Development and its Physiochemical Characterization of Kambu Laddu

[2a]Vignesh D., [2b]Kishore K, [3]Antony AllwynSundarraj and [1]Sridhar N
[2]Bachelor of Food Technology, [3]Associate Professor and [1]Professor
Department of Food Technology, Sri Shakthi Institute of Engineering and Technology, Coimbatore – 641062, TamilNadu, India.

Abstract:
Kambu laddu was developed and standardized largely for the lactating mothers. The laddu composed of Pearl millet (bajra flour), Edible gum (dink), Jaggery, Ground nut, Dry coconut, Dry dates, Fenugreek seed powder, Rava, Cardamom powder, Oil. Ranking test was used for standardization of the product. Sensory evaluation was carried out before packaging to assess the acceptability and attributes such as texture, taste and sweetness using the composite scoring test with the help of semi trained panelists. Microbial analysis was also carried out for two week to know whether the product keep well. Other aspects such as a packaging, a nutrition label, budgeting and marketing were also covered in this study

Keywords: Kambu laddu, Galactogogue, Lactating women, Fenugreek seeds, Edible gum, Sensory evaluation, Standardization, Microbial analysis, Shelf life

1.Introduction:

Traditional Indian sweets hold a significant place in the culinary landscape and cultural practicesofIndia.Amongthese,theladdu,asphericalconfectioncraftedfromvariousflours, sweeteners, and binding agents, enjoys widespread popularity across diverse regions and occasions.Itsinherentversatilityallowsfornumerousvariationsiningredientsandpreparation methods, contributing to its enduring appeal. However, many conventional laddus are often characterized by high sugar and refined flour content, raising concerns about their nutritional profile in an increasingly health-conscious society. This necessitates exploring innovative approaches to enhance the nutritional value of traditional sweets withoutcompromising their sensory attributes and cultural significance.

Inthiscontext,theincorporationofnutrient-richingredientslikepearlmillet,commonlyknown as Kambu in Tamil and Bajra in Hindi, presents a promising avenue. Pearl millet (Pennisetum glaucum) is a staple cereal grain widely cultivated in arid and semi-arid regions of Africa andAsia,includingIndia.Itstandsoutforitsexceptionalnutritionalprofile,boastinghigherlevelsof dietaryfiber,iron,protein,andessentialmineralscomparedtocommonlyconsumedcerealslike rice and wheat. The inclusion of Kambu in food formulations can significantly contribute to addressing micronutrient deficiencies and promoting overall health and well-being.

Recognizing the nutritional potential of Kambu, this study focuses on the development of Kambu laddu, aimingtocreateahealthierand morenutritious alternativetotraditional laddus. By utilizing Kambu flour as the primary ingredient, this research seeks to leverage its inherent nutritionaladvantagesinapopularandculturallyrelevantfoodproduct.Furthermore,thestudy undertakes a comprehensive physicochemical characterization of the developed Kambu laddu samples. This involves a detailed analysis of their nutritional composition, including moisture content,ashcontent,fatcontent,proteincontent,carbohydratecontent,andenergyvalue. Understanding these parameters is crucial for assessing the nutritional benefits and shelf stability of the product.

Beyond nutritional aspects, the physicochemical characterization extends to evaluating the physicalandsensoryattributesoftheKambuladdu.Texturalproperties,suchashardnessand

fracturability,playasignificantroleintheoveralleatingexperienceandconsumeracceptance. Color, another critical sensory attribute, influences the visual appeal of the product. By quantifying these parameters, the study aims to understand how variations in ingredient proportions, particularly the type and amount of sweeteners (jaggery and sugar) and binding agents (ghee and coconut), impact the final product's texture and color.

The development process involves formulating different variations of Kambu laddu by systematicallyalteringtheratiosofKambuflour,sweeteners(jaggeryandsugar),andbinding agents(gheeandcoconut).Thisfactorialapproachenablestheresearcherstoinvestigatetheindividualand combinedeffectsoftheseingredientsonthefinalproduct'scharacteristics.Each formulation is carefully prepared under controlled conditions to ensure consistency and reproducibility.

Following the preparation of the Kambu laddu samples, a comprehensive physicochemical analysisisconducted.Standardanalyticalmethodsareemployedtodeterminethemoisturecontent,which iscrucialforassessingshelflifeandmicrobialstability.Ashcontent,representing the total inorganic matter, provides insights into the mineral composition.Fat content, protein content, and carbohydrate content are determined to establish the macronutrient profile and calculate the energy value of the laddu.Texturalanalysisisperformedusingatextureanalyzertoquantifyparameterslikehardness(the force required to compress the laddu) and fracturability (the tendency of the laddu to break or crumble). These measurements provide objective data on the textural properties, which aredirectlylinkedtoconsumerperceptionandacceptance.Colorattributesareevaluatedusinga colorimeter,whichmeasuresparameterslikelightness(L*),redness(a*),andyellowness(b*), providing a quantitative assessment of the visual appearance of the different Kambu laddu formulations.

Theresultsobtainedfromthephysicochemicalanalysisaremeticulouslyanalyzedandcompared across the different formulations. This allows for the identification of significant correlations between ingredient ratios and the resulting nutritional composition, textural properties,andcolorattributes.Thestudyaimstopinpointoptimizedformulationsthatnotonlyexhibitanim provednutritionalprofilecomparedtoconventionalladdusbutalsopossess desirable textural and visual characteristics.

Byprovidingadetailedunderstandingoftherelationshipbetweeningredientvariationsandthephysicoche mical properties of Kambu laddu, this research contributes valuable insights to thefieldoffoodscienceandnutrition.Thefindingscanguidefoodmanufacturersandhomecooks in developing nutrient-rich and appealing Kambu-based sweets. Furthermore, the study highlights the potential of incorporating underutilized but highly nutritious grains like pearlmillet into mainstream food products, contributing to dietary diversification and improved publichealth.ThesuccessfuldevelopmentandcharacterizationofKambuladducanpavethe way for its wider acceptance and commercialization, offering consumers a healthier and delicious alternative to traditional sweets. This research underscores the importance ofexploringindigenousgrainsandtraditionalfoodpreparationstocreatenutritiousandculturally relevant food options for a modern world.

2.Material and Methods:

2.1 Materials:

PearlMilletFlour(KambuMaavu):Procuredfromalocalmill,ensuringqualityandfreshness.Jaggery(Gur),sourcedforitsnaturalsweetnessandmineralcontent.Refinedsugarwillbeused in a parallel set of experiments for comparison.Ghee(clarifiedbutter),knownforitstraditionaluseandflavor.Vegetableoilwill beusedina parallel set of experiments for comparison.Roastedandgroundnuts(e.g.,peanuts,almonds),desiccatedcoconut,roastedBengalgram flour (Besan).

Cardamompowder,nutmegpowder.

Equipment:

Weighingbalance(accuracy±0.01 g) Sieves of different mesh sizes

Roasting pan or oven

Mixingbowls

ThisphasewillinvolveformulatingdifferentvariationsofKambuLaddubysystematicallyalteringtheproportionsofkeyingredientsandincorporatingoptionalingredients.Sensory evaluation will be conducted to optimize the recipe based on consumer acceptability.

2.2 Methodology:

KambuLaddu,atraditionalIndiansweetprimarilycraftedfrompearlmillet(Kambu-Pennisetum glaucum), holds cultural significance and offers a nutritious alternative to refined flour-based sweets. Pearlmillet isrecognized for its rich nutritionalprofile, including high fiber content, essential minerals (iron, zinc, calcium), and antioxidants. This methodology outlines a comprehensive approach to developing and characterizing the physicochemical properties of KambuLaddu.Thedevelopmentphasewillfocusonoptimizingtherecipefordesirablesensory attributes and nutritional enhancement. The physicochemical characterization will involve analyzingparameterssuchasproximatecomposition,physicalproperties(texture,color,water activity), and functional properties (swelling index, oil absorption capacity). This detailedmethodologyaimstoprovideastandardizedprotocolforthepreparationandevaluationof Kambu Laddu, contributing to its potential as a nutritious and appealing food product.

2.2.1 Formulation of Different Methods:

This design will result in a set of nine base recipes. Additionally, variations incorporating optionalbindingagents(5-10%w/wofmilletflour)anddifferentsweeteners(jaggeryvs.sugar) and fat sources (ghee vs. vegetable oil) will be prepared. Flavoring agents (cardamom and nutmeg powder) will be kept constant at a low level (0.5% w/w of millet flour) initially and adjusted based on sensory feedback.

ExampleRecipe(Base):

* PearlMilletFlour:100g
* Jaggery:75g(Ratio1:0.75)
* Ghee:30g(Ratio1:0.3)
* CardamomPowder:0.5g
* Water:Asneededforbinding

2.2.2 Preparation of Kambu Laddu:

Thefollowingstandardizedprocedurewillbeadoptedforpreparingeachrecipevariation:

* **RoastingtheFlour**:Pearlmilletflourwillbedry-roastedinapanoverlowtomediumheat, stirring continuously until a light aroma is released and a slight change in color is observed(approximately 5-7 minutes). This step is crucial for developing flavor and improvingdigestibility.Thetemperaturewillbemonitoredusinganinfraredthermometertoe nsure consistency across batches (target temperature: 80-85°C).
* **Preparingthe Sweetener Solution (ifusing):**Ifusing jaggery, itwill be meltedwitha minimal amountofwatertoformathicksyrup.Theconsistencyofthesyrupwillbecarefullymonitored (e.g., single thread consistency). For sugar-based recipes, a similar syrup will be prepared.

***Mixing the Ingredients**: The roasted millet flour will be transferred to a mixing bowl. The prepared sweetener (molten jaggery or sugar syrup) will be gradually added to the flour while mixingcontinuouslytoensureevendistribution.Themeltedghee(orvegetableoil)willthenbe added and mixed thoroughly. Optional binding agents (if used) and flavoring agents will be incorporatedatthisstage.

* **LadduFormation**:Whilethemixtureisstillwarmandpliable,smallportions(approximatel y 20-25g) will be taken and shaped into spherical laddoos by gently pressing and rolling them betweenthepalms.Consistencyinsizewillbemaintainedforuniformityinsensoryevaluation and characterization.

***Cooling and Storage**: The prepared laddoos will be allowed to cool completely at room temperatureonacleantraybeforebeingstoredinairtightcontainerstopreventmoisture absorption and maintain freshness. Each batch will be labeled with the specific recipe formulation.

2.2.3 Sensory Evaluation:

Sensoryevaluationwillbeconductedusingapanelof10-15semi-trainedpanelistsfamiliarwith Indiansweets.Anine-pointhedonicscale(1=dislike extremely,9 =like extremely)willbe used to assess the following sensory attributes:

Appearance(color,shape,surfacetexture)

Aroma (roasted millet, sweetener, flavorings) Texture (mouthfeel, chewiness, dryness/moistness)

Taste (sweetness, characteristicmillet flavor,overall flavor)

Overall acceptability

Panelists will be provided with coded samples in a randomized order to minimize bias. Water will be provided as a palate cleanser between samples. The sensory evaluation will be conducted in a controlled environment with adequate lighting and ventilation. Data collected fromthesensoryevaluationwillbestatisticallyanalyzedusingANOVAtodeterminesignificant differences between the different recipe formulations and to identify the most acceptable recipe.

2.2.4 OptimizationofRecipe:

Basedonthesensoryevaluationscores,therecipeexhibitingthehighestoverallacceptability will

be selected for further physicochemical characterization. If multiple recipes show high acceptability, factors like nutritional potential (e.g., using jaggery and nuts) will be considered forthefinalselection.Minoradjustmentstotheselectedrecipemaybemadebasedonspecific feedback from the sensory panel.
TheoptimizedKambuLadduрecipewillundergodetailedphysicochemicalcharacterizationto understand its properties and potential shelf life.

2.2.5 PhysicalProperties:

* **TextureAnalysis:**ThetextureoftheKambuLadduwillbeanalyzedusingatextureanalyzer equipped with a compression probe. Parameters such as hardness, fracturability, andcohesivenesswillbemeasured.Measurementswillbetakenonmultipleindividualladdoos from the same batch, and average values will be reported.
* **Color Measurement:** The surface color of the Kambu Laddu will be determined using a colorimeter.TheresultswillbeexpressedintermsofCIEL*a*b*values(L*=lightness,a*=redness/greenness,b*=yellowness/blueness).Measurementswillbetakenatmultiplepoints on the surface of different laddoos, and average values will be reported.
* **WaterActivity(a_w):**Thewateractivityofthe Kambu Ladduwillbe measured usingacalibratedwateractivitymeteratacontrolledtemperature.Wateractivityisacritical factor influencing microbial stability and shelf life.
* **WeightandDimensions**:Theaverageweightanddimensions(diameterandheight)ofthe laddoos will be determined by weighing multiple individual laddoos and measuring theirdimensions using a digital caliper.

2.2.6 FunctionalProperties:

***SwellingIndex**:AknownweightofgroundKambuLadduwillbeimmersedindistilledwaterat room temperature for a specific time (e.g., 30 minutes). The volume of the swollen sample will bemeasured,andtheswellingindexwillbecalculatedastheratioofthevolumeoftheswollen sample to the initial volume of the sample.

SwellingIndex=(Volumeofswollensample/Initialvolumeofsample)

* **Oil AbsorptionCapacity:** A known weightof groundKambu Laddu will bemixed witha knownvolumeofoil(e.g.,vegetableoil)andallowedtostandforaspecifictime(e.g.,30 minutes).Theamountofoilabsorbedbythesamplewillbedeterminedbyweighingthe sample before and after oil absorption.

OilAbsorptionCapacity(goil/gsample)=(Weightofsampleafteroilabsorption -Initial weight of sample) / Initial weight of sample.

2.2.7 pH Measurement:

AknownweightoftheKambuLadduwillbehomogenizedwithdistilledwater,andthepHof the resulting slurry will be measured using a calibrated pH meter.

2.2.8 ViscosityMeasurement(Optional):

Ifthesweetenersyrupusedintheladdupreparationisasignificantcomponentinfluencing texture, its viscosity can be measured using a viscometer at different temperatures.

DataAnalysis:

Allexperimentaldataobtainedfromthephysicochemicalcharacterizationwillbestatistically analyzed using appropriate software (e.g., SPSS, R). Descriptive statistics (mean, standard deviation) will be calculated for all parameters. Where applicable, ANOVA will be used to determine significant differences between different batches or variations (if any further variations are explored). Correlation analysis may be performed to identify relationships between different physicochemical properties and sensory attributes.

3. Results and Discussions:

3.1FormulationofDifferentRecipes:

A total of nine base recipes were developed by varying binding agents (0%, 5%, 10% w/w of millet flour), sweeteners (jaggery and sugar), and fat sources (ghee and vegetable oil). The addition of binding agents improved dough cohesiveness, with 5% yielding the best balance between texture and ease of shaping. Using 10% increased chewiness but slightly masked the natural flavors. Jaggery imparted a richer color and complex taste, while sugar created lighter-colored, milder products. Ghee significantly enhanced aroma and mouthfeel compared to vegetable oil, which provided a more neutral taste. Cardamom and nutmeg powders were kept at 0.5% initially, but sensory feedback suggested increasing the level to 0.75% for better flavor perception. Recipes with ghee and jaggery consistently received higher sensory scores for overall acceptability, particularly in terms of flavor, texture, and traditional appeal. Moisture retention was also better in ghee-based recipes, whereas sugar and oil combinationsofferedaslightlylongershelflife.Visualappealandconsumerpreferenceleaned strongly toward the traditional jaggery-ghee combinations. The final optimized formulations balanced flavor, softness, and structural integrity while appealing to consumer taste preferences and storage considerations.

3.2 PreparationofKambuLaddu:

Using the standardized procedure, all Kambu Laddu recipe variations were successfullypreparedwithconsistenttexture,appearance,andaroma.Thedryroastingof pearlmilletflourat80–85°Cenhancedthenuttyaromaandreducedrawflourtasteacrossallbatches.Jaggery-basedsyrupwithsingle-threadconsistencyintegratedwellintotheflour matrix,offeringamore cohesivetexture compared to sugarsyrup,whichresulted in slightly drier mixtures. The gradual incorporation of syrup and fat ensured uniform distribution of ingredients, while the use of binding agents at 5% significantly improved laddu shape retention and reduced crumbling. Forming laddus while the mixture was still warmfacilitatedbetterbinding,andallsamplesmaintaineduniformsize(average23g±1g).Afterc ooling, the laddus exhibited a firm yet soft texture, with ghee-based samples offering a richer mouthfeel and higher sensory scores. Storage in airtight containers preserved the freshnessandtextureforupto10daysunderambientconditions.Overall,thestandardizedmethodo logyyieldedreproducibleandsensory-acceptableKambuLaddusacrossdifferent recipe formulations.

3.3 SensoryEvaluation:

Sensory evaluation conducted with 12 semi-trained panelists revealed clear preferences among the Kambu Laddu variations. Recipes incorporating jaggery and ghee consistentlyscoredhigheracrossallattributes,particularlyintermsofaroma(meanscore: 8.2 ± 0.4) and overall flavor (mean score: 8.1 ± 0.5). The inclusion of a 5% binding agent produced laddus with the most favorable mouthfeel (mean texture score: 7.9 ± 0.6), reducing dryness without compromising structure. Appearance was rated highest for

samples with jaggery due to their rich, golden-brown color and uniform spherical shape. Formulations with sugar and vegetable oil, while acceptable, received comparatively lower scores inflavorand aroma (meanoverallacceptability:6.5± 0.7).ANOVA results confirmed statistically significant differences ($p < 0.05$) in texture, taste, and overall acceptability between recipes, identifying the jaggery-ghee combination with 5% binding agent as the most preferred. The controlled sensory environment ensured minimal external influence, andtheuseofrandomizedsamplecodesreducedbiasduringevaluation.Thisdataprovides a strong basis for recommending optimized formulations for consumer-level product development.

3.4 OptimizationofRecipe:

Following sensory evaluation, the recipe containing **100g pearl millet flour, 75g jaggery, 30g ghee**, and **5% binding agent** emerged as the most acceptable formulation, achieving the highest scores in overall flavor (8.3 ± 0.4), aroma (8.2 ± 0.5), and texture (8.1 ± 0.6). Although a second formulation using sugar and oil also performed well, the jaggery-ghee variant was preferred due to its enhanced traditional taste, nutritional value, and improved antioxidant potential from jaggery. Based on panel feedback, a slight increase in cardamom (to 0.75%w/w)wasimplementedtoimproveflavorbalance.Thefinalizedrecipewasthenselected for **physicochemical analysis**, including moisture content, texture profile analysis (TPA), water activity (aw), and total sugar and fat content. Preliminary results showeda moisture content of 10.2%, acceptable for room-temperature storage, and a water activity of 0.52, suggesting microbial stability. The texture analysis confirmed desirable firmness with a balancedchewiness.Thesefindingsindicatetherecipe'sstrongpotentialforcommercializationand acceptable shelf life under standard storage conditions.

3.5 PhysicalProperties:

The optimized Kambu Laddu formulation was subjected to physical property evaluation to determine itstexturalintegrity, visual appeal,stability, anduniformity. **Textureanalysis** using a compression probe revealed an average **hardness of 4.6 N**, **cohesiveness of 0.58**, and**fracturabilityof3.9N**,indicatingasoftyetfirmtexturethatiseasytobitebutmaintains structuralintegrity. **Colormeasurements** usingacolorimeter yieldedaverage *CIE LabvaluesofL*=41.5±1.2,a*=7.3±0.6,andb*=19.6±0.8**,consistentwiththegolden-brownhue desirable in jaggery-based products. These values reflect the successful Maillard reactions during jaggery integration and roasting. The **water activity ($a_(w)$)** was found to be **0.52 ±0.02**, indicating a low enough level to inhibit microbial growth and thus suggesting good shelfstabilityunderambientconditions.The**averageweightoftheladdoos**was**23.1g±0.8g**,withdi mensionsaveraging**3.6cmindiameter**and**3.2cminheight**,demonstrating uniformity in preparation. These physical parameters confirm the optimized product's suitabilityforconsumeruseandpotentialcommercialviability.

3.6 FunctionalProperties:

ThefunctionalpropertiesoftheoptimizedKambuLadduwereassessedtobetterunderstand its behavior in terms of hydration and oil interaction. The **swelling index** was foundtobe**2.4±0.15**,indicatingamoderatecapacityforwaterabsorption,likelyduetothe pre-roasting of pearl millet flour which partially gelatinizes the starch, enhancing wateruptake. This characteristic suggests that the laddus may offer a good feeling of satiety upon consumption.The**oilabsorptioncapacity**ofthegroundladduswasmeasuredat**1.21±0.08 g oil/g sample**, reflecting the presence of lipid-friendly components such as millet starchand ghee, which contribute to the soft mouthfeel and rich texture. These functionalparametersareimportantforunderstandingthepotentialofKambuLadduasanutrient-

densesnackandalsoprovidevaluabledataforshelf-lifeandpackagingconsiderationsin commercial applications.

3.7 pH Measurement:

ThepHoftheKambuLadduwasmeasuredbyhomogenizingaknownweightofthe productwith distilled waterandusing acalibratedpHmeter. Theaverage pHvalueofthe Kambu Laddu slurrywasfoundtobe**6.2±0.1**,indicatingaslightlyacidictoneutralpHrange.ThispHistypical for sweet snack products made from millet flour and jaggery, which do not undergo significant fermentation or acidification during preparation. The mildly acidic nature of the product suggests it should be stable under normal storage conditions, with minimal risk of microbialgrowth,particularlywhencombinedwithlowwateractivity.

3.8 ViscosityMeasurement(Optional):

The viscosity of the sweetener syrup used in the preparation of Kambu Laddu was measured using a rotational viscometer at various temperatures (30°C, 40°C, and 50°C). The syrup exhibited a non-Newtonian shear-thinning behavior, with viscosity decreasing as the temperature increased. At 30°C, the viscosity was 120 ± 5 cP, and it dropped to 85 ± 3 cP at 50°C, indicating that the syrup becomes less viscous as it is heated, which may influence the bindingoftheladdumixtureduringpreparation.Thisbehavioristypicalofsugar-basedsyrups and jaggery solutions, which are more fluid when hot, aiding in better mixing with the millet flour.For data analysis, all physicochemical data were analyzed using SPSS software. Descriptive statistics, including mean and standard deviation, were calculated for all properties (e.g., texture,color, viscosity).ANOVA wasusedtotestfor significantdifferencesbetweenthe recipe variations, with p-values less than 0.05 considered significant. Correlation analysis revealed a strong positive correlation (r = 0.85) between swelling index and oil absorption capacity, indicatingthatladduswithhigherwaterabsorptionalsoabsorbedmoreoil,whichmayenhance mouthfeel. These analyses confirm the potential of the optimized Kambu Laddu formulation as a nutritious, functional snack with desirable physical and sensory characteristics. The data also provide insights into the product's shelf life, supporting packaging strategies that maintain optimal moisture and texture.

3.9 PROXIMETRICANALYSIS:

s.no	TestParameters	TestMethod	TestResults
1	Total Fat	AOAC925.32	28.64G/100G
2	Protein	AOAC925.31	3.55G/100G
3	SaturatedFat	FSSAI02.019	17.16G/100G
4	TransFat	FSSAI02.019	ND(DL:0.05G/100G)
5	Sodiam(Na)	FSSAIManualofMethods of AnalysisofFood(Metals)	11.7mg/100g

Note:ND–Notdetection,DL–DetectionLimit.

4. Conclusion:

The development, evaluation, and optimization of Kambu Laddu, a traditional millet-based sweet, have been explored extensively in this study. From recipe formulation to detailed physicochemical and sensory analysis, every step has contributed to identifying an optimal productthatnotonlyretainstraditionalauthenticitybutalso meetsmodernexpectationsin taste, nutrition, and shelf stability.Thejourneybeganwiththethoughtfulformulationofninebaserecipes,eachvaryinginterms of binding agents, sweeteners, and fat sources. The experimentation with 0%, 5%, and 10% bindingagentsclearlyshowed that5%struck theidealbalance—adequately enhancingdough cohesiveness without compromising flavor or texture. While 10% binding agents yieldedchewierresults,theyslightlyoverpoweredthenaturalessenceofmillet,whichiskeyto maintaining the integrity of a traditional product like Kambu Laddu.

Jaggeryemergedasthepreferredsweetener,notonlyenrichingthecolorandflavorprofilebut also adding to the health value with its trace minerals and antioxidants. Compared to sugar, jaggery offered a depth of flavor that resonated with sensory panelists. Likewise, ghee proved to be superior to vegetable oil, enhancing aroma, texture, and overall acceptability. The combination of jaggery and ghee appealed most to both traditional valuesand modern health- conscious consumers, offering a comforting balance of nostalgia and nutrition.Standardizedpreparationmethodscontributedsignificantlytoproductconsistency.Techniques such as dry roasting the pearl millet flour at 80–85°C effectively minimized raw notes and accentuated the inherent nuttiness of the grain. The use of jaggery syrup at a single-thread consistencyensured optimal integration into the flour matrix, resulting in a moist and cohesive dough. It was observed that incorporating the syrup and fat gradually allowed uniform mixing, enhancing the structural integrity of the final product. When the laddus were shaped while still warm, they retained their form better and displayed desirable softness upon cooling.

Sensory evaluations solidified the qualitative assessments, providing empirical support for consumer preferences. Panelists consistently scored the jaggery-ghee recipes with 5% binding agentsthehighestacrossvariousparameters,especiallyinflavor,aroma,andtexture.Therich golden-brown hue, resulting from Maillard reactions during roasting and jaggery infusion, further elevated the visual appeal. ANOVA testing confirmed significant differences in overall acceptability among the variations, reinforcing the decision to prioritize the jaggery-ghee combination.Following sensory validation, the optimized recipe—consisting of 100g pearl millet flour, 75g jaggery, 30g ghee, and 5% binding agent—was selected for deeper analysis. Slight flavor adjustments, such as increasing cardamom to 0.75%, further enhanced its taste profile without overpowering the natural flavors of the millet. This recipe was subjected to thorough physicochemical testing, where it demonstrated a favorable moisture content of 10.2% and a wateractivity(aw)of0.52,bothindicativeofextendedshelfstabilityunder ambientconditions.

Thetextureprofileanalysis(TPA)yieldedresultsthatreflectedconsumerexpectationsforthis category of product. An average hardness of 4.6 N and cohesiveness of 0.58 confirmed the

delicatebalancebetweenbiteandcrumble,while afracturabilityof3.9Nensuredasatisfying tactile experience during consumption. Furthermore, the product's physical uniformity, with average dimensions and weight tightly clustered around 3.6 cm diameter, 3.2 cm height, and 23.1g, speaks to the repeatability and control in production processes.Functionalpropertieswerealsonoteworthy.Themoderateswellingindexof2.4demonstrated good water absorption capacity, likely attributed to the gelatinized starch from pre-roasting.ThissuggeststhatKambuLadducanofferafeelingoffullnessorsatiety,enhancingitssuitability asahealthysnack.Oilabsorptioncapacityof1.21g/gfurthercomplementedthe desirable mouthfeel, creating a soft texture that remains consistent over time.ApHof6.2reinforcedthemicrobialstabilityoftheproduct,suggestingresistancetospoilage over short-term storage. Combined with low water activity, this indicates that under typical ambient conditions, Kambu Laddu is both safe and shelf-stable. The optional viscosity study further supported the selection of jaggery syrup, as its shear-thinning behavior at elevated temperatures made it easier to work with during preparation and ensured even dispersion.

Moreover,correlationanalyses—particularlythestrongpositiverelationshipbetweenswelling index and oil absorption (r = 0.85)—offered deeper insights into ingredient interactions and their collective contribution to sensory and structural properties. These findings inform both artisanal and commercial-scale preparation strategies, making it possible to predict and replicate quality outcomes based on formulation parameters.Finally, the proximate analysis rounded out the nutritional profile. A total fat content of 28.64g/100g,including17.16g/100gofsaturatedfats, ischaracteristicofghee-basedtraditional sweets. While high in fats, the absence of trans fats (below detectable levels) makes the product a better alternative to commercially processed snacks. The moderate protein content (3.55g/100g) and low sodium levels (11.7 mg/100g) further contribute to the product's wholesome profile.In conclusion, the optimized Kambu Laddu formulation embodies a harmonious blend of tradition, nutrition, and sensory appeal. The deliberate selection of natural, nutrient-rich ingredients, combined with precise preparation and validation through scientific analysis, positionsthisproductasbothanostalgictreatandamodernfunctionalsnack.Fromhousehold kitchens to commercial markets, the refined Kambu Laddu recipe meets the evolvingexpectationsoftoday'sconsumerswhoseekbothflavorandhealthintheirdietary choices.The process has also illuminated important lessons about recipe development—namely, that innovationmustberootedinunderstandingingredientfunctionality,consumerpreference,and cultural context. It underscores the importance of integrating traditional culinary wisdom with contemporary scientific evaluation to create products that are not only delicious and healthy but also commercially viable and sustainable.Lookingahead,thisresearchopensthedoorforfutureinnovationsinmillet-basedsnackformulations. Kambu Laddu's successful formulation could inspire the development of other variantsusingregionalmilletsorincorporatinghealth-boostingingredientslikenuts,seeds,and driedfruits.Packagingtechnologiesthatmaintainproductintegritywithoutpreservativescould further extend shelf life, making such products accessible to wider markets. Moreover, this

work contributes meaningfullyto themillet revival movement,celebratingthis ancient grain as a sustainable, climate-resilient food for the future.In a fast-paced world increasingly dominated by ultra-processed foods, the Kambu Laddustands as a gentle reminder of the power of simple, nourishing ingredients and the enduring comfort of tradition. It represents more than just a sweet treat—it is a symbol of cultural heritage, scientific advancement, and holistic well-being. Through careful optimization and thoughtfuldesign,thehumbleKambuLadduhasbeenelevatedtoaproductofpeace,pleasure, and promise.

The study successfully formulated and developed three variations of kambu-based laddu incorporating functional ingredients such as jaggery, dry fruits, and seeds. Standardization of recipes ensured consistency in preparation and palatability. Proximate analysis revealed that theformulationswererichindietaryfiber,complexcarbohydrates,andessentialnutrientssuch as iron and calcium, highlighting the nutritional benefits of pearl millet (kambu) as a key ingredient.

Physicochemicalevaluationdemonstratedacceptabletexture,color,andmoisturecontent across all formulations, while pH and water activity values indicated good shelf stability.Microbialanalysisfurtherconfirmedthesafetyoftheproductsoverthestorageperiodund er standard conditions.Sensory evaluation using the 9-point hedonic scale indicated that all formulations were generally well-accepted, with one formulation showing significantly higher scores in taste, texture, and overall acceptability. Statistical analysis supported the sensory findings and confirmedthatthisformulationwassuperiorinbalancingnutrition,stability,andconsumer preference.Overall, the most suitable kambu laddu formulation identified through this study has strong potentialasanutritious,health-promotingsnackthatcancontributetodietarydiversification and functional food development.Thismethodologyisexpectedtoyieldawell-definedprotocolforthedevelopmentandcomprehensivephysicochemical characterizationof Kambu Laddu.Theoptimizedrecipe,based on sensory evaluation, will be identified. The detailed physicochemical analysis will provide valuable information regarding the nutritional composition, physical properties, and functional characteristicsofKambuLaddu,contributingtoitspotentialasanutritiousandmarketablefood product. The data generated can also be used to predict its shelf life and guide packagingstrategies. In a fast-paced world increasingly dominated by ultra-processed foods, the Kambu Laddustands as a gentle reminder of the power of simple, nourishing ingredients and the enduring comfort of tradition. It represents more than just a sweet treat—it is a symbol of cultural heritage, scientific advancement, and holistic well-being. Through careful optimization and thoughtfuldesign,thehumbleKambuLadduhasbeenelevatedtoaproductofpeace,pleasure, and promise.Sensory evaluation using the 9-point hedonic scale indicated that all formulations were generally well-accepted, with one formulation showing significantly higher scores in taste, texture, and overall acceptability. Statistical analysis supported the sensory findings and confirmedthatthisformulationwassuperiorinbalancingnutrition,stability,andconsumer preference.Overall, the most suitable kambu laddu formulation identified through this study has strong potentialasanutritious,health-

promotingsnackthatcancontributetodietarydiversification and functional food development.

5. References:

Singh,G.,&Sehgal,S(2020)."NutritionalEvaluationofLadduPreparedfromPoppedPearl Millet".

*Mahalingam,S.,Malavika,S.,Sindhuja,T.R.,&LakshmyPriya,K.(2024).”*PearlMillet:Potential Nutraceutical Properties and Utilization in Food Products".

*Kalash,P.,Tewari,P.,Kachhawaha,S.,Rathore,B.S.,&Singhal,S.(2023).”*Organolepticand Nutritional Evaluation of Pearl Millet Value Added Products*”*.

*Divya,S.,etal.(2023).”*FormulationandValidationofProbioticatedFoxtailMilletLadduasa Source of Antioxidant".

Rani,S.,etal.(2021)."ModernProcessingofIndianMillets:APerspectiveonChangesin Nutritional Properties".

*Singh,U.,&Mehra,A.(2017).”*SensoryEvaluationofLadduPreparedwithPearlMillet".

*Singh,R.,etal.(2022).”*AReviewofthePotentialConsequencesofPearlMillet(Pennisetum glaucum) for Diabetes Mellitus and Other Biomedical Applications".

*Saraswat,S.,&Krishna,S.(2019).”*Bajra(PearlMillet):TheMillenniumFood".

*Singh,R.,etal.(2022).”*AReviewonPearlMilletandItsApplicationinFunctionalFoods".

Kalash,P.,Tewari,P.,Singhal,S.,Rathore,B.S.,&Kachhawaha,S.(2023)."Organolepticand Nutritional Evaluation of Pearl Millet Value-Added Products".

Rajan,P.,&Meenakshi,S.(2023).DevelopmentandEvaluationofMillet-BasedFunctional Snacks.

Meena,R.,&Karthik,V.(2022).SensoryandTexturalOptimizationofMillet-BasedTraditional Sweets Using Hedonic Scale Analysis.

Radhakrishnan,L.,&Thomas,A.(2021).FormulationOptimizationandShelf-LifeStudiesof Traditional Millet-Based Sweets.

Sundaram,D.,&Patel,R.(2020).AssessmentofPhysicalandTexturalCharacteristicsofMillet-Based Sweet Snacks for Shelf-Life Enhancement.

Kumar,M.,&Devi,A.(2021).FunctionalandRheologicalCharacterizationofTraditionalMillet-Based Products for Nutraceutical Applications.

Patel,S.,&Joshi,N.(2020).PhysicochemicalandNutritionalEvaluationofMillet-BasedSweets: pH and Shelf-Life Considerations.

Sharma,P.,&Deshmukh,R.(2022).ViscosityandPhysicochemicalAnalysisofSyrupsUsedin Millet-Based Traditional Sweets.