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Development of Vegan Chocolate Utilizing Millet Milk as a Dairy Substitute and its Analysis

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Abstract: The global food sector was undergoing a paradigm shift as customers gravitated towards vegan food options. The increasing demand for dairy-free alternatives has spurred innovation in the confectionery industry, particularly in chocolate production. This research focuses on the development of vegan chocolate using millet milk as a functional and nutritional alternative to traditional dairy milk. Millet milk is lactose-free, gluten-free, and environmentally friendly option that provides essential nutrients and vitamins that combat health. Pearl millet (*Pennisetum glaucum)* was processed and spray-dried to obtain millet milk powder and incorporated into chocolate formulations with addition of coconut butter and stevia as a natural sweetener. The study involved optimizing the ingredient in various proportions (V1, V2, V3) and evaluated for sensory analysis using 9-point hedonic scale with 50 semi-trained panel and accepted variation (V2) were subjected to further analysis of proximate composition, antioxidant activity, texture profile, SEM and microbial stability to assess its quality and shelf life. The Results indicated that millet milk effectively replaces dairy while contributing to the protein, mineral, and fiber content of the chocolate. Additionally, the use of stevia benefited a low-calorie, diabetic-friendly sweetening option without compromising taste. This innovation demonstrates the potential of millet milk in functional food development, contributing to sustainable food systems that align with health and lactose-intolerant consumer preferences.

Keywords: *Vegan Chocolate, Millet Milk, Dairy Substitute.*

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I. INTRODUCTION

Chocolate is one of the most beloved treats in the world and praised for its rich, complex flavors, smooth texture, and alluring appearance. From the time of ancient civilizations to the advanced confectionery industry of today, chocolate has always captivated consumers and connoisseurs worldwide. (Montagna MT *et al.,* 2019**)** When consumed, chocolate promotes the release of key neurotransmitters including serotonin, dopamine, and endorphins, creating a cascade of positive emotional responses that contribute to overall mental wellness (Garbarino *et al.,* 2022)

Chocolate is the finished product that made from cocoa solids or cocoa butter, sugar, and milk (Ditchfield *et al***.,** 2023**)** It seems that cocoa has had a variety of production processes since its discovery, even if chocolate is produced in accordance with current dietary trends. The journey of cocoa called the "food of the gods" (Lopes and Pires, 2015**).** The development of chocolate was influenced by Van Houten's method of extracting cocoa butter from roasted cocoa beans. The first modern chocolate production in England was made possible by the method that Joseph Fry adopted in 1847. Swiss chocolatier Daniel Peter originally created milk chocolate in 1879 by introducing the milk powder that chemist Henri Nestle had previously invented into the chocolate-making process. This issue has garnered attention ever since it was first introduced. The invention of the machine by Swiss inventor Rudolph Lindt in 1879 is credited with giving chocolate its velvety, smooth texture. Making use of this machine made it easier to carry out the "conching" step in the chocolate-making process. Consequently, there are two categories of procedures used in chocolate production. The one is the traditional method and the other is a contemporary method. Mixing, grinding, conching, and packaging are the steps involved in the traditional method. However, the present contemporary method consists of five separate steps of conching, tempering, shaping, mixing, and refining**.** (Savaş *et al*.,2024)

Europe accounts for 74% of the world's chocolate sales. In addition to being the biggest producer and exporter of

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chocolate worldwide, most European nations have comparatively high per capita consumption rates, which surpass the global average of 0.9 kg per person annually. The demand for organic and healthful foods has increased as a result of the COVID-19 pandemic, which has made consumers even more health and quality concerned. Furthermore, the development of low-calorie and vegan chocolate products is becoming more and more significant. (Appenheimer et al., 2021)

Vegan nutrition has become increasingly popular over the world in recent years, especially in European, American, and Asian countries **(**Earle and Hodson, 2017). Numerous variables have been identified as contributing to the increase in vegan nutrition **(**Dedehayir *et al.*, 2019). Nevertheless, a more thorough review of research indicates that vegan diets are becoming increasingly popular worldwide, with the number of people following veganism having increased sevenfold. According to **(**Ucan Kayaalp *et al.*,2023**),** almost 20% of food and beverage establishments have added vegan items to their menus throughout the last three years. However, there has been a notable shift in favour of plant-based chocolate substitutes as dietary preferences change and people become more conscious of ethical and environmental issues. The popularity of vegan chocolate has increased dramatically in recent years due to a number of factors, such as the rise of veganism, increased awareness of lactose intolerance and dairy allergies, and a greater emphasis on sustainable and ethical food practices. This increase in demand has sparked innovation in the chocolate industry, resulting in a wide variety of vegan chocolate products that appeal to a wide range of tastes and preferences (Rehman *et al.,* 2024)

Notably, many consumers are choosing plant-based milk substitutes in place of traditional cow milk due to dietary restrictions like vegetarianism or veganism or medical conditions like lactose intolerance, which affects 75% of the world's population (Mäkinen *et. al*., 2016). Moreover, the rising consumer awareness toward healthy eating, animal welfare, and environmental sustainability has fueled the global demand for plant-based food alternatives, including vegan confectioneries. Vegan chocolate, free from dairy and refined sugar, offers a sustainable and health-conscious alternative to conventional milk chocolate Vegan chocolate, which is devoid of dairy and processed sugar, provides a healthier and more environmentally friendly substitute for traditional milk chocolate. (Mehta *et al*., 2021).

Millet is the sixth most important cereal grain in the world and millions of people in India, Africa and China rely on millets for energy and sustenance, especially in arid and semiarid regions. (Das *et al.,* 2019)**.** According to (Saleh *et al*.,2013**),** millets are the significant crop in the world, providing food for one-third of the world's population. Over 170 lakh tons of millet are produced in India, which accounts for 20% of global production and 80% of Asia's (Ministry of Agriculture & Farmers Welfare, 2022**).** The two primary classifications of millets are major and small millets. Major millets include sorghum, pearl, and finger millet. while, small millets include kodo millet, barnyard millet, proso millet, and foxtail millet. (Banerjee and Maitra, 2020) Nutri-cereals are incredibly nutrient-dense grains that contain the same quantity of nutrients as commonly consumed cereal eating habits, according to the Indian Council of Agricultural Research and the Indian Institute of Millets Research (ICAR-IIMR). **(**Saini *et al.,* 2021)

In India, pearl millet ranks fourth in importance after sorghum, rice, and wheat. It is one of the eight major grains in the world **(**Prashant Sagar & Neetu Singh, 2024) Pearl millet (*Pennisetum glaucum*), is a symbol of tenacity and nourishment in a variety of agricultural environments around the world. (Akanbi T 2019) Pearl millet has a protein content of 9–21%, which is comparable to wheat (11.7 g/100 g) but higher than corn (4.8 g/100 g), rice (6.7 g/100 g) and sorghum (10.5 g/100 g). The amino acids found in pearl millet are composed of prolamin and prolamin-like (22–35%), albumins and globulins (22–27%), and glutelin and glutelin-like compounds (28–33%). Additionally, the protein content is higher than that of sorghum. According to (Nambiar *et al*.,2011), pearl millet has 40% more methionine and lysine and 8–60% more crude protein than maize.The remarkable nutritional profile of pearl millet is it has high protein, dietary fibre, and complex carbs which helps in maintaining good digestive health by regular bowel movements, avoiding constipation, and lowering the risk of gastrointestinal conditions including diverticulosis. Additionally, pearl millet's complex carbs digest slowly, lowering blood sugar levels and making it a great option for people with diabetes or insulin resistance. Due to its gluten-free characteristics, pearl millet provides a healthy grain option without causing negative side effects, making it a good substitute for people with coeliac disease or gluten sensitivity. Bioactive substances with antioxidant qualities, including flavonoids, tannins, and phenolic acids, are found in pearl millet. Antioxidants may lower the risk of chronic illnesses including cancer, heart disease, and neurological problems by shielding cells from the oxidative damage that free radicals produce**.** **(**Vishwaradhya M Biradar,2024)

There are several caloric sweeteners on the market right now, including aspartame, saccharin, acesulfame-K, sucralose, neotame, cyclamate, alitame, thaumatin, moneline, and pentadine. These compounds are categorised as natural and synthetic sweeteners by the European Food Safety Authority (EFSA) and the US Food and Drug Administration (FDA) as food additives **(**Wan *et al.* 2021). Many studies indicate that certain artificial sweeteners are unhealthy, which has led to a considerable deal of dispute. Though there aren't many natural sweeteners that don't contain calories, stevia *(Stevia rebaudiana*) is the one that has attracted the most attention from scientists recently. In 1887, the scientist Moise Santiago Bertoni discovered stevia (*Stevia rebaudiana)*, a small perennial shrub that is endemic to northern Paraguay and regions bordering Brazil. It is a member of the Asteraceae family. According to (Hossain *et al*., 2017) Japan has the most factories that process and extract stevioside, while China is the world's largest producer of stevia, exporting about 80% of its output.

Stevia has been linked to a number of health advantages, including anti-tumor, anti-hypertensive, anti-antidiabetic,

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anti-obesity, and antioxidant properties, according to various studies.**(**Ahmad *et al*. 2020) Stevia (*Stevia rebaudiana),* sometimes referred to as a honey leaf, caramel leaf, or sweet leaf. In many nations, stevia (*Stevia rebaudiana*) is used in place of sugar in meals, drinks, and medications. Stevia leaves are emerging as a significant source of extremely powerful sweeteners for the expanding natural food market. **(**Putnik *et al*. 2020).

The coconut, *(Cocos nucifera),* is a tropical palm tree that originated in Southeast Asia and is currently grown in many tropical and subtropical climates worldwide. (H.C Harries,1978) It is a member of the palm tree family and a member of the Arecaceae family. With 51.7% kernel, 9.8% water, and 38.5% shell, the coconut fruit is a unique plant-based food that is well-known for its high nutritional value and well-rounded character. Essential vitamins and minerals included in coconuts support general health and wellbeing. Vitamins are essential for immune system support, skin health, energy metabolism, and involvement in a number of enzymatic processes.(Yingshuang Lu *et al*.,2024) Each component of the tree offers a benefit and makes a significant contribution to human existence. Coconut fruit becomes a necessary ingredient in cooking, while other parts are used in industries such as food manufacturing, medicine, cosmetics, and odd applications in engineering and upholstery. (Divya, P. M *et al.,* 2023). Every edible part of the coconut fruit is used by people and contains important nutrients, some of which may help lower the risk of disease **(**Vitrac *et al.,* 2019**).** Since coconut kernel extract has been demonstrated in an animal model to decrease oxidative stress, show tumour suppression, and inhibit stemness (cancer stem cell phenotypic molecular programs), it may be useful in chemoprotection. **(**Sorra et al., 2019**).** Due to a variety of consumer incentives as well as their sensory qualities, coconut-based substitutes are becoming more and more popular in the food industry (Beegum et al., 2022).

According to (Zahid et al.,2021**),** the production of vegan chocolate necessitates substituting plant-based lipids for conventional fats, refined sugar for natural sweeteners, and dairy milk for plant-based substitutes. In this context, the combination of pearl millet milk, coconut butter, and stevia presents a promising matrix for the development of functional vegan chocolate.

II. MATERIALS AND METHODS

A. Selection and Collection of Sample:

The ingredients used to develop Vegan chocolate were pearl millet *(Pennisetum glaucum*) Coconut ***(****Cocus nucifera*) and Stevia as natural sweetner. The pearl millet were procured from reliable local markets in chinalapatti, Dindigul district, Tamil nadu, India. Fresh Coconut *(Cocus nucifera*) were sourced from uzhavar santhai (Farmer's market) in same locality and Stevia was procured from online store. All collected samples were examined before processing to ensure the quality parameter such as freshness, absence of contamination and physical integrity before processing.

B. Sample Processing and Preparation:

- *Pearl Millet (Pennisetum glaucum):*

The collected Pearl millet *(Pennisetum glaucum)* were subjected to manual cleaning process to remove extraneous matter and damaged grain. After that pearl millet were washed with water to remove dust particles and soaked for about 12 hours with change of water for every three hours and finaly after draining, the soaked grains were wrapped in a clean white cotton cloth and kept under appropriate conditions to facilitate germination for about 24 hours. Then the sprouted pearl millet was subsequently blended with a measured volume of water to extract its millet milk for further spray drying process.

- *Spray Drying:*

It is one of the best drying methods to convert fluid materials into solid or semi-solid particles. Spray drying is a process where a liquid feed is atomized into a hot drying chamber, turning the droplets into dry powder almost instantly due to the heat. Spray drying is commonly used to preserve heat-sensitive bioactive substances because of the short contact time with heat and produce powdered food ingredients or nutraceutical products. The process was carried out using the spray dryer available at the Prof. C.N.R. Rao Research Centre, Avinashilingam Institute for Home Science and Higher Education for Women, Coimbatore, India. The pearl millet milk was dried at an inlet temperature of 180 °C and an outlet temperature ranging from 80 °C to 90 °C. A vacuum pressure of 60 mm Hg and an atomic pressure of 1 bar were maintained throughout the 5-hour drying process. To prevent sedimentation during drying, a stirrer was operated at a speed of 300–350 RPM.

Table 1 Weight of the Pearl Millet Before and after Processing

Sample	Wt. of Raw (g)	Weight After Germination (g)	Weight After Spray Drying (g)
Pearl Millet	3000 g	4716 g	400g

- *Coconut (Pennisetum glaucum):*

The matured Coconut (*Pennisetum glaucum*) usually around 12 months old were collected and outer husk was removed using a manual dehusker, and the coconuts are then split in half to drain the coconut water and dried using solar dryer to produce copra, which is the dried kernel of the coconut. Once dried, the copra was deshelled to separate the hard shell from the white kernel. Then dried copra was cleaned to remove any impurities or charred bits and sliced into 5mm thickness pieces and grounded using a high-speed grinder. As the grinding continues, the oil within the copra is released, and the mixture becomes a thick paste. Further homogenizing was done to obtain paste into a smooth creamy paste and stored in air tight sterile containers to obtain coconut butter.

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- *Stevia Sugar:*

The Stevia was selected as a sweetening agent over conventional white sugar in the development of vegan chocolate to meet vegan standards, enhance potential health benefits, and align with increasing consumer preference for natural, low-calorie, and ethically sourced alternatives. To improve consistency, mouth feel and overall quality of the final vegan chocolate, the procured stevia was finely pulverised with a mixer grinder to remove the coarse particles. The powdered stevia was then gently sieved to produce a fine, smooth texture comparable to icing sugar. This procedure ensured that the stevia blended evenly with the other components without leaving a gritty texture.

C. Standardization and Development of Vegan Chocolate

To develop a vegan chocolate, components such as spray dried pearl millet powder, coconut butter, and powdered stevia were blended in different proportions (V1, V2, V3) .The obtained coconut butter was slowly melted through double boiling method. The Powdered stevia sugar was mixed into the heated coconut butter until dissolved. The spray-dried pearl millet powder was progressively added to the mixture and blended uniformly to obtain its consistency. Then, the warm chocolate mixture was poured into silicone moulds and refrigerated for around 2-3 hours, until solid. After being set, the chocolates were unmoulded.

Table 2 Standardization of Vegan Chocolate

Ingredient	Variation I	Variation II	Variation III
Pearl millet milk powder	75	65	55
Coconut Butter	15	25	35
Stevia Powder	10	10	10

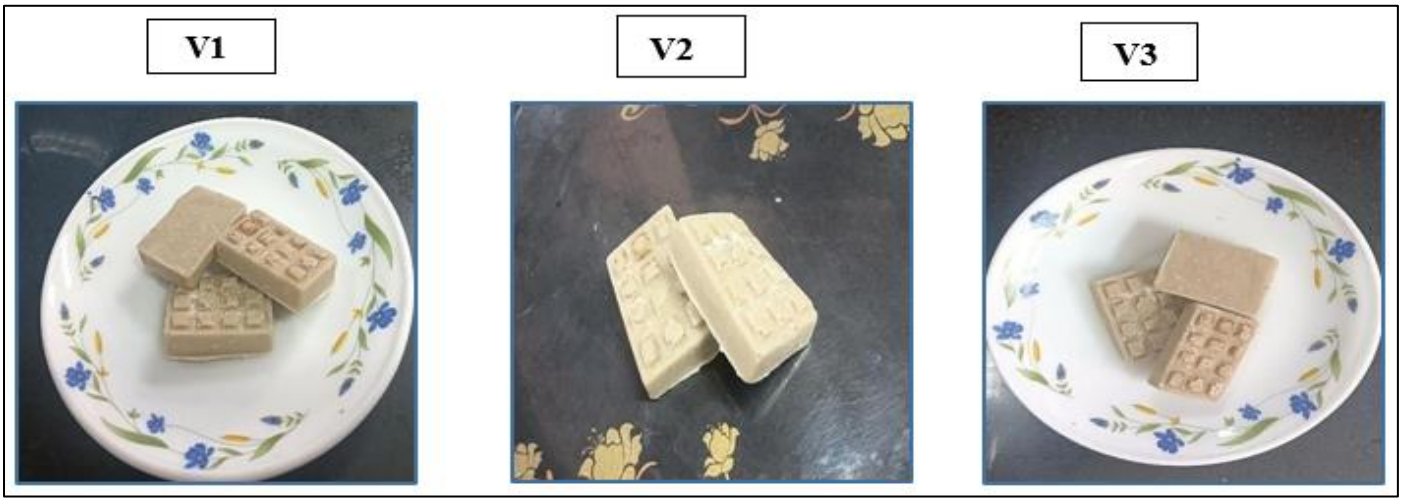

Fig 1 Developed Vegan Chocolate

➢ *Sensory Analysis*

Sensory analysis of vegan chocolate was subjected to organoleptic evaluation such as appearance, texture, colour, taste and flavour and overall acceptability using 9 -point hedonic scale . Total of 60 untrained panel members analysed the chocolate. The variation which was highly acceptable among all was selected and subjected to further analysis.

➢ *Determination of Proximate Composition*

The moisture, protein, fat, crude fiber, and ash content of the developed vegan chocolate were determined using the standard methods described by AOAC International. Total carbohydrate was calculated as the difference between 100 and sum of the percentage of moisture, crude protein, total fat, and ash. The sample calorific value was calculated from the percentages of crude protein, total carbohydrates and total fat. The sample calorific value was calculated from the percentages of crude protein, total carbohydrates and total fat. The conversion factors used were 9.0kcal/g for total fat and 4.0kcal/g for carbohydrates and protein % of carbohydrate = [100 – (Moisture% +Ash%+Protein %+ Fat % +Crude fiber%] Energy (kcal/100g) = [(Carbohydrate% × 4) +(Fat % × 9) + (Protein% × 4)].

➢ *Texture Analysis*

Texture analysis of chocolate helps in assessing the critical quality attributes in the chocolate like hardness, snap, cohesiveness, and mouth feel. This is especially useful when formulating vegan chocolate, as the fat composition and non-dairy ingredients can significantly affect texture. The brittleness, hardness, springiness, gumminess, chewiness, adhesiveness, cohesiveness and break force are analyzed using the texture analyzer. Force vs Distance curves are generated. The texture analyzer at Avinashilingam Institute for Home Science and Higher Education for Women, Coimbatore were used for analysis.

➢ *Antioxidant Activity*

The antioxidant activity of the developed vegan chocolate was determined by DPPH assay method using UV-Vis Spectrophotometer. It ensures chocolate maintains its nutritional value through production. While Coconut butter is lower in polyphenols than cocoa, may contain trace antioxidants. DPPH assay helps quantify how much additional

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antioxidant capacity these ingredients contribute to the final product.

➢ *SEM Analysis*

The surface morphology and microstructural properties of the chocolate samples were examined using (SEM)scanning electron microscopy. SEM involves electron beams and can describe the morphology of a chocolate sample at high magnification. This method generates detailed images, allowing for the evaluation of texture, particle distribution, and potential crystallisation patterns within the chocolate matrix.

➢ *Microbial Analysis*

The shelf life of vegan chocolate was determined by its microbiological stability over time, with Total Plate Count (TPC) and Yeast & Mould Count serving as crucial markers. These analyses are necessary to assess the product's quality and safety during storage. Food safety regulations (FSSAI and Codex) require acceptable microbiological levels for TPC (< 10^4 CFU/g) and Yeast & Mould (< 10^2 CFU/g).

III. RESULTS AND DISCUSSION

➢ *Sensory Evaluation*

The Developed Vegan Chocolate of Variation 1 as (V1), Variation 2 as (V2) Variation 3 as (V3) were subjected to sensory test using 50 untrained panelists. Each attribute was scored based on its intensity scaled on a nine-point hedonic scale (9 = like extremely; 8= like very much; 7= like moderately; 6=like slightly; 5=neither like nor dislike; 4=dislike slightly; 3=dislike moderately; 2= dislike very much; 1= dislike extremely) for Appearance, Texture, Taste, Flavor and Overall acceptability.

Table 3 Sensory Analysis of the Developed Vegan Chocolate

Sensory Attributes	V 1	V 2	V 3
Appearance	7.8±0.79	8.8±0.43	7.5±1.18
Flavour	7.5±0.5	8.3±3.09	7.6±0.70
Texture	7.2±1.03	8.4±0.84	7.1±0.88
Taste	7.4±0.53	7.9±0.43	7.0±0.82
Overall Acceptability	7.2±0.53	8.7±0.43	7.0±0.82

Table 3 shows the sensory analysis of variations V1, V2 & V3 of the developed vegan chocolate. The overall acceptability of V1 scores 7.2; V2 scores 8.7 and V3 scores 7.1 out of 9 points. It is concluded that out of all three different variations V2 has a high overall acceptability of 8.7. The appearance of V1 has a good acceptability but it lacks the taste and overall acceptability. This variation gave more coconut flavor as it has more coconut butter. The taste, texture, appearance and aroma of V2 has high acceptability compared to other three variations. This variation has mild sweet taste. In variation 3, the texture was not acceptable due to high millet proportion

➢ *Proximate Composition*

Table 4 The Nutritive Value were Calculated for the Selected Variation (V2)

Parameters	Amount per serving (100g)
Moisture	2.43%
Ash	2.30%
Carbohydrate	40.4g
Energy	250 kcal
Fat	7.6 g
Fibre	3.5 g
Protein	5.2 g
Calcium	103 mg
Potassium	132 mg

Table 4 presents the nutrient composition of the developed vegan chocolate formulated using the Millet milk powder. The moisture content was found to be 2.43%, which indicates a potentially longer shelf life due to reduced microbial activity. The ash content was 2.30%, reflecting the total mineral presence. The chocolate contained 40.4 g of carbohydrates, which can serve as a primary energy source. The protein content was 5.2 g, supporting its nutritional value. The fat content measured 7.6 g, and energy has 250 kcal contributing to texture and energy density. The sample also contained 3.5 g of dietary fiber, which may aid in digestive health. Regarding mineral content, the chocolate had 103 mg of calcium and 132 mg of potassium, both essential for bone health and electrolyte balance.

➢ *Texture Analysis*

Texture analysis of the developed vegan chocolate was evaluated has a critical aspect in the quality evaluation of vegan chocolate, as it directly influences consumer acceptance. Unlike conventional chocolate, vegan formulations lack milk solids and cocoa butter in standard proportions, which can affect parameters like hardness, snap, cohesiveness, and mouthfeel. Instrumental texture analysis using a texture analyzer involves quantify hardness and fractur ability.

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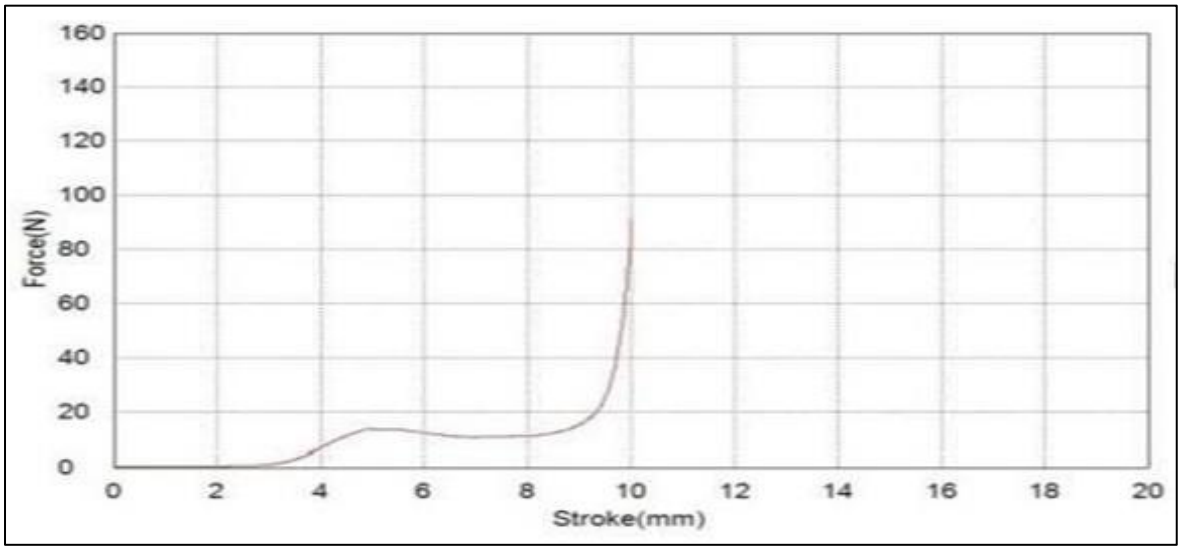

Fig 2 Texture Analysis of Vegan Chocolate.

Figure 1. shows that the Hardness (Force) Value**:** 91.1214 N. This indicates the force required to break the sample. A value of 91.12 N suggests the sample is relatively firm**.** Brittleness, Springiness, Gumminess, Chewiness, Cohesiveness, Break Force all are marked as not available**.** Adhesiveness Value is 0.00000 J**.** This suggests the sample does not adhere or stick to the samples and it exhibits high hardness and zero adhesiveness with strong structural integrity**.** The absence of data for other parameters like chewiness and cohesiveness limits further interpretation, but the available data still supports that the product is firm, non-sticky, and brittle in nature**.** A study by Ballesteros et al. (2020) highlighted that plant-based chocolates made with non-dairy fats exhibit significantly different mechanical properties, often being softer or more brittle depending on the fat composition. Similarly, de Melo et al. (2021) emphasized that the use of alternative ingredients like coconut butter and millet milk can alter the crystalline structure, thus affecting texture. The absence of dairy proteins also reduces emulsification, leading to changes in cohesiveness and melting behavior.

➢ *Antioxidant Activity*

The antioxidant activity of the developed vegan chocolate was evaluated using the DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging assay, which is a reliable method to assess the free radical neutralizing potential of bioactive compounds. The assay measured the ability of the chocolate extract to donate hydrogen atoms or electrons to stabilize DPPH radicals, resulting in a reduction in absorbance at 517 nm.

Table 5 Antioxidant Assay

Name of the test	**100 mg**	**250 mg**	**500 mg**	**750 mg**	**1000 mg**	**IC50**
DPPH activity	8.5%	19.0%	36.4%	54.1%	70.6%	**689mg**

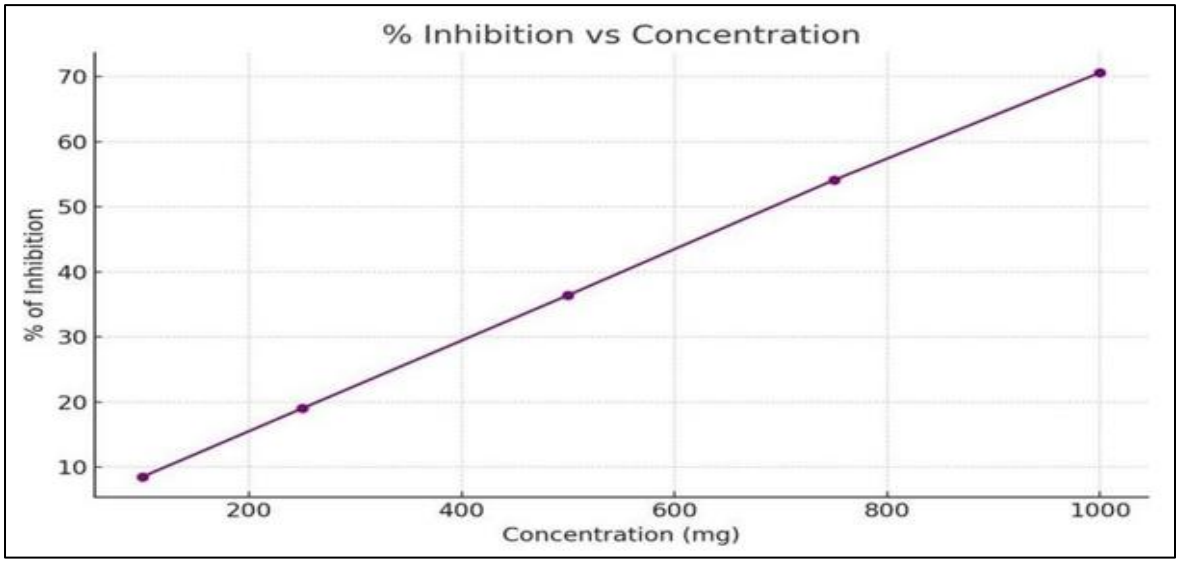

Fig 3 Antioxidant Content of Vegan Chocolate

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In Figure 3, The antioxidant potential of the developed vegan chocolate was determined using the DPPH radical scavenging assa**y**, and the results are presented in Table 3.3**.** The chocolate extract was tested at five different concentrations: 100 mg, 250 mg, 500 mg, 750 mg, and 1000 mg. A progressive increase in percentage inhibition of the DPPH radical was observed with increasing concentration of the extract. At the lowest concentration (100 mg), the sample exhibited 8.5% inhibition of DPPH radicals. This increased to 19.0% at 250 mg, 36.4% at 500 mg, 54.1% at 750 mg, and reached a maximum of 70.6% at 1000 mg. The data indicated a clear dose-dependent antioxidant effect, where higher concentrations of the extract demonstrated greater free radical scavenging activity. The IC_{50} value of the concentration inhibit 50% of DPPH radicals and was calculated to be 689 mg**,** indicating the moderate antioxidant strength of the formulation. This value suggests that the chocolate possessed effective antioxidant properties, likely due to the combined presence of polyphenols, flavonoids, and other bioactive components from cocoa, millet milk, stevia, and coconut butter. Recent studies have shown that vegan plant-based or fortified chocolate products and dark chocolates formulated with functional plant extracts exhibit enhanced antioxidant profiles due to their high content of polyphenols and flavonoids **(**Polinski et al., 2022).

➢ *SEM Analysis*

In Fig 4, Microstructural analysis of the vegan chocolate using SEM showed variation in the crystal network structure, inter-crystal interaction, and particle distribution using 127x, 264x, 501x, 1000x, 2.57xx, 5.01xx magnification. Image (A) at 127x magnification shows a broad, low-magnification view of the chocolate's surface. The structure appears coarse and irregular. Image (B) at 264x shows moderately magnified image revealing clusters of particles which has plant-based solids and fat globules. Where, the vegan chocolate has millet milk as main substitute. Image (C) at 501x magnification surface shows small cavities and cracks that indicating air entrapment or phase separation during cooling. Image (D) at 1000x higher magnification shows fine microstructural details which highlights particle agglomeration and irregular edges that suggest a lack of proper emulsification. Where, the vegan chocolate refines coconut butter has a plant based emulsifier. Image (E) at2.57xx magnification shows better dispersion than Image (A, B, C) with fewer large voids. While micro-roughness remains that refinement has been occurred. Image (F) at5.01xx shows a detailed image of slightly smoother surface with fewer aggregates which suggesting this as more refined sample to conclude that comparatively (E) and (F) images demonstrated improved microstructural uniformity and compactness, suggesting partial enhancement in processing techniques. Overall, the SEM analysis indicates that the vegan chocolate formulation maintains structural integrity.

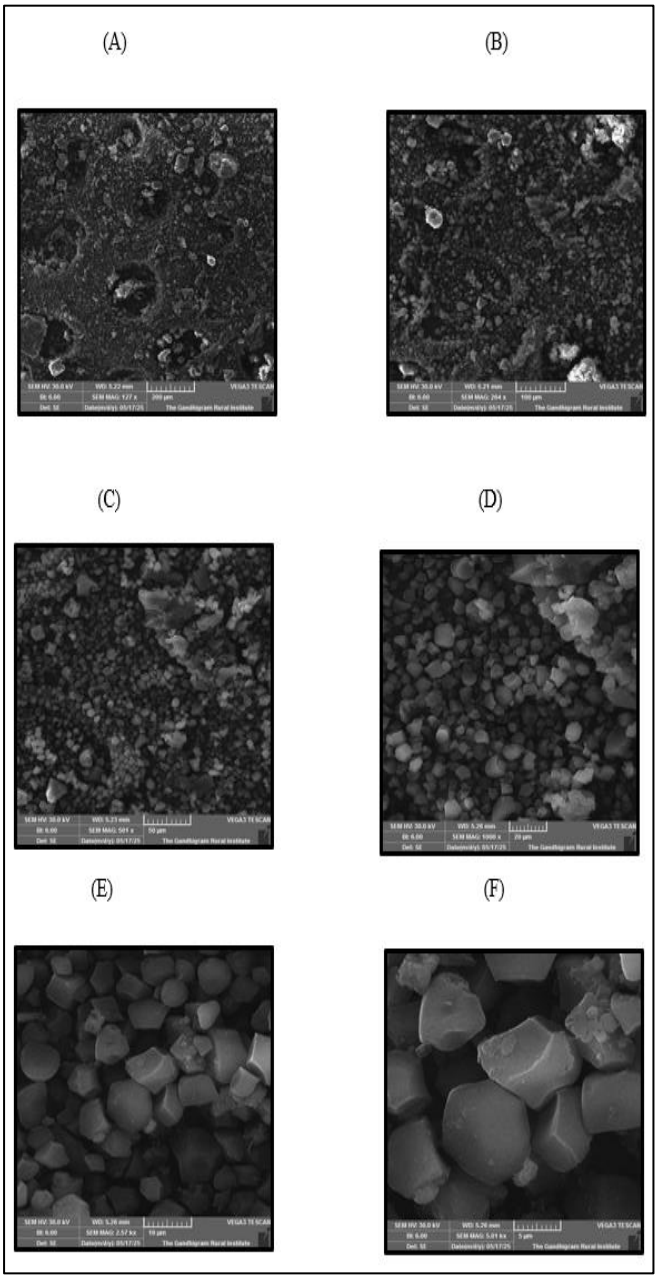

Fig 4 SEM Image of Developed Vegan Chocolate

IV. CONCLUSION

The development and evaluation of vegan chocolate from millet milk demonstrated a promising alternative to conventional commercial chocolates. The pearl millet milk powder along with coconut butter and stevia produced a vegan chocolate that free from lactose and gluten which offers beneficial nutrients and bioactive compounds. Comparatively, commercial chocolate may rely on animal fat for creaminess and richness, but the developed vegan millet milk-based chocolate achieves similar quality without compromising on taste or texture. Sensory evaluation indicated that the vegan chocolate was highly accepted in terms of flavor, texture, and overall appeal. Analytical results confirmed that the developed vegan chocolate maintained a balanced composition of carbohydrates, proteins, healthy fats, Calcium and Phosphorous with promising antioxidant

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activity Overall, this plant-based formulated vegan chocolate supports health conscious and environmentally aware of consumption patterns and offers a viable, scalable option for future functional food innovations in the confectionery industry.

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