AATCC Review

14 February 2025: Received
10 April 2025: Revised
17 April 2025: Accepted
19 May 2025: Available Online

https://aatcc.peerjournals.net/

Review Article Open Access

# Flaxseed as a Functional Ingredient: A Review of Nutritional Attributes and Value-Added Applications

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## ABSTRACT

*Flaxseed (Linum usitatissimum), renowned for its rich nutritional profile, has emerged as a valuable raw material for the development of a wide range of value-added products. Packed with alpha-linolenic acid (ALA), lignans, dietary fiber, protein, and essential micronutrients, flaxseed offers numerous health benefits including cardiovascular protection, antioxidant activity, and digestive health support. The increasing consumer demand for functional foods and nutraceuticals has accelerated the innovation and commercialization of flaxseed-based products. Value-added flaxseed products include cold-pressed flaxseed oil, flaxseed meal, bakery products, protein-enriched snacks, dietary supplements, and cosmetic formulations. These products not only enhance the bioavailability of flaxseed nutrients but also improve shelf life and palatability, catering to both health-conscious consumers and those with specific dietary needs such as gluten-free or plant-based diets. Additionally, flaxseed by-products generated during oil extraction are being efficiently utilized in animal feed and biodegradable packaging materials, promoting zero-waste processing. However, challenges such as preserving sensitive bioactive compounds during processing and mitigating anti-nutritional factors like cyanogenic glycosides pose significant hurdles to product development. Technological advancements in food processing, microencapsulation, and functional ingredient blending further contribute to the stability and sensory quality of flaxseed-enriched formulations. This review contributes to the field by synthesizing current knowledge on the nutritional attributes, processing technologies, and applications of flaxseed, thereby offering valuable insights for researchers, product developers, and policymakers in the functional food sector. Overall, the development of flaxseed value-added products holds promising potential for the food, health, and wellness industries, offering sustainable economic opportunities while addressing global trends toward healthier and eco-conscious consumption.*

***Keywords:*** *Flaxseed, ALA, value-added products, flaxseed oil, flaxseed meal, flaxseed nutritional benefits, flaxseed lignans, dietary fiber in flaxseed, flaxseed protein content.*

## Introduction

Since the Stone Ages, people have known about flaxseed. It has a long history of use in India and was a staple food before World War II, despite having its origins in Mesopotamia. After Rome fell, flaxseed cultivation and consumption decreased, and they were eventually forgotten until the 1990s. There are numerous potential applications for flaxseed oil and its mucilage as a nutraceutical (drug) in the prevention or treatment of disease. Dietary flaxseed is an effective way to prevent a number of lifestyle diseases, such as hormone-responsive tumors, cholesterol-induced atherogenesis, and abnormalities in endothelial-dependent vasorelaxation. This insightful rediscovery demonstrates that there is a great opportunity to reintroduce this significant food to the global community by looking into its current nutritional knowledge [23]. As a blue flowering rabi crop and a member of the flax family, linseed (*Linum Usitatissimmum*) is also known as alsi in hindi, jaws, and akebia in Indian languages.

It is a member of the Linaceae family. This crop has its roots in the Mediterranean and West Asia [14]. The Latin word 'usitatissimum', which means "most useful," and the Celtic word 'lin', which means "thread" are the origins of the names *Linum* and *usitatissimum*, respectively.

Due to this crop's remarkable nutritional value and high biological activity, which enable its usage in a variety of goods like functional foods, health supplements, and beauty products, its relevance has significantly expanded in the modern era. Due to the growing veganism trend among customers worldwide and the numerous social, ethical, religious, moral, environmental, and ecological issues connected to the usage of animal-based goods, flaxseed's significance has also lately expanded.

Due to its therapeutic effects on controlling gut flora and soothing the symptoms of numerous human diseases, including menopause, cancer, diabetes, cardiovascular disease, neurological disorders, and menstrual problems, flaxseed is gaining more and more notoriety as a superfood. Furthermore, it has been determined that the proteins and cyclic peptides

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*DOI: https://doi.org/10.21276/AATCCReview.2025.13.03.17*

present in flaxseed have the best anti-oxidant, anti-inflammatory, immunosuppressive, and anti-diabetic characteristics [29].

The five compartments in the spherical fruit capsules hold two seeds. The actual seed has a pointy apex and is flat and oval in shape. It has a smooth, glossy surface, and is somewhat bigger than a sesame seed. The color of flaxseed can vary from a light yellow to a medium reddish-brown. The amount of pigment in the outer seed coat determines the color of the seed i.e. the more pigment, the darker the seed. The seed's measurements range from 3.0 to 6.4 mm in length, 1.8 to 3.4 mm in breadth, and 0.5 to 1.6 mm in thickness.

The flaxseed seed contains five unique layers, the two most important of which are the testa, which is made up of pigmented cells that define the seed's color, and the epidermal layer, also known as the mucilage layer.

Flaxseed comes in two shades: brown and yellow. The typical flaxseed that is grown in Canada has brown seeds and is rich in the omega-3 fatty acid alpha-linolenic acid (ALA). Yellow-seeded flaxseed, on the other hand, comes in two different varieties. The first kind, called Omega, was created in the United States and has a high ALA concentration like the brown variant. Other varieties of yellow-seeded varieties are referred to as "solin" and they contain little ALA. It was created to be used in food [40].

It has a lovely nutty flavor when chewed. Flax seed shows oxidative polymerization and high quantities of fatty acid insaturation in triglyceride oil. Fat, dietary fiber, protein, minerals, vitamins, and carbs can all be found in whole flaxseed. Flaxseed is a low-saturated fat food because of its peculiar oil, which is made up of 73% polyunsaturated fatty acids (PUFA), 18% monounsaturated fatty acids (MUFA), and 9% saturated fatty acids. The omega 3 (n-3) fatty acid, ALA, which accounts for about 55% of all fatty acids, is only found in flaxseed oil, which is the richest source known of it. According to Bloedon and Szapary (2004), flaxseed has 5.5 times more fat in the form of ALA than the next two sources, walnuts and canola oil [8].

Nearly all of the flaxseed plant's components are used commercially, either as it is or after processing. The stem produces high-quality fiber with a long lifespan and excellent strength. The seed offers digestible proteins, lignans, and oil with a high omega-3 content [35]. Consuming flaxseed has been linked to a number of potential health advantages. Evidence suggested that consuming flaxseed (oil enriched product) could aid in the prevention of a number of illnesses, including chronic, cardiovascular, obesity-related, and cancerous diseases. However, considering the effects of lignans in men and pregnant women, as well as the presence of other phytochemicals and toxic substances with negative health effects in the seed, chronic ingestion of it may present danger to the body [7].

The cyanogenic presence of flaxseed meal, however, might negate some of its potential advantages. Whole flaxseed contains cyanogenic substances, especially cyanogenic glycosides, which, when consumed, can break down to poisonous HCN. Other foods like cassava, almonds, wheat, barley, sorghum, apples, and stone fruits also frequently contain cyanogenic chemicals. Following oil extraction, the amount of cyanogenic chemicals in flaxseed may rise in flaxseed meal. If flaxseed meal is utilized directly in food applications, the presence of cyanogenic glycosides could constitute a possible health risk.

Therefore, before taking into account any prospective applications for flaxseed meal in food items, detoxification from cyanogenic content is necessary. Many commercial foods, including bread, cereals, muffins and snack bars, use whole flaxseed as an ingredient. Since customers are already familiar with these items, adding flaxseed meal to them can be a smart place to start when using flaxseed [6].

According to several research, eating more omega-3 fatty acids lowers the risk of developing breast cancer. The ability of linolenic acids to inhibit the growth, size, and proliferation of cancer cells as well as to promote breast cancer cell death has been demonstrated in animal experiments. According to other research on animals, ingesting flaxseed along with tamoxifen can reduce tumor size more than just taking the medication by itself. Furthermore, according to several clinical studies, flaxseed can significantly lower the incidence of breast cancer, particularly in postmenopausal women [10].

Mucilage is another crucial element of flaxseed. This is derived from aqueous extractions, and it contains a heterogeneous blend of polysaccharides (75% neutral and 2 acid fractions) including xylose, glucose, galactose, arabinose, rhamnose, fructose and galacturonic acid [15].

Consumers who are concerned about their health are aware of the nutritional benefits of cold-pressed flaxseed oil. It is promoted in specialized and healthy food stores and sold to consumers at a premium price as "First Press" oil or encapsulated. It does not go through any refining operations.

. As a useful food, flaxseed is becoming more and more significant in the global food chain. Foods or dietary elements that may have physiological benefits and aid in the prevention and/or treatment of diseases are referred to as functional foods. Flaxseed currently offers new opportunities as a functional food due to consumers' rising interest in foods that have excellent health advantages. It has gained popularity as a desirable item in diets created specifically to provide certain health benefits due to its outstanding nutritional profile and potential health benefits. Despite the numerous clinical studies supporting flaxseeds, few individuals are aware of their true nutritional, therapeutic, and other health benefits [36].

## Nutritional Composition of flaxseed

### Oil

Flaxseed oil content typically ranges from 30 to 44%, depending on a number of variables including cultivars, location, environmental conditions and analytical techniques [41]. 13 flaxseed samples grown in China had crude flaxseed oil concentrations that ranged from 28.9 to 41.4% [46]. One of the most plentiful sources of ALA is flaxseed [1]; [19]; [21]. Flaxseed oil contains 48–62% ALA [5];[26].

Growing circumstances, cultivars, and environmental factors all have an impact on the amount of ALA in flaxseed oil [12]; [42].

Fatty acid makes up the majority of flaxseed oil, just like it does in other dietary oils. It has been discovered that flaxseed oil contains other substances, including phytosterols, volatile chemicals, phenolic compounds, and tocopherol. Triacylglycerides (TAG) make up around 96% of flaxseed oil, with polar lipids, glycol, and phospholipids making up 1.4% [12].

Table 1 lists the fatty acids that are present in flaxseed oil [45].

***Table 1. Composition of fatty acids present in flaxseed oil***

| Fatty acid | Constitution |
|---|---|
| Linolenic acid | 53.36-65.84 % |
| Linoleic acid | 10.14-16.39 % |
| Oleic acid | 10.03-12.37 % |
| Stearic acid | 3.98-9.85 % |
| Palmitic acid | 2.41-7.97 % |

**Proteins**

Flaxseed protein content in whole flaxseed varies greatly, ranging from 10 to 31%, depending on a variety of factors, including cultivars, processing techniques, and environmental circumstances. The two primary components of flaxseed protein are 1.6-2S albumin and 11-12S globulin. 1.6-2S albumin, a water-soluble protein, has a low molecular weight of 16–17 kDa, while salt-soluble protein 11–12S globulin has a large molecular weight of 252-298 kDa [3]; [34]; [33].

64–85% of the total protein in flaxseed is made up of 11–12S globulin, also known as linin [3]; [20]. Disulfide bonds bind the four subunits of 11S globulin, which have a mass of 36, 46, 50, and 55 kDa [18]. About 40–42% of the protein in flaxseed is made up of 1.6-2S albumin, also known as colinin. It is a single polypeptide chain with 168–169 amino acids [6]; [33].

**Tocopherol**

The strongest antioxidants that are fat soluble are tocopherols or vitamin E. They are found in four homologous isomers, with varying numbers or positions of methyl groups in the molecules: α (5, 7, 8-trimethyltocol), β (5, 8-dimethyltocol), γ (7, 8-dimethyltocol), and δ (8-methyltocol). The overall tocopherol content of flaxseed was 9.3 mg/100 g on average, with γ-tocopherol accounting for 48-96% of the total tocopherols [30].

**Lignans**

Flaxseeds are the richest dietary source of lignan precursors. When ingested, lignan precursors are converted to enterolignans, enterodiol, and enterolactone, by bacteria that normally colonize the human intestine. The principal lignan precursor found in flaxseed is seco-isolariciresinol di-glucoside (SDG) [7]. After being consumed, SDG is transformed in the colon into enterodiol, entero-lactone, and active mammalian lignans. These compounds have the potential to slow the growth of malignant tumors, particularly those that are hormone-sensitive as those found in the breast, endometrial, and prostate. Lignans are beneficial to human health because of their capacity to combine divalent transition metal cations and for their hydrogen-donating antioxidant action [39]. The hepatoprotective effects of flax seed have also been observed. Flax seed or SDG has been shown to have reproductive effects, which are dose and time-related [43].

**Dietary fiber**

The term "dietary fiber" refers to a broad range of plant materials that are difficult for human digestive enzymes to break down [13]. Diets high in dietary fiber might help lower the risk of obesity, inflammation, diabetes, colon cancer, and heart disease.

Flaxseed is a substantial source of dietary fiber, including 28% of soluble and insoluble fibers. Fiber may be categorized into two main groups of chemicals: 1) Lignins and 2) Non-α-glucan polysaccharides, such as cellulose, hemicellulose, and pectin. Within the digestive system, dietary fiber works as a polymer matrix with a range of physicochemical characteristics, such as its ability to store water, exchange cations, be susceptible to bacterial fermentation, and perform adsorptive tasks.

Consuming a high-fiber diet lowers the chance of contracting the following conditions: obesity, diabetes, hypertension, stroke, coronary heart disease, and several gastrointestinal issues. Moreover, higher dietary fiber intake decreases blood pressure, raises regularity, helps with weight reduction, enhances blood glucose management in diabetes, and looks to boost immunity. It also improves serum lipid concentrations.

**α-linolenic acid (ALA)**

Eating a diet rich in fiber reduces the risk of developing obesity, diabetes, hypertension, stroke, coronary heart disease, and a number of gastrointestinal disorders. Increased dietary fiber also improves blood glucose control in diabetics, lowers blood pressure, increases regularity, aids in weight loss, and may even strengthen immunity [2].

Cardioprotective properties, inflammatory response regulation, and favorable effects on behavior and central nervous system function are some of the potential advantages of ALA [37]. Maintaining optimal tissue function may need adequate intakes of preformed n-3 polyunsaturated fatty acids, especially docosa-hexaenoic acid, as α-linolenic acid appears to be a limited supply of longer-chain n-3 fatty acids in humans. The ability of women to upregulate the transformation of α-linolenic acid may be crucial in fulfilling the needs of the fetus [9].

**Value added products**

**Bakery products-**

One of the most organized sectors of the processed food industry is baking. Products from bakeries are widely consumed because they are inexpensive, readily available, and easily transportable. They also come in a variety of flavors and texture profiles. The main advantage of bread goods is their docility for fortification with grains, millet, or other components.

Numerous researchers have looked into the possibility of substituting wheat flour for ground flaxseed or whole flaxseed grains while making pancakes, muffins, breads, and cookies. The highest levels of consumer acceptance of flaxseed flour - 5, 15, and 30% were associated with 3.5–6.2 g of dietary fiber and 445-2,500 mg of linolenic acid in cakes, 100 grams per kilogram. The cakes were marketed as good and exceptional sources of dietary fiber and linolenic acid, two bioactive substances. One helpful tactic to maximize the consumption of foods high in functional nutrients is to use up to 30% flaxseed flour when making cakes [27].

Whole flaxseed (flour) has been added to foods to improve health and prevent disease since it is a strong source of omega-3 fatty acids and phytochemicals with both nutritional and functional qualities [44]. The protein content of refined wheat flour was determined to be 4.26% and the fiber content to be 0.04%. These percentages increased to approximately 9.25% and 2.37%, respectively, after raw flaxseed flour was added in a 70:30 ratio.

As the amount of flaxseed flour in cookies grew, cohesiveness, gumminess, tractability, and resilience decreased and hardness, resilience, chewiness, and springiness increased.

An increase in the amount of flaxseed was linked to an increase in dough stickiness and water absorption. As the amount of flaxseed grew, so did the crumb's suppleness [25]. Researcher examined the flaxseed content of bread rolls and how chemical analysis (fatty acids, fiber, secoisolarisinol glycoside, and cadmium), instrumental texture measurement, and sensory evaluation (texture, odor, and flavor) determine the flaxseed and flaxseed oil content of cinnamon rolls [31].

The findings show that compared to the control rolls without flaxseed, the flaxseed rolls are better at retaining moisture and suppleness. During the 0–6 day storage period at room temperature (+22 °C), no off-odours were noticed. Consumers enjoyed cookies with 6%–12% flaxseed content, and there was no discernible difference in the cookies' physical or sensory qualities.

The amount of omega-3 fatty acids in cookies can be increased by 14.14% and up to 30% by using flaxseed oil instead of shortening.

Banana nut muffin is prepared using flour, 30-33% ground flaxseed, and 50% ground flaxseed. Both 30-33% and 50% flaxseed incorporated muffins were found more acceptable as compared to the pale one muffin. A muffin with ground flaxseed in it gives a "whole grain" look.

Lohan et al. developed a rusk using flaxseed and finger millet enriched with α-linoleic acid and fiber. The proportions of finger millet, flax seed, and wheat flours were optimized using Response Surface Methodology (RSM). On the basis of fiber and ALA content and baking quality characteristics of rusk 13.13%, 6.0%, and 80.6% of finger millet, flax seed, and wheat flours, respectively was finalized. The developed rusk contained 4.81% fiber and 1.36% α-linolenic acid. Wet and dry gluten content, SDS sedimentation, falling number, dough raising capacity of yeast, and baking time of mixed flour of these components were statistically ($p>0.05$) similar to that of wheat flour [22].

**Dairy products**

The fatty acid composition of milk is positively impacted by whole flaxseed supplementation in the summer. Specifically, milk from cows supplemented with flaxseed exhibited an increase in monounsaturated fatty acid and a decrease in saturated fatty acid [11]. Azarpazhooh et al. conducted an experiment in which he prepared cocoa milk enriched with flaxseed mucilage and stevia. In the study, the effects of flaxseed-mucilage (2, 4, and 6%), Stevia (0, 50, and 100%), and ultrasound (5, 10, and 15 min at a constant frequency of 20 kHz) on physico-chemical properties, antioxidant activity, color, and sensory evaluation of formulated flaxseed-mucilage cocoa milk (FCM) product were evaluated using a response surface methodology. Results demonstrated that increasing the flaxseed-mucilage content reduced ($p<0.01$) the pH and the extent of sedimentation, decreased ($p<0.01$) the lightness (L∗), and increased ($p<0.01$) the viscosity in all test samples. The effect of Stevia on various physico-chemical properties was also significant ($p<0.01$). Further, increasing the ultrasound treatment time reduced the product viscosity ($p<0.01$). With the application of the desirability function concept, the optimum formulation conditions for preparing the FCM were established as 2.5% flaxseed-mucilage, 1% Stevia, and 10.9 min ultrasound treatment time. The characteristics product obtained under the optimized conditions were pH 6.34, viscosity 10.4 mPas, sedimentation 0.71%, L∗value 48.4 and overall acceptability value 4.98. Antioxidant activity and total phenolic content of the optimized FCM were notably higher than those in the control sample and the associated peroxide values were low. Thus, this product can be commercialised taking in a way the beneficial effects of flaxseed and stevia on health of human beings [4].

Flaxseed oil and lignan have also been added to dairy products, such as butter, whey, cheese, yogurt, and ice cream. To make a 12% (w/w) ice cream combination, 2% (w/w) flaxseed oil is added without significantly altering the way the ice cream functions overall. Hyvärinen et al. found that SDG applied to milk, yogurt, and cheese can withstand fermentation, renneting, and pasteurization with effectiveness. Three different formulations of microencapsulated flaxseed oil powder- 1%, 2%, and 3% were added to dahi, or Indian yogurt. This could be a potential ω-3 fatty acid delivery system [17].

Marand et al. in his experiment found that the addition of flaxseed powder improved the physicochemical characteristics of yogurts. The SFA content and omega-6 to omega-3 ratio of yogurts significantly decreased with the addition of flaxseed powder, while the PUFA content of samples was increased. The antioxidant activity of flaxseed-enriched yogurts was significantly higher than that of the control sample. In addition to the nutritional benefits, the organoleptic characteristics of yogurts containing flaxseed powder were acceptable [24].

**Roasted products**

In India, rice and morning foods like chapatti, idly, dosa, and vada are eaten with an abundance of chutneys and pickles made from vegetables, pulses, and spices. There is literature on the creation and standardization of a number of food adjuncts such as instant chutneys, traditional chutneys and chutney powders, based on the different raw materials that are available at different times of the year.

A tasty functional dietary supplement called flax (*Linum usitatissimum* L.) chutney powder (FSCP) was created by combining ground and roasted flaxseeds with other carefully chosen spice components. Flaxseed powder (FSP) and flaxseed meal powder (FSCP) have protein contents of 24.2% and 23.4%, respectively. FSP and FSCP had total polyphenol contents of 439 and 522 mg/100 g, respectively. For FSP and FSCP, the critical moisture content was 10.2 and 13.5%, respectively, and they were equilibrated at 82 and 68% relative humidity.

Even after six months of storage, the overall sensory quality of FSCP given with cooked rice received a "good" (7.4) rating [32].

For the creation of coconut-flaxseed balls, flaxseed composite flour was enhanced with 5% coconut, 5%, 10%, 15%, 20%, and 25% chia seeds. The chia seed enrichment impact was assessed for the coconut-flaxseed balls' physicochemical and sensory characteristics. The content of bioactive phenolics and antioxidant activity were also ascertained. Along with enhancing the mineral profile for iron, magnesium, manganese, and zinc content up to 50.8, 40.1, 34.1, and 60.2 ppm, respectively, the product can have up to 4.1% of ash, 33% of crude fiber, and 12.9% of the nitrogen-free extract.

The coconut-flaxseed balls passed the sensory evaluation, receiving high marks for acceptability overall, color, and flavor. A product has nutraceutical qualities if it is high in fiber and low in fat [16].

**ω-3 rich Energy Bar with Flaxseed:**

A wholesome energy bar was created by incorporating flaxseed into the recipe along with white oats, legumes (soy protein), and pulses (roasted bengal gram), all at different percentages of sweeteners (45, 50, and 55%) to create a healthful product [28]. A considerable rise in total calories was observed as flaxseed content increased, the highest amount (397.95 kcal) was obtained in bars containing 20% flaxseed and 45% sweeteners. The maximum protein (12.41%), crude fat (11.86%), ash (1.65%), iron (3.77 mg/100 g), crude fiber (2.18%), and ω-3 as α-linolenic acid (22.50% fatty acid basis) content were also found in this energy bar sample. Along with other ingredients, 15% flaxseed and 45% sweeteners may be taken into consideration for the development of an energy bar high in omega-3 fatty acids that are of acceptable quality and can be stored well in a refrigerator on a commercial scale.

In a different trial, commercially available quick oat flakes and full-fat roasted flaxseed flour were combined at 5, 10, 15, and 20% to create an oatmeal bar. The impact of adding flaxseed flour was examined in terms of the cereal bar's approximate composition, and calcium, iron, and phosphorus levels.

The cereal bar's nutritional value was enhanced ($p<0.05$) by the addition of flaxseed flour in terms of crude protein, crude fat, crude fiber, and total ash, however, the amount of carbohydrates drastically dropped. A fatty acid-rich energy bar that is commercially available and keeps well in a refrigerator [38].

**Conclusion**

Flaxseed, with its rich profile of alpha-linolenic acid, lignans, dietary fiber, and high-quality protein has emerged as a functional ingredient with immense potential in the development of health-oriented processed food products. This review highlights the diverse applications of flaxseed in bakery items, beverages, dairy alternatives, and nutraceutical formulations, demonstrating its compatibility with current consumer demands for plant-based and wellness-focused foods. Processing techniques such as roasting, extrusion, and microencapsulation have been pivotal in enhancing the bioavailability, stability, and sensory acceptability of flaxseed-enriched products. However, challenges remain in optimizing processing conditions to preserve its sensitive bioactive components and mitigate anti-nutritional factors. Continued interdisciplinary research and innovation are essential to unlock the full potential of flaxseed in value-added food applications, thereby contributing to both public health and the functional food industry.

**Future Scope**

Future research on flaxseed should focus on optimizing processing techniques to preserve its heat-sensitive bioactive compounds such as ALA and lignans. Additionally, the development of cost-effective detoxification methods to eliminate anti-nutritional factors like cyanogenic glycosides is essential for expanding flaxseed's safe use in food products. Further exploration into the synergistic effects of flaxseed with other functional ingredients and its integration into plant-based food systems, personalized nutrition, and therapeutic diets presents exciting opportunities. Long-term clinical studies are also needed to validate its health benefits across diverse populations and disease conditions.

**Conflict of Interest**

There is no conflict of interest regarding the publication of this paper.

**Acknowledgment**

I would like to express my sincere gratitude to Dr. B.S. Dilta for his invaluable guidance, encouragement, and critical insights throughout the preparation of this manuscript. Special thanks are extended to all co-authors for their collaborative support and contributions.

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