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Creative Food Product of Healthy Puffed Riceberry Snack Bar Developed by Private-Community-University Collaborations

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***Abstract*— "*Riceberry*" a variety cultivated for its high anthocyanin content, offers bio-functional benefits. The development of Riceberry products not only enriches the nutritional profile but also adds a creative dimension to the One Tambon One Product (OTOP) initiative of Thailand. The collaborative effort of Hin Kling, a community enterprise in Nakhon Sawan, Chiang Mai Rajabhat University (CMRU), and the support from the Petroleum Authority of Thailand (PTT) Public Company Limited, has been instrumental in this venture. Adopting the Four Ps model (process, product, packaging, and product marketing), the collaboration focused on refining production processes, ensuring product quality, providing informative packaging, and devising effective marketing strategies. The study revealed that saturated fat content was reduced by two-fold through the innovative approach of blending palm oil with soybean oil for frying puffed rice. The resulting puffed rice was then combined with various ingredients and shaped into bars, offering a product with a commendable shelf life of up to three months. Moreover, a commitment to health was demonstrated by reducing the added palm sugar, leading to lower sugar content, reduced calories, and improved texture in the healthier product. Rigorous quality checks, including water activity value, anthocyanin content, and total and pathogenic bacteria count, ensured that the product met the standards set for cereal bars. To enhance consumer awareness, the product's nutritional value was highlighted through a detailed nutritional facts section on the food label. Additionally, a captivating community story was crafted to introduce the health-focused product to the wider health food market. The three-party collaboration behind the Riceberry initiative has successfully delivered a bio-functional, nutritious, and creatively presented product tailored for health-conscious consumers.**

Keywords— **puffed rice; rice berry; snack bar; community product; creative food**

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I. INTRODUCTION

The community-based processed food products are manufactured using local resources, labour, and local food wisdom. The products are created to be consumed and distributed to buyers within and outside the community. Consequently, these products generate employment opportunities, contribute to economic development, generate a reputation for the community, and sustain food security [1].

The successful collaborative model relied on the participation of three elements, as per the "Triangular theory of pushing mountains" [2]: community social mobilization, university knowledge, and financial support from the private sector.

Thai government promotes the "One Tambon One Product (OTOP)" project adapted from the successful original case; "One Village One Product (OVOP)" made in Japan. The project has been implemented for the Thai grass-root society since 2001 aiming for small-scale producers to distribute nationally and globally their high-quality products [3]. Similarly, many Asian countries have adopted OVOP concepts for their own community economic development, e.g. "Saka Sakti" or "One Regency One Product" plan of

Indonesia and "One Town One Product" of The Philippines [4].

Food products and beverages comprise the majority of OTOP products [4] from various raw materials, rice, vegetables, fruits, herbs and spices, mushrooms, seaweed, meat, milk, seafood, honey, flour, sugar, salt and other food seasonings. These common raw materials are formulated and then applied to local technologies and food processing machines for making ready-to-eat or cooked products. To standardize the OGOP food products, the Ministry of Industry, Thailand has announced community product standards covering more than 500 food products of processed meat, seafood products, preserved fruits and vegetables, desserts, herbal drinks fruit juices, dipping sauces, and Nam Prik (a chilli dipping sauce) [5]. Each food standard details product definition, expected characteristics, packing, labelling and quality control. The Ministry of Public Health, Thailand, has conducted the Good Manufacturing Practice (GMP) for small-scale food production. The GMP guidelines address the following five components of basic structure, machinery, process control, sanitation, and good personnel to ensure safety and upgrade the local food products [6].

Fig. 1 Purple Riceberry (a) cooked Riceberry (b) and puffed Riceberry (c) obtained from a sustainable community in Nakhon Sawan province, Thailand.

Rice serves as a primary source of carbohydrates for the Asian people. A Southeast Asia region exports 40% of rice to feed the world. In 2022, Indonesia had the biggest rice production yielding 34,600,000 Metric Tons, followed by Vietnam 27,400,000 Metric Tons and Thailand 19,800,000 Metric Tons [7]. Apart from packaged rice for cooking as a staple food, the community can process rice in diverse products served for a daily consumption, e.g. rice flour, rice noodles, rice snacks, rice milk, fermented rice, and food supplement. Some types of rice, for example, brown rice has considerable health functionality due to high contents of vitamins and minerals [8].

As shown In **Figure 1**, Riceberry is a new Thai rice variety innovated from a cross-breed of *Jao Hom Nin* (JHN, a local non-glutinous purple rice) and *Khao Dawk Mali **105*** (Hom Mali rice). Currently, that is Thailand's latest *"superfood"* having major phytochemical, anthocyanin and phenolic compounds and exhibiting antioxidant activities of 2,2-diphenyl-1-picrylhydrazyl (DPPH) and 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid (ABTS) radical scavenging activity assays [9]. In addition, organic Riceberry rice has a high content of iron, gamma-aminobutyric, and fatty acid profiles (oleic acid, linoleic acid (omega 3), hexadecanoic acid), however it is low in sugar [10,11]. The biopotential of Riceberry serves health-conscious consumers, e.g. ready-to-drink powder for the elderlies, aiming to relieve digestive problems, brighten and lighten dull cells, and reduce the risk of diabetes, blood pressure, and blood sugar [10]. Furthermore, Riceberry products provide environmental footprinting information for sustainable food systems and green choices for consumers [12]. Nowadays, Riceberry is promoted as a healthy ingredient in some food items, e.g. yoghurt [13] and waffle [14].

The community development of Riceberry products will bring greater benefits to society if the university engages in gathering educational and research ideas, incorporating scientific knowledge and traditional food wisdom. This includes developing production processes, ensuring quality control in accordance with GMP principles, determining shelf life, and providing comprehensive marketing support for the community. Therefore, this collaboration research between the community, university and private business aims to implement a "*4Ps model comprising of process design, product, packaging and product marketing*" for upgrading local Riceberry grown in Nakhon Sawan as a creative and healthy plant-based snack bar.

II. Research Methods

A. Community and university define Riceberry product using 4Ps Model

Thai Community enterprise, *"Hin Kling"*, Nakhon Sawan, collaborated with the CMRU research team. The enterprise profile is a large group of Riceberry farmers, comprising 58 members covering an area of 3.2 hectares. The cultivation process took place in August 2022, with harvest scheduled for November 2022. After harvesting, the rice was dried to reduce moisture to 13-14% before being stored in sacks. The community team consisted of five members, including the group leader, the three members of processing, and the marketing person.

The CMRU research team included, the project leader, the rice expert, the OTOP specialist, a quality control expert for processing, and the member of packaging design and marketing. Both the research team and the community team gathered the *4Ps Model* for the development of Riceberry-based products.

The research funding, market promotion, and assessment and evaluation were facilitated through the Innovation for Society program of the Petroleum Authority of Thailand (PTT) Public Company Limited.

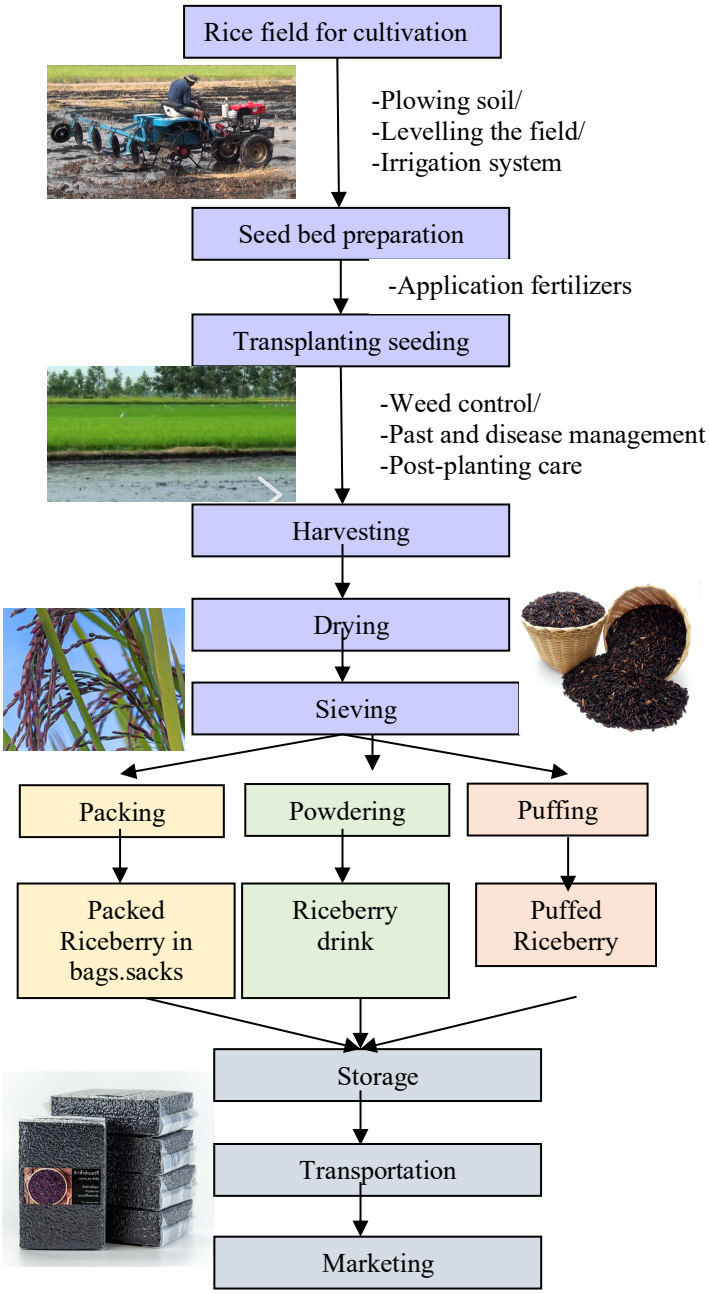

Fig. 2 Supply chain of *Hin Kling* Riceberry products

Processing: The community team cultivated organic Riceberry and possessed the skill of frying rice using palm oil to create puffed rice (**Figure 2**). The CMRU team had a cereal bar formula. The process adjustment goal was to reduce the amount of saturated fat in the puffed rice before mixing it with other ingredients and later bar shaping.

Product: The community team surveyed 400 general consumers in Nakhon Sawan province. The respondents expressed a desirable production of Riceberry snack bars with a taste that was neither not sweet nor salty, providing low energy and ensuring safety. The CMRU team has conducted practical training with the community group to adjust the snack formula. They used the *"Healthier Choice"* criteria from The Institute of Nutrition, Mahidol University, Thailand, comparing factors such as saturated fat, sugar, sodium, and energy. The product quality according to Thai community product standard (Cereal Bar, TCPS 902/2562) involved water activity and peroxide values, aflatoxin content, and microbial counts. Additionally, university laboratory assessed the important quality in terms of anthocyanin content and mechanical texture analysis.

Packaging: The community team prepared food labelling based on the Notification of the Ministry of Public Health, Thailand (2014). The details were reported on include the name of the food, name and address of the manufacturer, contents of food, percentage by weight of main ingredients, information for food allergy and food additives, date, month and year of shelf life, and storage instruction. The research team gathered labelling information from the community team to design labels for packaging on plastic cans. Additionally, they presented nutrition labelling, following the Notification of the Ministry of Public Health, Thailand (1998). The purpose of this nutritional analysis was to inform its health benefits for use in sales promotion.

Product Marketing: The community team engaged in marketing and selling rice at the central rice market during provincial and community festivals. They distributed packaged rice in bags at these events but had not yet ventured into online sales. In response, the CMRU research team analyzed the new market to develop a distribution plan for Riceberry rice snack bar using the *"Lean Canvas model"* [14]. This model explores all nine components, including key partners, key activities, key resources, value propositions, customer relationships, customer segments, channels, cost structure, and revenue streams.

B. Creative development healthy puffed Riceberry snack bar

The community team's rice processing began by selecting the rice with no broken grains or insect damage. The chosen rice was then sieved to remove dust, washed, and cooked at a rice-to-water ratio of 1:2. The cooked rice was then oven-dried in a hot air oven at 70ºC for 48 hours. The dried rice was subsequently deep-fried in hot palm oil at 150ºC for 10 seconds. After frying, the proportions of the binder mixture were measured, including 25% w/w palm sugar, 12.5% w/w glucose syrup, and 12.5% w/w coconut milk. The ingredients were mixed and cooked over medium heat until the mixture thickened. Puffed rice (37.5% w/w) was then mixed with roasted sesame seeds (12.5% w/w), and the mixture was moulded into a block shape using a stainless frame and cut to a size of 10x2.5x1.5 cm **(Figure 3 (a)).** The bars were allowed to cool before being arranged and packaged in plastic containers, each weighing 60 grams, sealed with an aluminium cap, covered with a plastic lid, and finally labelled see **Figure 3 (b).**

Fig. 3 Moulding Riceberry rice with other ingredients mixture (a) and the finished product contained in labelled plastic cans.

The community-university teams adjusted the process and ingredient formula for their snack, taking into consideration the "*healthier choice*" criteria set by The Institute of Nutrition, Mahidol University, Thailand for the snack category. The criteria include a total energy content of less than 150 kilocalories per serving, a total sugar content of less than 7 grams per 100 grams, saturated fat content of less than 6 grams per 100 grams, and sodium content of less than 500 milligrams per 100 grams. Therefore, adjustments have been made at the rice centre factory by using palm oil and reducing the amount of palm sugar in the following manner:

Original	palm oil + 25% palm sugar+ coconut milk
Method 1	mixed palm/soybean oils+ 15% palm sugar+ coconut milk
Method 2	mixed palm/soybean oils+ 10% palm sugar+ coconut milk alternative

C. Quality and shelf-life studies of the puffed Riceberry snack

Adjusting the frying process and reducing sugar in the recipe may affect the product's quality. To assess changes in quality within three months at room temperature (approximately 30ºC), the CMRU research team sampled the community-made products and then conducted various testing methods at the food science laboratory, such as:

Chemical analysis; Water activity values were measured by a water activity meter at 30 ºC (AQUA LAB, 4TE, USA). Peroxide values were quantified by the American Oil Chemists' Society (AOCS) iodometric titration method [15]. The pH different method was selected to analyse total anthocyanin content [16]. Aflatoxin content at less than 20 ppb was tested by Revealâ test kit (NEOGENâ, USA).

Physical analysis; The bending test of snack bars was investigated by using a texture analyser (TA.XT plus, Stable Micro System, UK). The experiments were performed on the three-point bend rig. The sample was static at the base graduated two supports lengths up 6 cm. while the moving arm attached to the probe went down to the lower direction. The low-speed test was set at 0.5 mm/s. The combined compression/tension results showed a relationship between force (N) and time (second). The brittleness or hardness was calculated as the tallest peak force.

Microbiological analysis; Snack bar samples were transported to Central Laboratory (Thailand) Co. Ltd. for a test report of total plate count, yeast and mold, and some pathogens (Salmonella spp., *Staphylococcus aureus*, *Bacillus cereus*, *Clostridium perfringens*, and *Escherichia coli*)

Nutritional analysis; Central Laboratory (Thailand) Co. Ltd. was carried on 15 items of full version of nutritional labels as follows: total energy, energy from fat, total fat, saturated fat, cholesterol, protein, total carbohydrate, total fibre, sugar, sodium, vitamin A, vitamin B1, vitamin B2, calcium, and iron serving for population over six years of age based on 2,000 kilo calories diet.

D. Statistical analysis

The frying process and product quality data were analysed statistically to compare peroxide values, sugar content, anthocyanin content, and hardness values of puffed Riceberry snack bar using Complete Randomized Design (CRD). The chemical/physical data analysis was carried out in five replicates and reported as mean±standard deviation of mean (SD). The Least Significant Difference (LSD) test was used to analyse mean separation using Statistix 10 USA program with the confidence limit ($P<0.05$).

III. Results and Discussion

A. Development of healthy puffed Riceberry rice snack bar

The current consumers prioritize alternative food products, being cautious of the quantities of energy and some nutrients such as saturated fat, and sugar. Therefore, the research team adjusted the use of frying oil for rice puffing and reduced the amount of sugar in the snack formulation.

Figure 4 Comparing the amount of saturated fat in snack bars, it was found that the community switched from using palm oil to a blend of palm oil (35%)/soybean oil (65%), reducing the saturated fat content in the finished product from 11.38 grams per 100 grams snack in the original method to 7.54 grams per 100 grams snack in the adjusted *method 1*. Further replacement of coconut milk with coconut milk alternative (made from rice bran oil) in *Method 2* had 6.21 grams per 100 grams snack or less saturated fat 45.43% than the original. Saturated fat in palm oil is palmitic acid (C16:0) and stearic acid (C18:0) [17] and coconut milk has a large amount of myristic acid (C14:0) and lauric acid (C12:0) [18]. These long-chain saturated fatty acids (C12-C18) may increase the risk for cardiovascular disease development [19]. Currently, alternatively, healthier ingredients are commercially available for food producers to design food formulations. Therefore, promotion soybean oil and rice bran oil are healthy sources of unsaturated fatty acids; linoleic acid (C18:2) and oleic acid (C18:1).

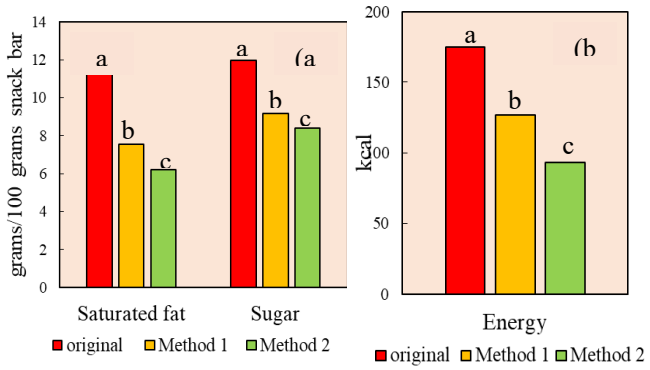

Fig. 4 Comparison of puffed Riceberry snacks having different levels of saturated fat and sugar contents (a), and energy (b) after adjustments in frying oils and reduced-sugar formulations.*a-c following the mean value (n=5) of each column suggested a significant difference between methods at $p<0.05$.

Sugar intake is generally more harmful in cardiometabolic disease. Reducing the consumption of free sugars or added sugars to below 25 g/day (approximately 6 teaspoons/day) with WHO recommendation [20]. The community active research reduced palm sugar addition from 25% (11.95 grams per 100 grams snack), original to 10% (8.4 grams per 100 grams snack), *Method 2* in a healthier snack. In addition, sugar and fat are critical sources of energy in riceberry snack bars. Therefore, reducing both concern nutrients in *method 2* resulted in a healthy product with 93.12 kilocalories per 35-gram serving size, which was close to the calorie content of high fiber plant-based bars [21]. Additionally, Riceberry has the potential to control blood sugar due to improvement in postprandial glycaemia *via* delayed gastric emptying [22].

B. Quality and shelf life of the puffed Riceberry snack bar

The quality of Riceberry rice snack bars was influenced by storage time, which may lead to chemical changes such as changes in water activity, the occurrence of peroxide value, loss of anthocyanins, and physical changes like texture loss. Moreover, microbial growth and the production of toxins from fungi could occur. Therefore, monitoring these quality changes ensured the community's confidence in the quality and safety of the products standard. Changes in the quality parameters of processing methods are outlined in **Table 1.**

The term "water activity" refers to the amount of free water in food that is related to chemical changes and the growth of microorganisms [23]. The standard for cereal bars (TCPS 902/2562) uses this value to predict the stability of the product during storage. It was found that storage at ambient temperature for three months did not affect changes in this value (p>0.05). Reducing the amount of sugar in the original formula lowers the water activity because sugar has humectant properties. In addition, sugar binding to water molecules in the food system also affected the delay of lipid oxidation [24]. Experimental results indicate that the oxidation of snack bars stored for three months at a relative humidity of 60-70% increased in all processing methods. Methods involving oil blending (*Method 1* and *Method 2*) showed higher peroxide values than the original method in the last month($p\leq0.05$). That was consistent with research findings in energy-baked bar [25] and dry crackers [26]. The peroxide values for all storage methods over a period of three months met the TCPS 902/2562 standard (< 30 milliequivalents of peroxide/kg product).

TABLE 1
CHANGES IN AW VALUE, ANTHOCYANIN CONTENT, PEROXIDE VALUE, AND HARDNESS OF DIFFERENT PRODUCTION METHODS DURING 3-MONTHS UNDER AMBIENT STORAGE AT 35 °C, AND 65-70% RH

Method	Month		
	0	2	3
	Water activity value		
original	0.56±0.03aA	0.58±0.02aA	0.61±0.03aA
1	0.46±0.04bA	0.48±0.04bA	0.50±0.04bA
2	0.43±0.02bA	0.47±0.02bA	0.52±0.02bA
	Peroxide value (milliequivalents of peroxide/kg product)		
original	5.33±0.12aA	6.51±0.21aB	7.02±0.32aB
1	5.45±0.15aA	6.76±0.31aB	7.24± 0.24aC
2	5.48±0.16aA	6.81±0.33aB	7.35±0.31bC
	Anthocyanin content (mg/100 g)		
original	33.65 ±2.13aA	30.15±2.15aA	28.32±1.48aB
1	34.32±2.48aA	31.16±3.12aA	29.45±1.36aB
2	35.22±2.61aA	31.22±1.16aA	28.32±1.52aB
	Hardness (N)		
original	90.66±3.62aA	90. 65±4.15aA	87.32±4.52aA
1	80.36±2.36bA	79.63±1.55bA	78.65±3.62bA
2	68.33±2.15cA	67.64±3.14cA	68.32±5.66cA

*a-c following the mean value (n=5) of each column suggested a significant difference between methods at $p<0.05$.
*A-C following the mean value (n=5) of each row suggested a significant difference between storage months at $p<0.05$.

Degradation of anthocyanin was detected in all snack bar processing methods during storage for three months. That was possibly affected by the ultraviolet (UV) light exposure [27]. The transparent packaging might not block some light from the UV spectrum, and especially from the ultraviolet field of the spectrum so creating a wrap-around label as a protective barrier was a solution of choice (**Figure 5**).

The hardness of a cereal bar depends on the ingredients, such as flour, fat, and protein [28]. This study further indicated that sugar affected the texture. While reducing the amount of sugar had positive health implications, it could result in Riceberry snack with a more brittle texture. Therefore, packaging in plastic containers could reduce damage during product transportation.

Fig. 5 Labelling and packaging of Riceberry snack
(a) the product logo, and (b) the labelling on plastic can

Food safety is a crucial factor that processed food products in the community must be aware of. Chemical safety, particularly concerning aflatoxin, which is a common issue in plant-based products containing rice, beans, sesame, and dried chilli as components, is vital [29]. It was found that Riceberry snack bars had a quantity of aflatoxin not exceeding 20 micrograms per kilogram, following the standards set by TCPS 902/2562.

In addition, the total quantity of microorganisms in all products processed by different methods did not exceed the standard, with less than 10^4 colony-forming units (CFU) per gram for yeast and mould not exceeding 10 CFU per gram. No Salmonella was found in the 25-gram sample. *Bacillus cereus* and *Clostridium perfringens* which may be found in rice; and sesame were below 10 CFU per gram. *Staphylococcus aureus* was not detected due to the good hygienic production process under GMP control, and *Escherichia coli* contamination possibly due to unclean water during production was less than three most probable number (MPN) per gram thus it was reported as safe. In summary, the community-produced processed products met the community product standards for chemical and microbial safety categories.

Nutritional facts for the health-oriented product (*Method 2*) per serving of 35 grams are as follows: total energy 93 kilocalories, energy from fat 36 kilocalories, total fat 4 grams, saturated fat 2 grams, protein 1 gram, carbohydrates 13 grams, dietary fibre 1 gram, sugar 3 grams, sodium 105 milligrams, sodium 3.2 milligrams, iron 0.12 milligrams. The product is cholesterol-free.

C. Marketing of the puffed Riceberry snack bar

The product marketing for the Riceberry snack bar was analysed using a business tool called "*The Lean Canvas*" developed by *Ash Maurya* [30]. In general, business seeks avenues to address customer problems and how the business gives solutions, with key metrics tied to defining a cost structure. It then identifies unique selling points and advantages. Communication of these advantages is done through various channels to ensure a return on investment for the business. The unique value proposition, specific to the business, is used to directly address customer needs most effectively.

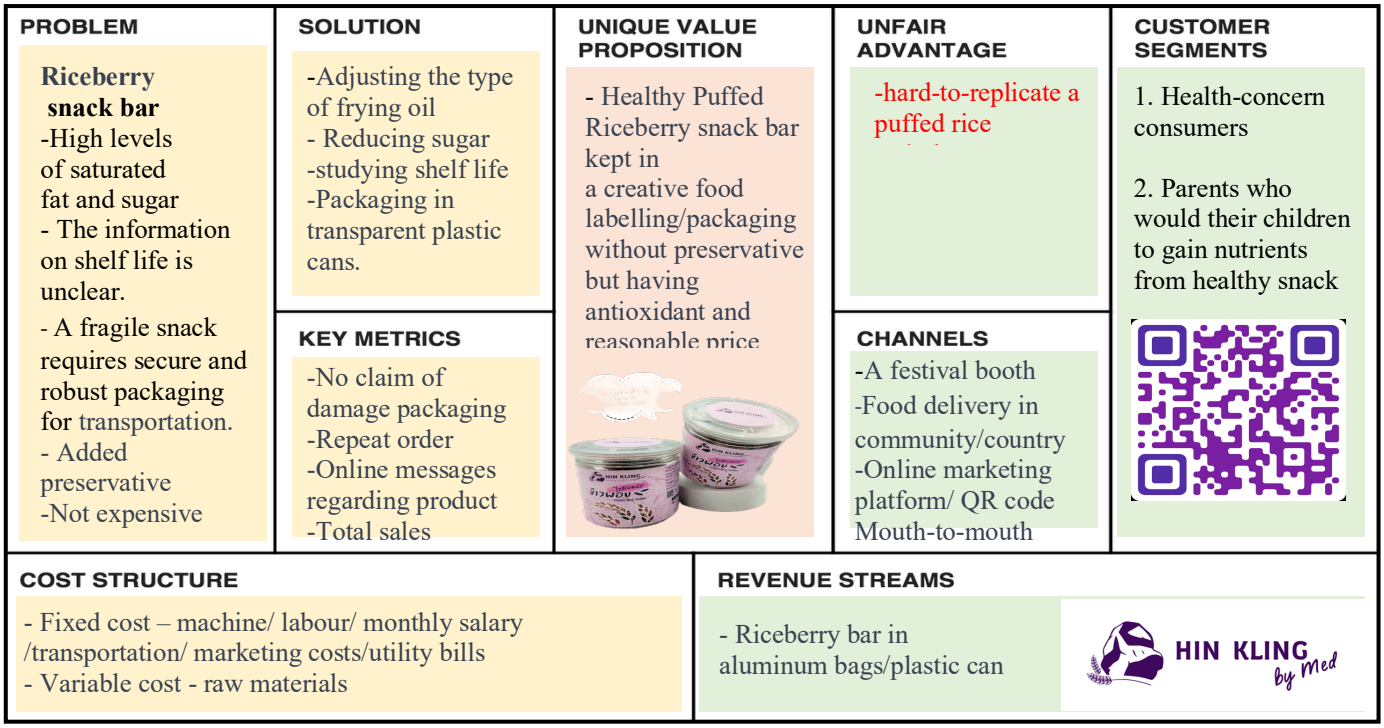

Fig. 6 Lean canvas analysis of Riceberry snack bar

In terms of production as seen in yellow blocks of **Figure 6,** The buyers' responses on the Riceberry snack bar under the brand "*Hin Kling*" (**Figure 5a**) included a desire for reduced fat, lower sugar content, convenient product transport, and a shelf life exceeding two months. Consequently, based on previous studies, adjustments were made to reduce saturated fat, decrease sugar, and present nutritional facts, along with specifying the product shelf life when packaged in plastic cans (**Figure 5b**). These modifications in raw materials, packaging, and product formulation impacted the cost and pricing strategy of the product. For example, the switch from aluminium foil bags to plastic cans increases costs approximately tenfold. However, the cans can be recycled or reused for various purposes, contributing to sustainability in use or resale.

For the marketing side in green blocks of **Figure 6**, The strength of the *Hin Kling* group lies in the intellectual capacity for producing puffed Riceberry without relying on advanced technologies such as industrial-scale vacuum frying. This approach reduces the costs associated with machinery and operations. Moreover, other enterprises have yet to replicate the unique raw material of puffed Riceberry. This distinctiveness allows the *Hin Kling* group to effectively communicate the value of their intellectual (petty patent/trade mark) and nutritional contributions to various consumer segments, including individuals focused on vegetarians, weight management personnel, the elderlies, athletes, university students, and public health personnel. The group reaches out to diverse audiences, including singers and actors, through community-based and provincial retail outlets. They also employ online marketing strategies, utilizing market applications to enhance their reach to the target groups and promote sales.

The Unique Value Proposition (UVP) in the context of this community-based food product refers to the distinctive and difficult-to-replicate value that only this brand provides to customers [31]. In the case of this community-processed food product, the "*Healthy Puffed Riceberry Snack Bar*" is presented with creative food labelling and packaging. The product provides nutritional information, emphasizing three levels of sugar content: low (for health-conscious consumers), moderate (as an alternative), and standard (traditional). That allows consumers to adjust their behaviour towards a sweeter taste while reducing saturated fats, as on the food label.

The product also weaves in the community story of *Hin Kling*, portraying it as a significant transformation, promoting safe and organic agriculture, and serving as a knowledge hub for community-based rice farming. Additionally, the group emphasizes use of recyclable packaging to contribute to environmental sustainability. This combination of health-conscious choices, community story, and environmentally friendly packaging sets the product apart as a unique offering to the current trend of health-conscious consumption.

The research project aligns with the "*Triangular theory of pushing mountains*", as stated by Prawet Wasi, Thai social developer [31], emphasizing that the development of community enterprises leading to social business arises from:

Knowledge: the application of private market knowledge

Social mobilization: communication of enterprise social movements within and outside the community through various media.

State organizations not seeking profit: a mechanism to support knowledge, technology, and research funding.

IV. CONCLUSION

Thai farmers, commonly known as the backbone of Thailand, are primary rice producers. The rice cultivation and preprocessing are serial steps ploughing the field, transplanting, harvesting, and packing rice. Some community has their own local wisdom of rice puffing. This research added to the current rice supply chain by applying *the "4Ps model"* , *an abbreviation of process, product, packaging, and product marketing.* to design a healthy Riceberry snack. Puffed rice processing was optimised to reduce calories, saturated fat, sugar, and sodium contents. The product was qualified by the Thai Community product standard of fruit, vegetable, and cereal bars. The packaging of the finished product was fully detailed in food labelling and nutrition fact information. In addition, product marketing was promoted in both OTOP centres and online stores. The creative production of the health food product is connected to the local wisdom of making puffed rice, integrating with food science and technology. That results in economic opportunities for farmers and communities, creating new occupations and advancing the global trend of sustainable food products that are beneficial to health and the environment. Additionally, it generates the new value for the community's processed food.

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CONFLICT OF INTEREST

Authors declare no conflict of interest to disclose.

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