has a substantial impact on the tablet's performance. A lower composition of MicroceLac® 100 results in slightly higher friability, although still within an acceptable range. Additionally, this lower composition is associated with significantly longer dissolution times, differing by 600-700 seconds compared to Tablet A. Microcrystalline cellulose is known for its excellent disintegration properties (Saigal et al., 2009; Hindi et al., 2017). It tends to rapidly break down into smaller particles when exposed to moisture (Amidon & Houghton, 1995), promoting quicker active ingredient release. Compacted at 52.75MPa, as opposed to compaction pressures of 22.61MPa, 37.68MPa, and 67.82MPa, the specific combination of densification and porosity achieved in Tablet B's case may be optimal for rapid dissolution. The increased pressure may create a more

porous structure that promotes the swift movement of dissolution media into the tablet. Additionally, different compaction pressures can affect the arrangement of excipients within the tablet (Thapa et al., 2017), influencing their roles in tablet breakdown.

In terms of elastic work and plastic work, higher compaction pressures lead to increased plastic work, where the tablet material undergoes irreversible deformation. This results in tablets with higher mechanical strength but may also prolong disintegration times due to reduced porosity (Hamidi et al., 2019). Lower compaction pressures typically result in tablets with higher elastic work, where more energy is stored elastically within the tablet structure. This is due to less permanent deformation, allowing the tablet to recover its original shape after compression (Shamjuddin et al., 2014).

With the mechanically optimal tablet formulation selected, this subtopic explores the implications on the findings on chewing techniques observations. By understanding how different variables affect tablet properties and performance, the aim is to facilitate for a deeper understanding of how to achieve the intended chewability in *Parkia speciosa* Hassk chewable tablets. This section reflects the practical implications of the research, guiding future endeavours in tablet formulation and development.

4.5 Chewing efficiency

After identifying two tablet formulations, Tablet A and Tablet B, that meet the stringent mechanical standards required for chewable tablets, it becomes

essential to delve deeper into their performance during the chewing process. This subtopic aimed to discern which formulation delivers optimal active ingredients release and overall subject experience. Through this analysis, an informed decision to select the best-engineered formulation, ensuring that it meets mechanical criteria and stands out in terms of practicality and efficacy. Table 4.3 shows the chewing process results of two tablet formulations.

Table 4.13: Chewing process of two tablet formulations

	Tablet A	**Tablet B**
Volume of tablet (g/cm^3)	527.35	759.85
No. of chews	17	11
Time taken (s)	12.43	7.86
Chewing rate	1.3677	1.3995
Mean disintegrated bolus size (mm^2)	203.50	169.96

The study involved chewing two different tablets, Tablet A and Tablet B, each having distinct volumes of 527.35 mm^3 and 759.85 mm^3, respectively. Their difference in their volume could be attributed to particle properties such as shape and size and the degree of interparticulate friction (Ayorinde et al., 2013). The subject exhibiting normal occlusion (Owens et al., 2002), with a gum area of 73.51mm^2 as shown in Figure 4.9, chewed Tablet A on her right side until it was deemed ready for swallowing. This process required 17 chew cycles with an average time of 12.43 seconds, resulting in a chewing rate of 1.37 chews per second. The average bolus size generated by chewing Tablet A was measured at 203.50 mm^2.

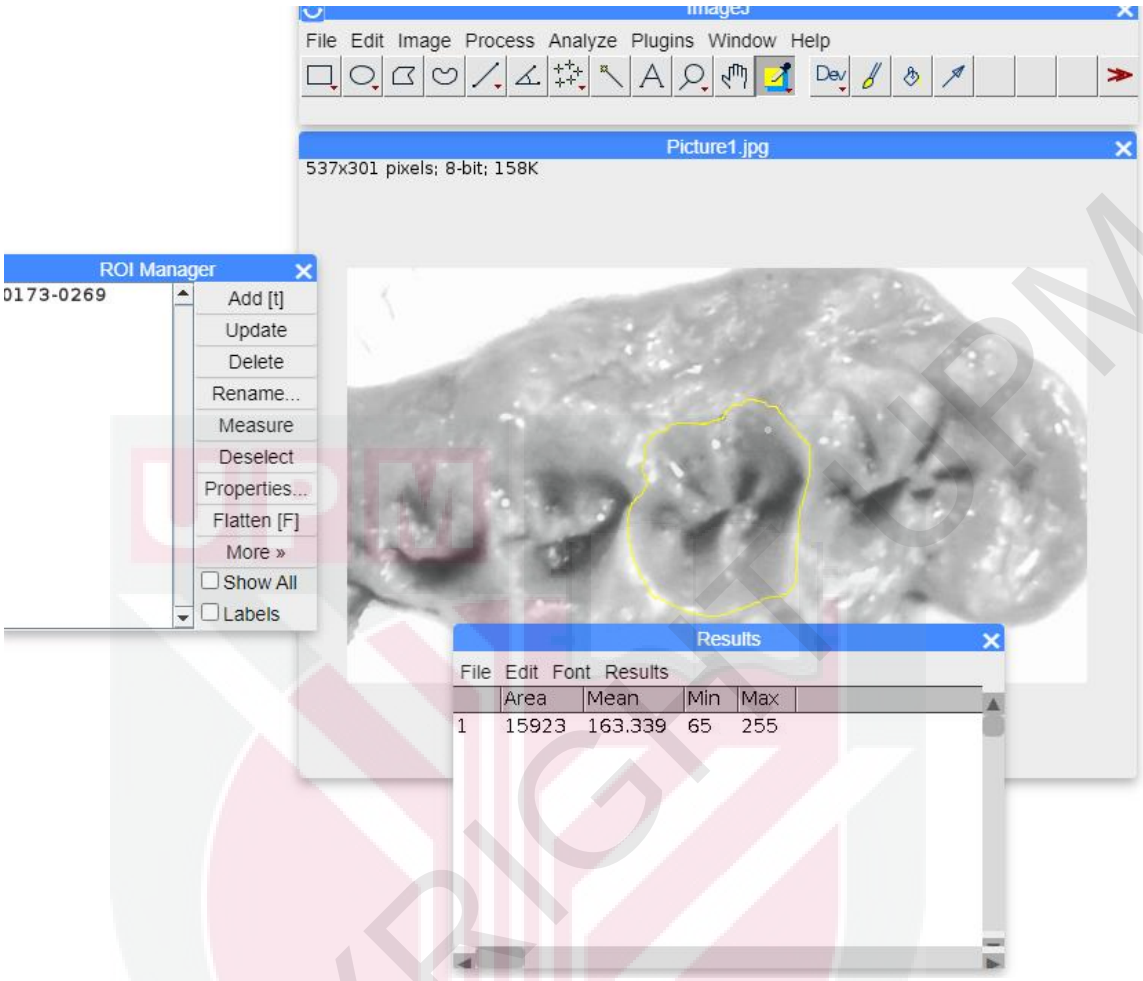

Figure 4.9: Measurement of the occlusal area (right side) using ImageJ

In contrast to Tablet A, Tablet B, despite its larger volume, required fewer chew cycles (11 in total) and had a faster average chewing rate of 1.4 chews per second. This resulted in a shorter average chewing time of 7.86 seconds. Notably, despite Tablet B having a higher chewing rate, it produced a smaller average bolus size of 169.96 mm^2 compared to Tablet A. This suggests that Tablet B is more efficient in breaking down into smaller particles, leading to a more manageable bolus size with fewer chew cycles. Therefore, Tablet B is considered

a better formulation because it achieves a smaller bolus size with less effort and time (Buschang et al., 1997).

This efficiency can be attributed to the properties of the excipients used. Tablet B's use of MicroceLac® 100, which has a finer particle size distribution and higher bulk density (0.46 g/ml) compared to Tablettose® 80 used in Tablet A, contributes to its effective breakdown. The higher compaction pressure of 52.75 MPa for Tablet B further enhances its density, allowing it to disintegrate more effectively into smaller particles. In contrast, Tablet A, with its lower density and larger particle size distribution, results in a larger bolus size. Consequently, Tablet B's formulation not only facilitates a more efficient breakdown but also reduces the effort and time required to achieve a smaller bolus size.

Tablet B has a larger volume primarily due to its different excipient composition compared to Tablet A. The formulation of Tablet B includes excipients that contribute to a larger tablet volume, which affects the overall tablet size and structure. The differences in tablet volume between Tablet A and Tablet B can be attributed to variations in excipient composition and the manufacturing process. Tablet B may use excipients with different physical properties, such as bulk density and particle size, which influence the tablet's overall volume. The choice of grams over percentages for describing excipient quantities provides a more accurate representation of the tablet's physical characteristics. Using grams allows for precise quantification of excipient amounts, ensuring consistency and accuracy in the formulation process.

To quantify the size of the bolus formed after compression, ImageJ software was utilized to analyze the tablet images. By measuring the area and dimensions of the bolus in these images, the software provided accurate data on the bolus size. This method ensured consistency and precision in evaluating the physical characteristics of the tablets, allowing for a detailed comparison between different formulations. The measurement process is illustrated in Figure 4.10

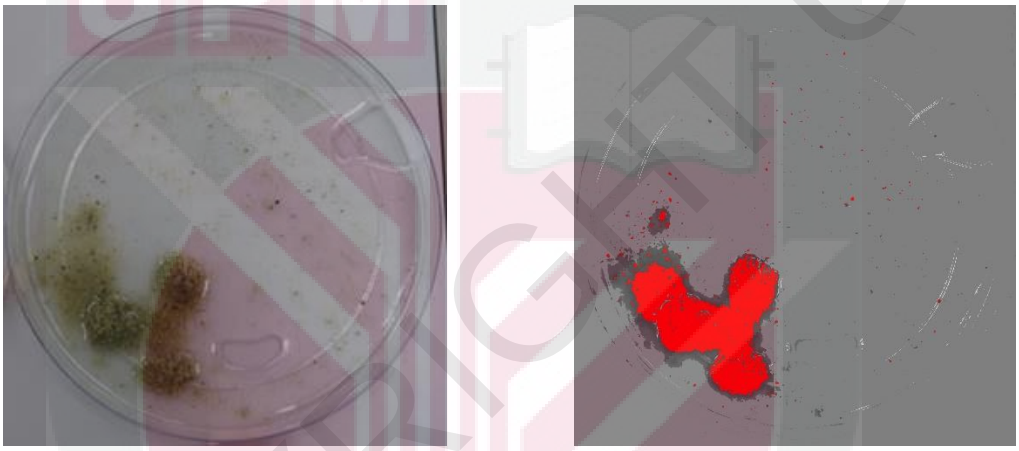

Figure 4.10: Measurement of bolus size using ImageJ (right)

According to Figure 4.11, during various chewing cycles: in cycle 1, the tablet was chewed multiple times until ready to swallow; in cycles 2, 3, and 4, chewing times were reduced to 75%, 50%, and 25% of their initial durations, respectively.

Chewing of Tablet A at 75% of the original number of habitual chews (17), which equates to 13 chews with an average duration of 8.4 seconds, resulting in an average bolus size of 252.63 mm^2. When reduced to 50%, or 9 chews lasting 5.59 seconds, the average bolus size increases to 388.99 mm^2. Further reducing the

number of chews to 25%, which amounts to 4 chews lasting 4.07 seconds, leads to an even larger average bolus size of 519.71 mm^2.

Similarly, when chewing Tablet B at 75% of the initial number of chews, which is 8 chews with an average duration of 6.1 seconds, the average bolus size measures 211.5 mm^2. Reducing the chews to 50%, or 6 chews with an average duration of 5.51 seconds, yields a larger average bolus size of 261.5 mm^2. Finally, at 25%, with only 3 chews lasting 3.58 seconds, the average bolus size further increases to 367.73 mm^2.

Based on the recorded data, Tablet A consistently yields larger average bolus sizes than Tablet B across all three scenarios. This could be attributed to Tablet A's greater excipient composition, which contributes to a larger overall volume. This finding also supports that the tablet formulation of Tablet B has better chewing efficiency from the trend that shows less chewing rate is needed to break tablet at smaller average bolus size (Figure 4.11).

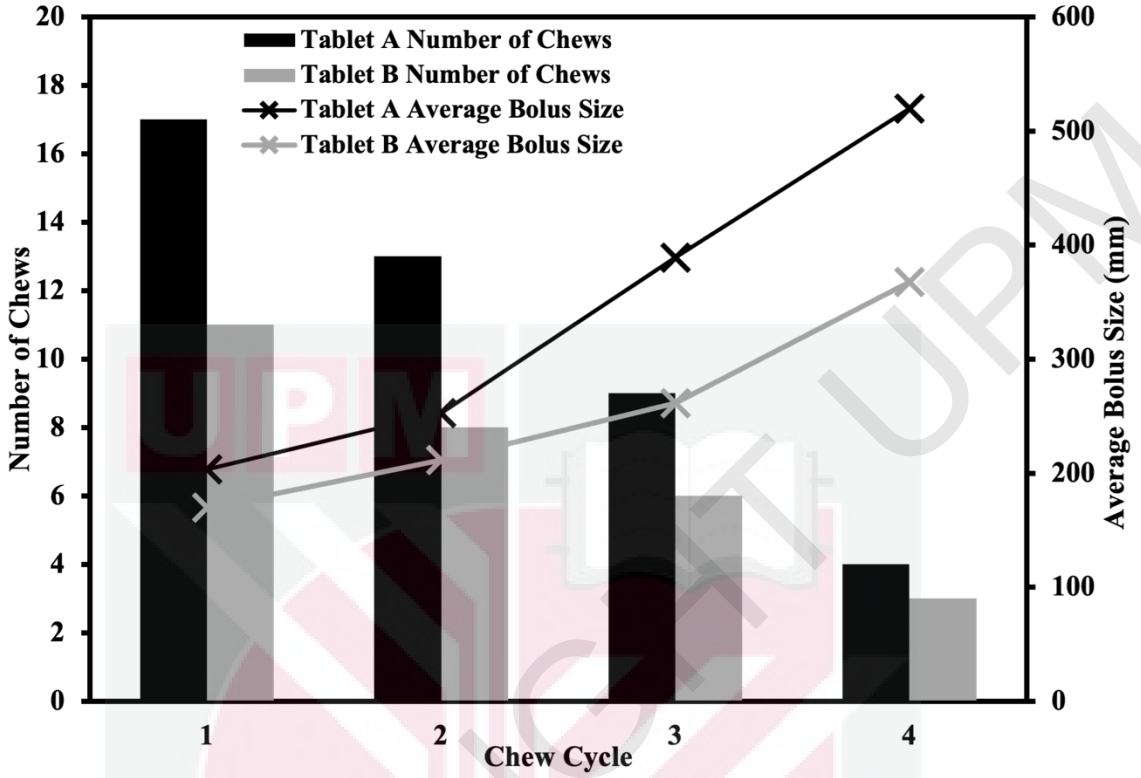

Figure 4.11: Chewing efficiency comparison: time taken per chew cycle (Tablet A vs. Tablet B) alongside average bolus size trends

CHAPTER 5

CONCLUSIONS AND RECOMMENDATION

5.1 Summary of findings

The examination of the physical properties of freeze-dried *Parkia speciosa* Hassk powder revealed that while it has flowability characteristics suitable for tablet compaction, additional excipients were needed to enhance compactibility for use in pharmaceutical and nutraceutical formulations. Additionally, the nutritional assessment emphasized its potential health benefits, particularly as a valuable protein source due to its high protein content. These combined findings not only affirm the appropriateness of *Parkia speciosa* Hassk for tablet formulation but also focus on its nutritional significance, showcasing its dual potential for nutraceutical applications and as a health-promoting dietary supplement.

The comprehensive investigation into the influences of compaction pressure, excipient types, and composition on tablet compaction behaviour yielded invaluable understandings. The observed increases in both plastic and elastic work with varying compaction pressures highlight the relationship between pressure and material behaviour, emphasizing the need for a detailed understanding of optimizing tablet formulations. Furthermore, the distinct effects exhibited by different excipients highlight the importance of tailoring formulations to specific compaction requirements. These findings contribute to a more detailed and informed approach to designing tablet formulations, considering the dynamic

interactions between compaction parameters and excipient characteristics for enhanced pharmaceutical and nutraceutical development.

The evaluation of mechanical characteristics provided a clear illustration of the direct influence of compaction pressure, excipient types, and composition on tablet properties. Tensile strength, fracture energy, friability, and dissolution times were identified as key parameters significantly affected by these factors. This comprehensive analysis guided the selection of optimal tablet formulations, aligning with the specific mechanical requirements for effective tablet performance. Consequently, the study establishes a thorough understanding of the relationship between formulation choices and the mechanical attributes crucial for ensuring the desired quality and functionality of tablets in nutraceutical development.

Chewing techniques emerged as a practical method for assessing tablet formulations during the oral processing stage. Among the formulations tested, Tablet A (14.07% Tablettose® 80, 22.61MPa) and Tablet B (44.11% MicroceLac® 100, 52.75MPa) stood out as frontrunners as they met stringent mechanical standards, and Tablet B showcased superior chewing efficiency. The favourable combination of mechanical strength, low friability, and appropriate dissolution times positions these formulations as promising candidates for further development in nutraceutical applications. The success of Tablet B in the chewing stage illuminates its potential for delivering optimal active ingredient release and a positive subject experience, providing a foundation for advancements in oral active ingredient delivery technologies.

5.2 Conclusions

The physical properties of the dried *Parkia speciosa* Hassk tablet, including its fine particle size, optimal bulk and tapped densities, and moderate flowability, make it highly suitable for tablet development. The study highlights the significant impact of compaction pressure on tablet compaction behaviour and mechanical characteristics. Notably, specific excipient compositions, exemplified by Tablet A and Tablet B, exhibited superior performance, meeting stringent mechanical standards. Tablet A, with 14.07% Tablettose® 80 at 22.61MPa, and Tablet B, comprising 44.11% MicroceLac® 100 at 52.75MPa, emerged as promising formulations for further development. These findings emphasize the crucial relationship between compaction parameters and excipient characteristics in optimizing tablet formulations with potential implications for nutraceutical applications.

5.3 Implications of the study

Insights gained from researching tablet compaction behavior and mechanical properties lay the groundwork for improving tablet formulations. The results indicate that tablets with optimal mechanical strength could be utilized for nutraceutical tablet development.

5.4 Recommendations for future research

Future research endeavours should focus on exploring the long-term stability and bioavailability of the selected tablet formulations, Tablet A and Tablet B, to provide

a comprehensive understanding of their pharmaceutical and nutraceutical applications. Investigating excipient interactions and their concentrations is crucial for uncovering their impact on tablet properties, ensuring optimal formulation outcomes. *In vitro* studies should be conducted to assess the actual health benefits of *Parkia speciosa* Hassk chewable tablets, shedding light on their potential impact on human well-being. Additionally, researchers should explore alternative excipients and their effects on tablet characteristics and chewing efficiency, fostering innovation in formulation development.

To enhance the taste-masking properties of dried food powders, especially those with strong flavours, incorporating tablet coating methods is recommended. Increasing the volume of data collected per variation and per test, coupled with statistical optimization techniques, will contribute to more precise and reliable outcomes. Furthermore, transitioning to a proper tablet maker with automated processes is essential to optimize time and labour, minimizing human errors associated with manual tasks. Lastly, researchers from diverse fields, including pharmaceuticals, health sciences, and medicine, are encouraged to further investigate the potential of *Parkia speciosa* Hassk chewable tablets, promoting interdisciplinary collaboration for a more holistic understanding of their effects on human health and encouraging innovative developments in healthcare and pharmaceuticals.

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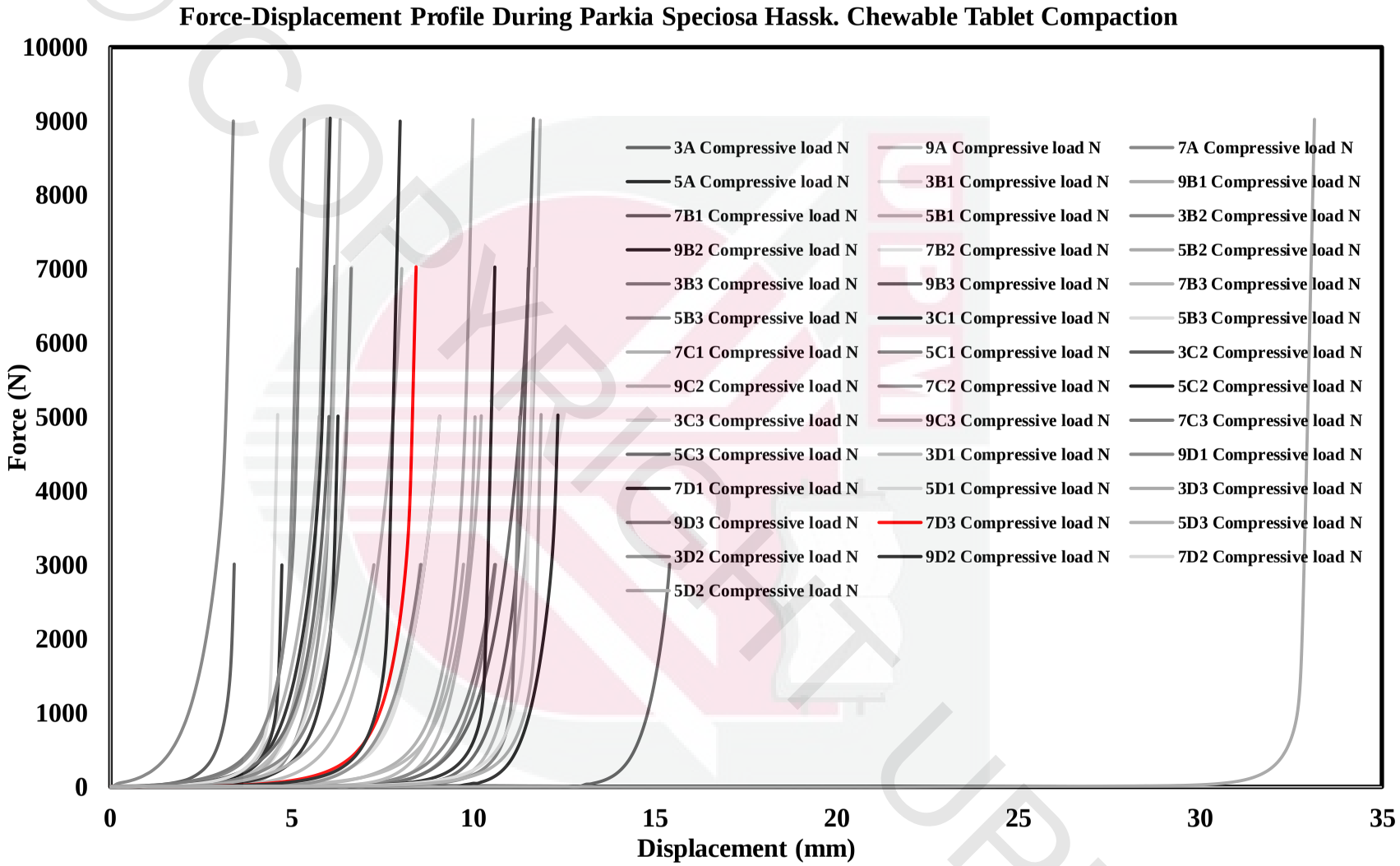
Appendix B: Compaction Behaviour and Frictional Characteristics During Ejection

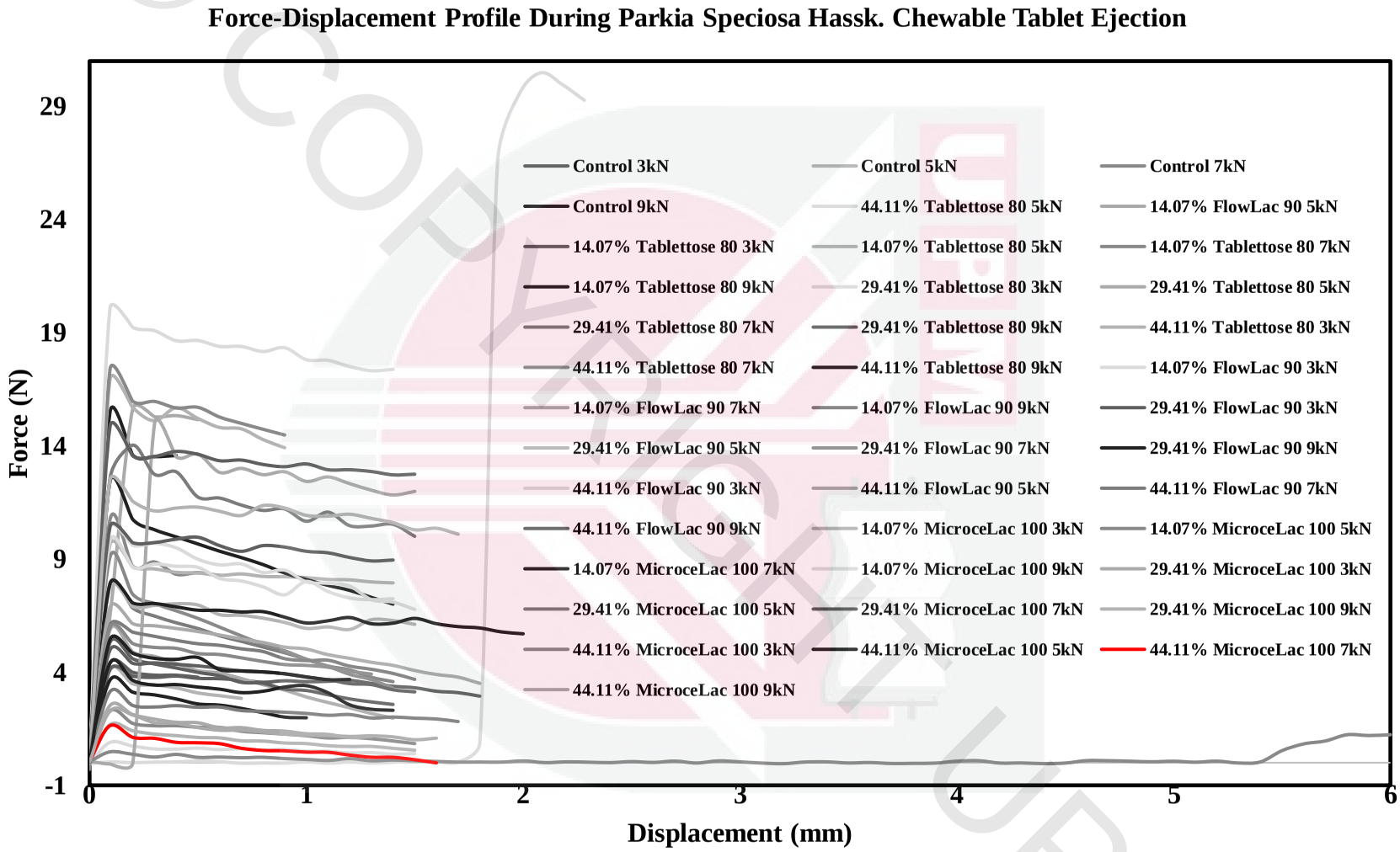
Excipient	Composition of Excipient	Compaction pressure (MPa)	Plastic Work (kJ)	Elastic Work (kJ)	Ejection Pressure (Pa)	Ejection Work (J)
Control	0%	37.68	90.06	1.81	0.034	0.21
		52.75	148.23	2.39	0.031	0.20
		67.82	278.06	2.81	0.082	0.49
		67.82	278.06	4.10	0.117	0.73
Tablettose® 80	14.07%	22.61	41.15	1.82	0.032	0.20
		37.68	113.04	3.00	0.129	0.80
		52.75	175.66	3.33	0.132	0.81
		67.82	250.26	3.69	0.028	0.18
	29.41%	22.61	48.61	2.15	0.154	0.95
		37.68	125.85	3.34	0.045	0.28
		52.75	225.77	4.28	0.060	0.38
		67.82	310.62	4.58	0.041	0.26
	44.11%	22.61	57.43	2.54	0.073	0.46
		37.68	157.50	4.18	0.234	7.01
		52.75	289.60	5.49	0.069	0.43
		67.82	438.12	6.46	0.095	0.59
FlowLac® 90	14.07%	22.61	18.09	0.80	0.007	0.04
		37.68	48.23	1.28	0.118	1.47
		52.75	100.23	1.90	0.115	0.75
		67.82	172.26	2.54	0.108	1.99
	29.41%	22.61	18.54	0.82	0.038	0.24
		37.68	71.22	1.89	0.013	0.08
		52.75	141.90	2.69	0.017	0.11
		67.82	300.44	4.43	0.034	0.21
	44.11%	22.61	49.29	2.18	0.074	0.46
		37.68	120.58	3.20	0.017	0.11
		52.75	199.92	3.79	0.024	0.15
		67.82	306.55	4.52	0.114	0.70
MicroceLac® 100	14.07%	22.61	45.90	2.03	0.059	0.37
		37.68	43.71	1.16	0.009	0.51
		52.75	100.75	1.91	0.060	0.37
		67.82	301.12	4.44	0.078	0.49

	29.41%	22.61	54.04	2.39	0.052	0.33
		37.68	66.69	1.77	0.046	0.29
		52.75	129.24	2.45	0.080	0.49
		67.82	213.63	3.15	0.095	0.59
	44.11%	22.61	68.51	3.03	0.045	0.29
		37.68	116.43	3.09	0.041	0.26
		52.75	184.10	3.49	0.012	0.08
		67.82	257.72	3.80	0.019	0.12

Appendix C: Force-Displacement Profile During Compaction



Appendix D: Force-Displacement Profile During Ejection

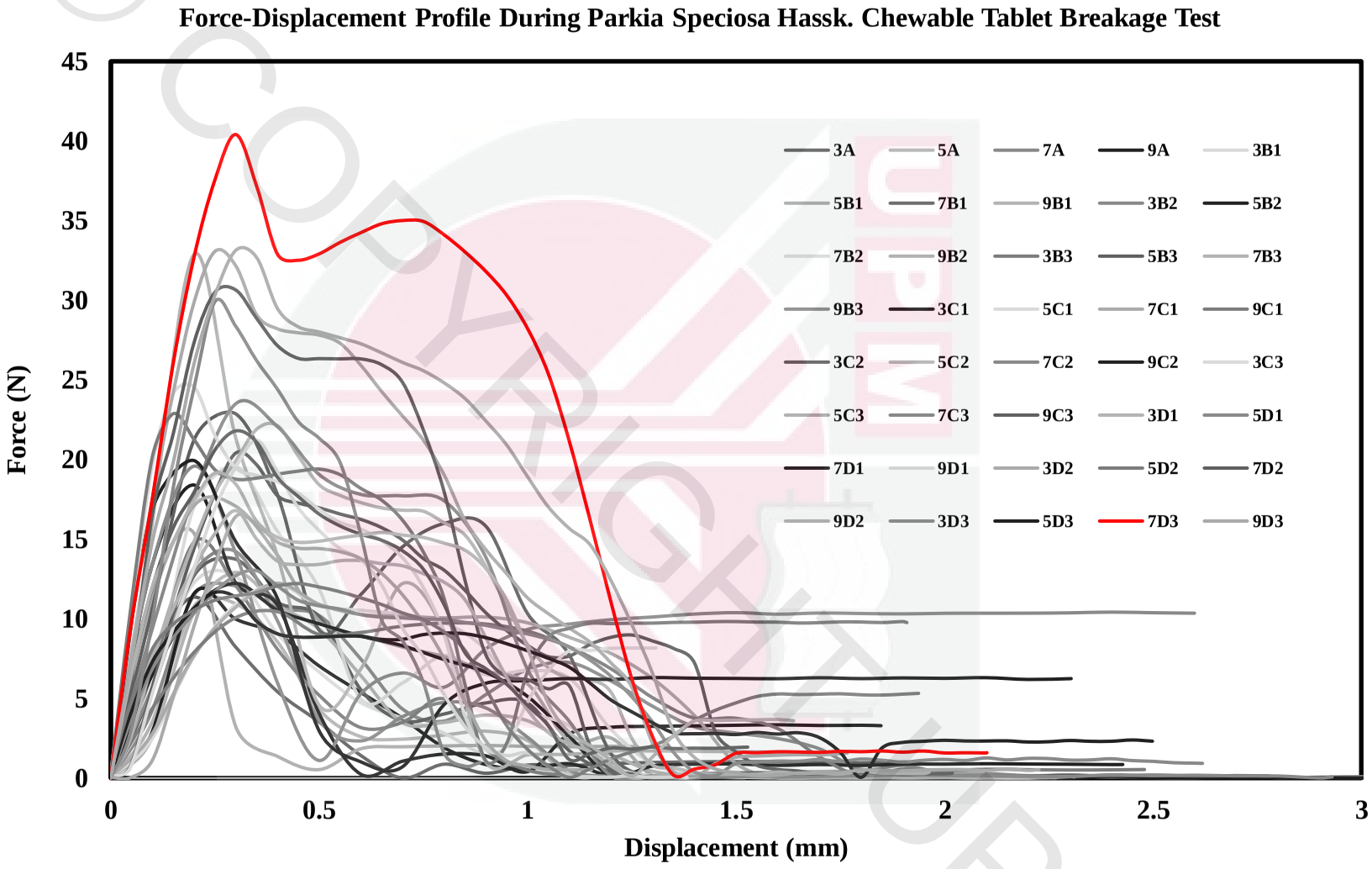


Appendix E: Compaction Behaviour and Frictional Characteristics During Ejection

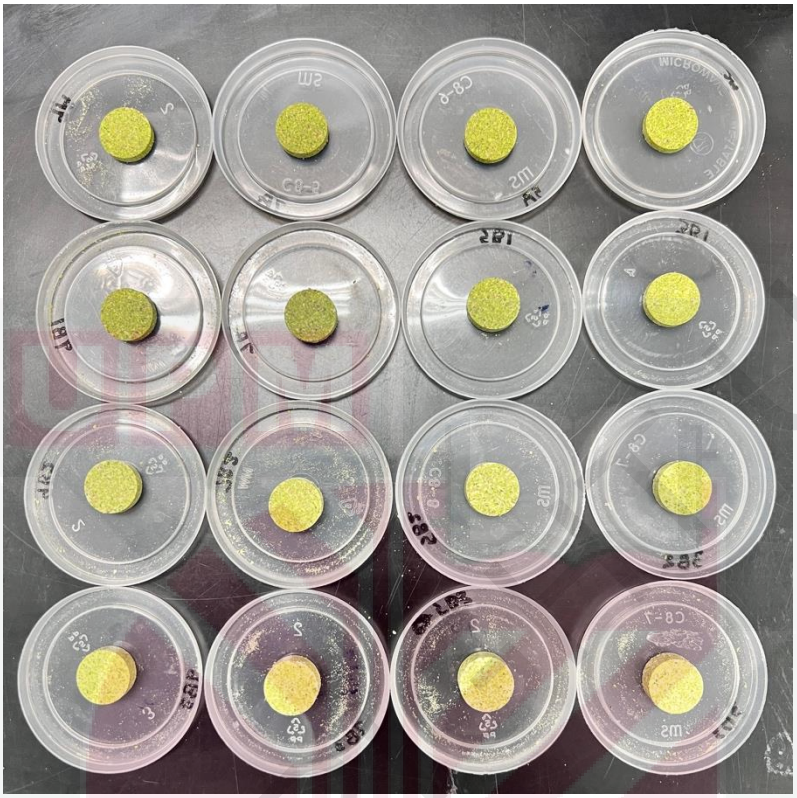
Excipient	Composition of Excipient	Compaction pressure (MPa)	Tensile strength (MPa)	Fracture Energy (J)	Friability (%)	Dissolution Time (s)
Control	0%	22.61	0.1710	1.35	0.55	1238
		37.68	0.1684	1.98	1.42	1211
		52.75	0.1867	2.18	2.98	1184
		67.82	0.1828	0.87	1.54	1204
Tablettose® 80	14.07%	22.61	0.1580	2.52	0.76	1023
		37.68	0.2081	1.95	0.72	1394
		52.75	0.1931	2.51	0.81	1676
		67.82	0.1832	1.94	0.71	1302
	29.41%	22.61	0.1558	2.57	0.52	1242
		37.68	0.2064	2.26	0.72	1426
		52.75	0.2259	3.22	1.05	1384
		67.82	0.1992	1.98	0.61	1409
	44.11%	22.61	0.1275	1.40	1.26	1480
		37.68	0.2087	4.34	0.66	1048
		52.75	0.3163	3.24	1.14	1689
		67.82	0.1883	2.33	0.44	1112
FlowLac® 90	14.07%	22.61	0.1595	2.33	0.97	1735
		37.68	0.1557	2.72	0.93	1577
		52.75	0.1589	2.74	1.01	1568
		67.82	0.1413	2.76	1.36	1561
	29.41%	22.61	0.2054	2.98	2.51	1844
		37.68	0.2449	5.35	1.46	1855
		52.75	0.2430	3.90	1.32	1711
		67.82	0.2286	2.70	1.70	1355
	44.11%	22.61	0.2257	3.33	0.84	1849
		37.68	0.3085	4.91	0.71	1978
		52.75	0.2086	2.14	1.80	1965
		67.82	0.2815	5.89	1.86	1577
MicroceLac® 100	14.07%	22.61	0.2103	2.97	0.76	1713
		37.68	0.1658	3.05	0.88	1724

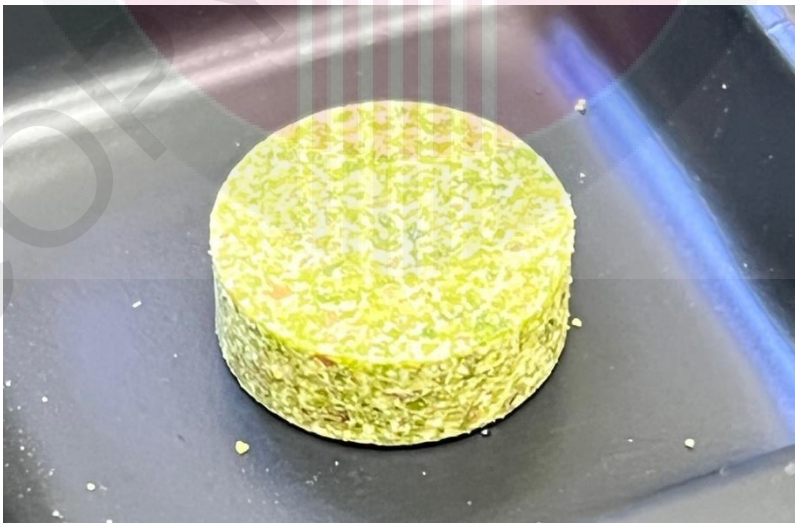
		52.75	0.1486	1.86	0.81	1654
		67.82	0.2718	3.80	0.91	1666
	29.41%	22.61	0.1669	1.88	0.50	1711
		37.68	0.1349	4.29	0.43	1315
		52.75	0.2349	4.19	0.67	1669
		67.82	0.2035	3.03	0.97	1653
	44.11%	22.61	0.2405	3.54	0.27	1653
		37.68	0.3367	3.34	0.44	1643
		52.75	0.3846	7.21	0.55	1078
		67.82	0.3669	5.76	0.57	1776

Appendix F: Force-Displacement Profile During Breaking

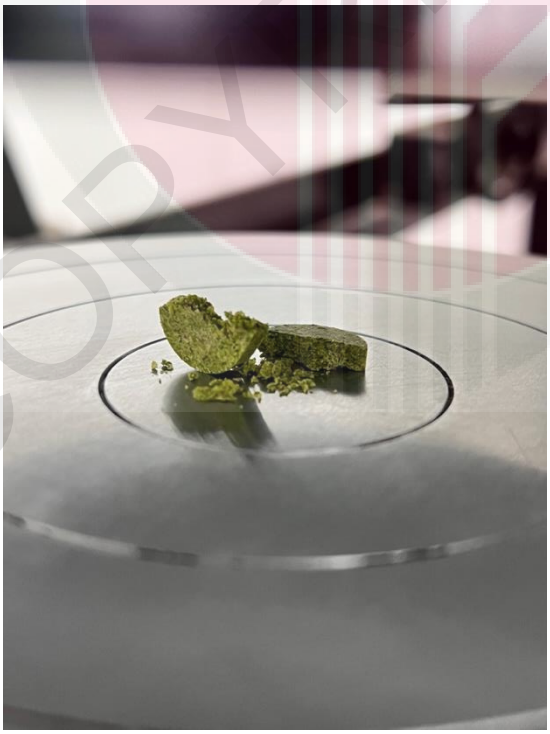


Appendix G: Parkia Speciosa Hassk Chewable Tablets

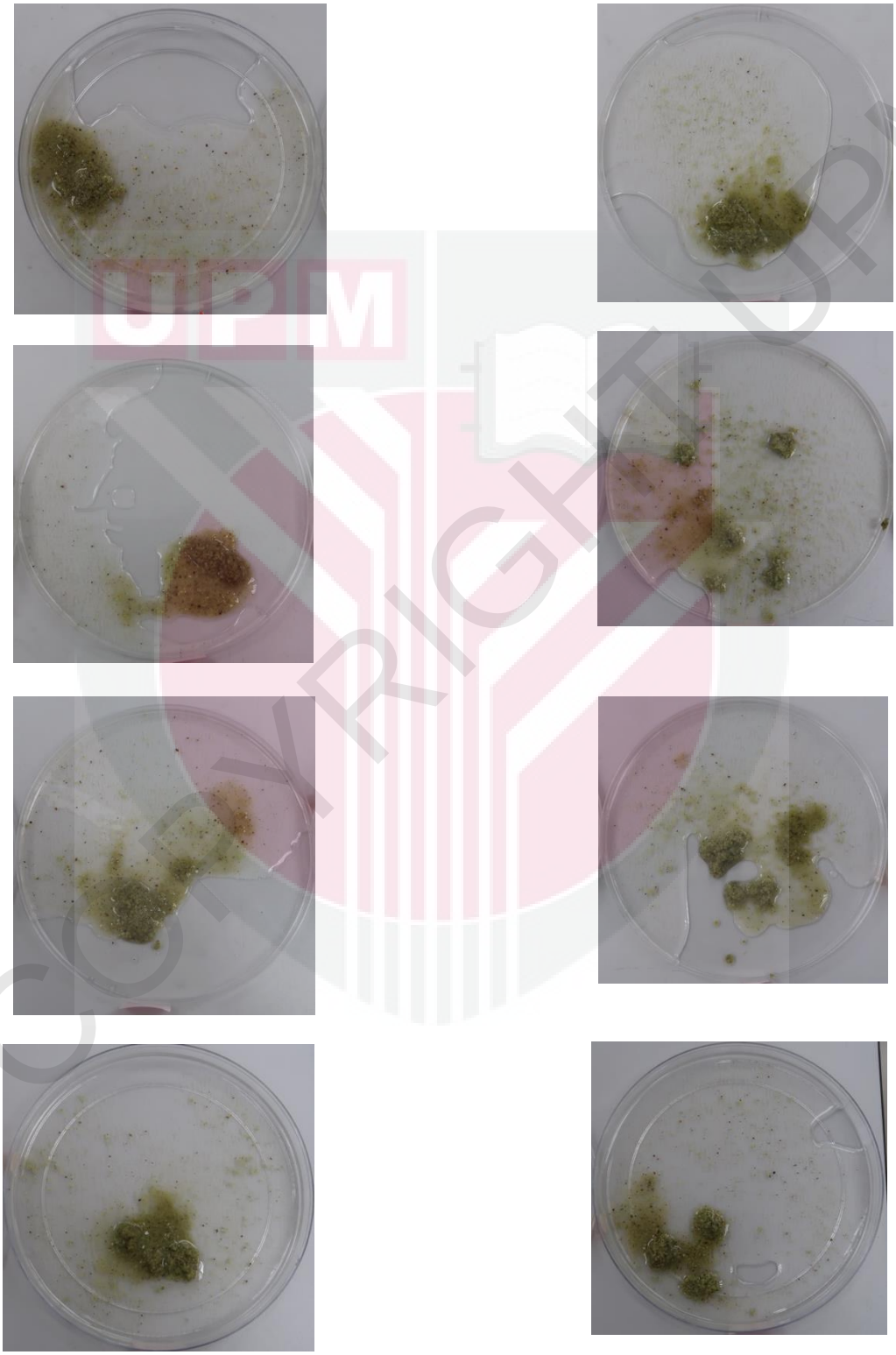




Appendix G: Breaking of Parkia Speciosa Hassk Chewable Tablets



Appendix H: Bolus Collected After Chewing of *Parkia Speciosa* Hassk Chewable Tablets



LIST OF PUBLICATIONS

Bakaruddin, F., Anuar, M. S., & Nor, M. Z. M. (2024). Evaluation of the effect of excipient content on the physical properties of *Parkia speciosa* Hassk. tablets through regression analysis. *International Journal of Pharmaceuticals, Nutraceuticals and Cosmetic Science*, *7*(2), 34-43.