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Review Article

Health benefits of ghee: Review of Ayurveda and modern science perspectives

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ABSTRACT

The scientific view on dairy fats is undergoing a change. While at one time they were associated with negative health effects, recent scientific research has provided new insights into the functional benefits of dairy fats and their fatty acids. This changing scientific view on dairy fats is also resulting in a scientific interest in Ghee, the clarified butter obtained from milk. Ghee, besides being a traditional milk product of cultural importance in India and finding extensive use in its cuisines, is also one of the most important ingredients of the *materia medica* of Ayurveda, the traditional system of medicine that originated in India. While modern scientific literature has limited studies on functional benefits of ghee, Ayurveda literature extensively catalogues the therapeutic potential of ghee and details different types of ghee based on source of milk, manufacturing method, maturation and physical phase. This work reviewed the Ayurveda literature on health benefits of ghee and examined the complementarity and gaps between Ayurveda literature and modern scientific literature to identify research questions and hypotheses for further exploring the therapeutic potential of ghee. The Ayurveda literature review involved curation of references to ghee in eleven important Ayurvedic texts spanning over 3000 years. 4000 references to milk and milk products were curated from these texts, of which 2913 mentions were in the context of therapeutic benefits of milk products. Of these, ghee had 774 mentions, the highest amongst milk-based products. These mentions were grouped into 15 benefit clusters. A review of ghee in modern literature published between 1990 and 2023 was also conducted. A comparison of this with the Ayurveda literature showed that there were major differences in the focus areas of health between the two. While recent research primarily focused on ghee's connection with cardiovascular health, wound healing and skin health, Ayurveda prioritized cognitive benefits, gastrointestinal health, and nourishing. These later areas are of growing importance to human health as global population ages, and chronic and brain related diseases start dominating public health concerns. As scientists search for solutions to these, ghee, its usage and formulations in Ayurveda and the detailed associations between ghee's animal source, processing, maturation, phases and health benefits, may have scientific insights to offer that can guide future research.

1. Introduction

Ghee is an integral part of Indian food and culture. Statistics indicate that 30–35 % of milk is converted into ghee in India [1]. The culinary use of ghee has grown in India over the centuries with its rich flavour positioning it as a health plus taste ingredient. As part of complex recipes ghee provides textural & food structuring properties such as in Indian sweets like *ladoo, mysore pak* and *halwa*, much like cocoa butter does in chocolate. It is used as a frying medium due to its relative stability on exposure to high temperatures and high smoke point (~250 °C) compared to most other edible oils [2,3]. It is also used as a spread or topping on cooked food like *rice, khichdi, daal, chappati* and coffee [4].

The per capita consumption of ghee and butter in India has increased to 4.48 kg/yr (12.3 g/person/day) in the year 2020 from 2.7 kg/yr (7.4 g/person/day) in 2007 [5]. To put this number into perspective, clarified ghee and butter contributes about 110 calories/day/person or 5.5 % of the daily energy on a 2000 calorie diet comes from dairy fat. Though ghee is a culturally and commercially important food product, it remains

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a controversial food ingredient as the modern nutritionists and codified traditional medicinal knowledge systems view it differently. While traditional knowledge systems such as Ayurveda perceive ghee as a healthy food with therapeutic value, from the modern nutritionist's perspective consumption of dairy fat should be limited due to the presence of saturated fatty acids. However, this single-point view of ghee's impact on human health is beginning to get challenged [6–11]. Research on the functional roles of lipids, their fatty acid constituents, association with maintaining energy balance in the body and reducing the risk of several diseases such as cancer, obesity, neurological, and cardiovascular disorders has led to a growing interest in ghee and its unique fatty acid profile amongst the world of edible fats and oils [12, 13]. As interest in understanding the correlation between the components of ghee fatty acids grows, it is important to review the therapeutic value of ghee in Ayurveda literature as this may lead to generation of new hypotheses for testing in pre-clinical and clinical studies. This paper presents a comprehensive literature review on the role of ghee in Ayurveda. It also examines the complementarity between the focus of modern scientific research with that of Ayurveda.

1.1. What is ghee

Definitions of ghee in CODEX Alimentarius and Food Safety Standards Authority of India (FSSAI) are broad, and it has been defined as "a product exclusively obtained from milk, cream or butter, by means of processes which result in almost total removal of water and non-fat solids, with an especially developed flavour and physical structure" [14,15]. Accordingly, ghee is predominantly comprised of 99.5 % fat and less than 0.5 % moisture content. Furthermore, ghee is a source of fat-soluble vitamins including vitamin A (28.21 ± 0.142 IU/g), vitamin D (11.42 ± 0.425 IU/g), vitamin E (31.55 ± 1.109 IU/g), vitamin K, and phospholipids [16].

Food chemists further describe ghee by its fatty acid composition. The fatty acids are categorized in two ways – based on chain length and based on degree of unsaturation. Based on chain length, fatty acids are categorized as SCFA (Short Chain Fatty Acids), MCFA (Medium chain Fatty Acids) and LCFA (Long Chain Fatty Acids). Degree of unsaturation results in classes of fatty acids such as SFA (Saturated Fatty Acids), MUFA (Mono-unsaturated Fatty Acids) and PUFA (Poly-unsaturated Fatty Acids). Further sub-categorization includes the position of the double bond from the end of the hydrophobic chain classifying the fatty acids as omega-3 and omega-6, the conjugation of fatty acids, and phospholipids. The presence of SCFAs, conjugated linoleic acids (CLAs), omega-3 and omega-6 fatty acids and phospholipids make ghee unique in the world of edible fats and oils. These fatty acids are receiving attention from the scientific community for playing important roles in our body such as anti-inflammatory and antioxidant action as well as association with brain health and the discussion in modern science is beginning to broaden from the narrow focus on saturated fats to the wider benefits of the full spectrum fatty acid profile [17]. Initially, epidemiological observations of Greenland Eskimos established the potential health benefits of n-3 PUFAs and other dietary lipids [18]. Since then, researchers have paid substantial attention to the non-calorific roles of not just the n-3 PUFAs but also SCFAs, MUFAs and phytosterols and their impact on disease progression. Various studies have demonstrated that dietary intake of SCFAs and lipids like MUFAs, PUFAs, and phytosterols have significant therapeutic properties [19]. Consuming some of these fatty acids and lipids suppresses inflammation, Aβ production and deposition, hypercholesterolemia, and dyslipidemia [20]. Additionally, some of them play a crucial role in other cellular signaling pathways such as cell proliferation, programmed cell death, and cell survival [21]. While a detailed review of the benefits of the different fatty acid components of ghee are out of scope of this paper, a tabulation of the detailed composition has been included in supplementary material (S1).

2. Methodology followed for ayurveda literature review

To investigate ghee from Ayurveda perspective, a comprehensive review of relevant sections of eleven important Ayurveda texts was conducted to map ghee and its functional uses in Ayurveda. The referred texts included seven Samhitas, two lexicons (Nighantu), and two relatively recent classical texts, spanning a period of over 3000 years, from the 15th century BCE to the 17th century CE. The list of texts and the selected sections used in the review is given in the supplementary material (S3). Sections (*vargas)* in these texts explaining the milk and milk products were referred. References specific to ghee were found in the chapters on "*Ghrita Varga*" and related verses regarding the classification and properties of ghee, *ghrita, ajya*, and *sarpi* were compiled.

The selected sections were read manually and all mentions to ghee, milk, curd, butter, and buttermilk were curated to create a database. All the details such as source of milk, processing, Ayurveda pharmacological properties, *rasapanchaka* prosperities, *tridoshik* actions, therapeutic uses, health benefits and contraindications were recorded as metadata. Wherever multiple attributes were mentioned in a single sentence, each attribute was given a separate line in the database. A total of 4000 references to milk and milk-based products were curated through this process.

2.1. Literature review of ghee from Ayurveda texts

The review of traditional literature suggested that ghee is mentioned extensively in Ayurveda as a therapeutic on its own and as an ingredient in complex medicine formulations (*ghrita*). Ghee also finds mention as a food in Ayurveda and is listed in *Caraka Samhita* as one of the eleven food items recommended for daily consumption - *Nityasevaniya Ahaara*. This not only points to its goodness as a daily nourisher, but also that it was considered as a food that does no harm on daily consumption. Several of many Sanskrit & vernacular names for ghee are indicative of its goodness, such as *pavitra* indicating the purity of ghee, *ajya* portraying the long-lasting nature of ghee, *amrita* representing the life-giving qualities of a nectar, and *tejas* representing the potency of ghee.

Of the 4000 mentions to milk and milk-based products curated from the Ayurveda texts, 2913 references were in the context of functional benefits. Amongst the milk-based products, ghee finds the most mentions in context of functional benefits with 774 mentions (Fig. 1). While some mentions of ghee in Indian classical medicinal literature are without any classifier, many of the mentions had additional details such as manufacturing process, animal source of milk from which ghee was made, age of the ghee and the phase of the ghee.

Ayurveda explicitly mentions two different methods of manufacturing ghee. The default method involves fermenting milk to make curd, spinning the curd to separate butter from buttermilk, and heating the butter on slow fire till all the water is evaporated. The milk solids in the butter slowly precipitate during this step and are filtered out to yield a clarified liquid that partially solidifies on cooling. The resulting product is referred to as ghee, and the Ayurveda literature generally considers ghee made through this method as the standard process for producing various types of ghee, unless explicitly stated otherwise. The second method mentioned in Ayurveda involves creaming the milk, churning butter and then slowly heating it to remove water and solids. Fermentation step is not specifically mentioned in this second method.

Other qualifiers of ghee in Ayurveda included the animal source of milk from which ghee is made, the age of the ghee and its phases. This analysis reveals 10 different types of ghee based on the animal source of milk, 7 different types of ghee based on the duration of aging, 2 broad types based on manufacturing method and 2 types based on the phase used. Where no classifier was mentioned, the ghee was classed as 'General'. Refer to the supplementary material (S2) for Ayurveda classification of ghee.

A frequency analysis on the number of mentions of each ghee type

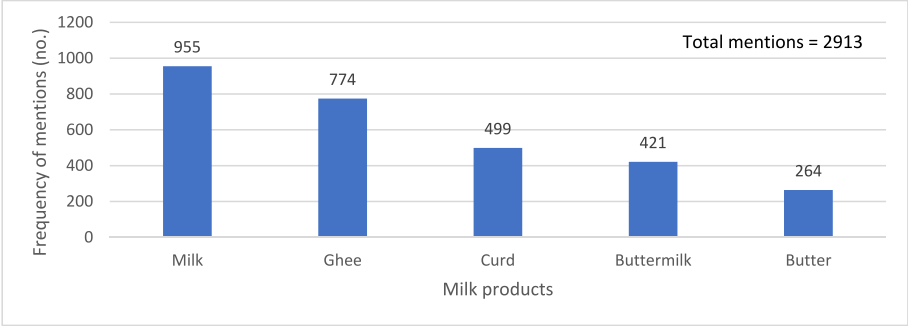


Fig. 1. Number of mentions of milk and milk products in the selected Ayurveda texts.

was done to understand the how each correlated with benefits. Only 774 mentions with functional or therapeutic annotations were considered for this analysis. Cow ghee is the top in the animal source classifier, with the maximum number of mentions in the context of health benefits, followed by goat, camel, buffalo, and other species of ghee. While cream ghee had higher mentions among the processes used to make ghee, curd ghee is highly recommended in Ayurveda. Almost all ghee made from different animal milk sources, aged ghee, and other types of ghee were recommended to be made using the curd ghee process. Old ghee (*purana ghrita*) is also highly regarded in Ayurveda and is considered to have numerous health benefits (Fig. 2).

The pharmacology of the different types of ghee was also curated from the Ayurveda texts **(Table 1)**. Ayurveda pharmacology uses the concepts of *rasa, guna, virya, vipaka* and *dosha karma* to describe the pharmacology of ingredients in its *materia medica*. Explanations of these concepts can be found in many good texts [22].

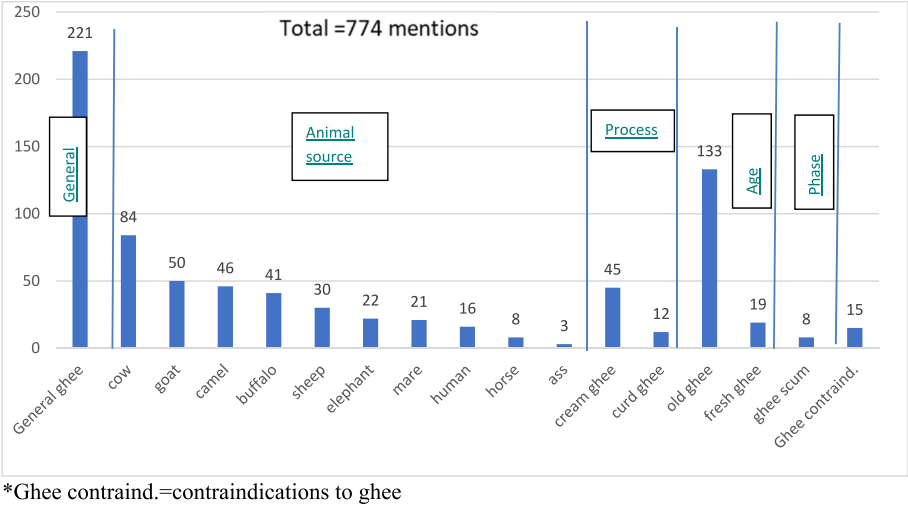
Cow, goat and human ghee reduce all three doshas, while buffalo ghee increases pitta and horse ghee increases *vata*. While cow & buffalo ghee are sweet in rasa, goat, mare, horse, ass and elephant ghee are astringent, and camel & mare's ghee are saline. These differences in the pharmacology lead to varying effects on health of individuals and suitability of ghee can be ascertained as per one's prakriti and doshas. The health benefits annotated in the 774 mentions of ghee were clustered into 15 benefit groups e.g. cognitive health, nourishment, rejuvenation qualities and benefits that target particular organ system in the body. This analysis reveals that the top five benefit mentions are for cognitive health, gut health, nourishing benefits, vision and ear, nose and throat health, and cleansing and respiratory health.

Ayurveda indicates that ghee made from milk of different animal species can be used for various functional purposes (Fig. 3). Cow ghee also has the highest mentions for its nourishing properties and rejuvenation among all other species ghee. Camel's ghee receives the most mentions for its digestive properties, goat's ghee for respiratory health benefits, and sheep's ghee for excretory system benefits. This analysis suggests that while ghee from all sources have a baseline of benefits across the spectrum, there is also specificity of benefits for the different animal sources. Ayurveda pharmacology further supports this notion, as the properties mentioned vary for ghee derived from different sources. The analysis of Ayurvedic literature, presented in Fig. 3, reveals that ghee's properties, obtained from different animal species influence gastrointestinal health in the order of camel > buffalo > goat > cow.

3. Comparison of the fatty acid profiles of ghee from different animal sources

The specificities of benefits should be reflected in the profile of the constituent fatty acid of the milk fat from the different animal sources including their chain length, degree of unsaturation, orientation of double bonds, distribution in the triglyceride structure, and composition of the non-glyceride fraction [23]. The fatty acid profiles of milk fat of various animal species were compiled from available the literature and analyzed to understand the diverse pharmacological and therapeutic properties **(Table 2)** [24–30].

Buffalo, cow, and sheep milk fat contain a greater proportion of short chain fatty acids compared to other species. Mare's milk contains the highest levels of linoleic acid (C18:2) & linolenic acid (C18:3). It is



*Ghee contraind.=contraindications to ghee

Fig. 2. Number of mentions of ghee based on type - its animal source, process, age and phase (Only the 774 mentions that had therapeutic annotations were considered for this analysis)
*Ghee contraind. = contraindications to ghee.

Table 1
Qualities (rasapanchaka) and tridosha modulation of different types of ghee in Ayurveda.

S.No.	Types of ghee	Vata	Pitta	Kapha	Rasa	Guna	Virya	Vipaka
1.	Ghee (General)	↓[b]	↓[b]	↑[b]	Sweet[a]	Heavy[a,b]	Cold[a,b]	Sweet[a]
2.	Cow ghee	↓[b,e,d,c]	↓[a]	↓[b,e]	Sweet[b,c]	Heavy[b]	Cold[a, b,c]	Sweet[a,b,c,f]
3.	Buffalo ghee	↓[a,d,e]	↑[a]	↓[a,b,e]	Sweet[a,f]	Heavy[c,f]	Cold[c,f]	Sweet[a]
4.	Goat ghee	↓[b]	↓[b]	↓[b,e]	Astringent[c]	Light[c]	Cold[c]	Pungent[a,b]
5.	Sheep ghee	↓[c,e]	↓[c,e] ↑[a]	↓[c,e]	–	Light[f]	Cold	Pungent[a]
6.	Camel ghee	–	–	–	Saline[c]	Light[c]	Hot[c]	Pungent[a,b]
7.	Mare ghee	–	↓[a]	–	Saline[c] Astringent[a]	Light[c,e]	Hot[a,c,e]	Sour[c]
8.	Horse ghee	↑[e]	–	–	Astringent [e]	Heavy[e]		Pungent[e]
9.	Ass ghee	–	–	↓[g]	Astringent[g]	Light[g]	Hot[g]	
10.	Elephant ghee	↓[e]	–	↓[b]	Astringent[g]	Heavy[c] Light[a]		Bitter[a]
11.	Human ghee	↓[a]	↓[a]	↓[a]				Light[e]
12.	Old ghee	↓[a]	↓[a]	↓[a,b]				Pungent[a]
13.	Cream ghee	–	–	–	Sweet[g]	Heavy[g]	Cold	

*(↑ indicate increase; ↓ indicate decrease).
Source.
[a] Susruta Samhita.
[b] Bhavapraksha.
[c] Charaka Samhita.
[d] Kshemkuthuhalam.
[e] Rajnighantu.
[f] Harita Samhita.
[g] Bhojanakutuhalam.

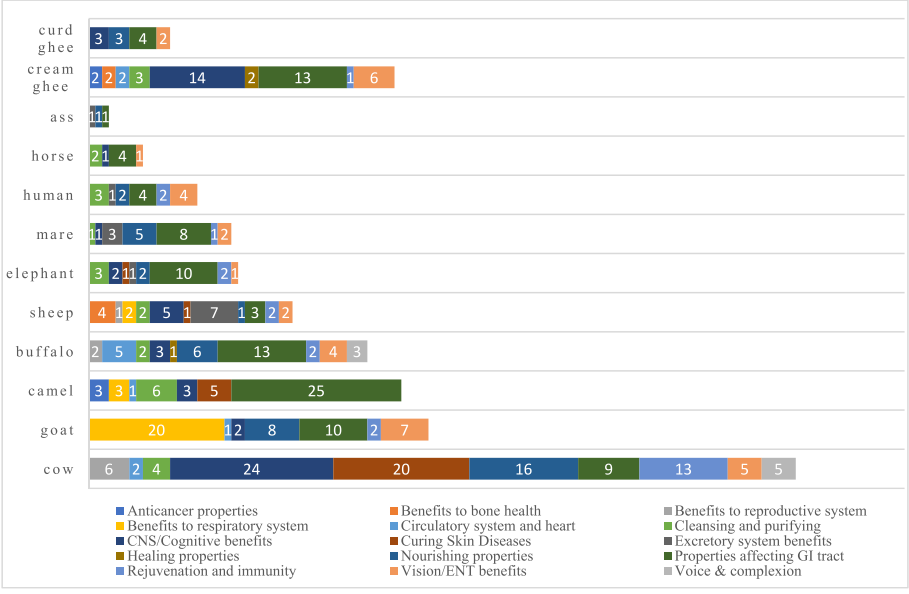


Fig. 3. Frequency of mentions of ghee based on its 'source' for the 15 benefit clusters
[Mentions of ghee based on source (321 mentions) is a subset of 'all types of ghee' (774 mentions) given in Fig. 3].

noteworthy that human milk fat displays the lowest saturated fatty acids (SFA) content, i.e. 39.9 %, as compared to the corresponding values of 65.4 % and 67.4 % observed for cow and buffalo milk fat, respectively. Elephant's milk fat has very high C10:0 & C12:0 fatty acids [39]. Mare, Sheep & Goat have much lower levels of these compared to elephant's milk fat but still very substantially higher than cow & buffalo milk [31–39].

While the fatty acid profiles have unique signatures, to draw specific correlations will require more data. Never-the-less, the review does highlight that ghee or milk fat derived from various species exhibits substantial variations in their fatty acid composition, thereby indicating the uniqueness of each type and the potential health benefits arising from their varying proportions of fatty acids.

4. Review of modern literature on ghee in context of the 15 benefit groups identified in ayurveda

To draw connections between traditional knowledge and modern science on ghee, a systematic literature search was conducted on PubMed to identify peer-reviewed articles published in English from January 1, 1990, to April 10, 2023. The search aimed to explore the potential benefits of ghee based on 15 predefined benefit clusters found in classical Ayurveda literature. Relevant literature was identified by using specific search terms related to each benefit cluster, along with ghee/ghrita/clarified butter. The table is given in the supplementary material (S4). The title/abstract filter in the advanced search feature of the PubMed database was utilized for this purpose.

Following the literature search, the title/abstracts of the retrieved

Table 2
Fatty acid profile of milk fat from different animal species (% Fatty Acid).

Common name	Fatty acids	Cow milk fat	Buffalo milk fat	Goat milk fat	Sheep milk fat	Camel milk fat	Human milk fat	Mare milk fat	Elephant milk fat
Butyric acid	**C4:0**	3.17 ± 0.78	4.06 ± 1.71	2.07 ± 0.64	3.66 ± 0.87	0.20 ± 0.33	–	0.35 ± 0.26	–
Caproic acid	**C6:0**	2.11 ± 0.39	1.98 ± 0.72	1.99 ± 0.45	2.48 ± 0.52	0.15 ± 0.12	–	0.45 ± 0.26	–
Caprylic acid	**C8:0**	1.43 ± 0.28	1.22 ± 0.53	2.28 ± 0.56	2.18 ± 0.43	0.12 ± 0.08	0.08 ± 0.00	2.85 ± 0.25	2.37 ± 0.41
Capric acid	**C10:0**	2.92 ± 0.23	2.08 ± 0.72	7.22 ± 3.08	6.46 ± 0.98	0.27 ± 0.00	1.16 ± 0.32	6.47 ± 0.73	27.78 ± 7.61
Lauric acid	**C12:0**	3.32 ± 0.21	2.81 ± 0.47	4.10 ± 1.07	3.87 ± 0.38	0.110.82	4.03 ± 2.52	7.01 ± 0.59	16.94 ± 9.26
Myristic acid	**C14:0**	11.11 ± 0.50	10.71 ± 1.26	10.54 ± 1.14	10.32 ± 0.43	10.64 ± 0.00	6.74 ± 0.55	6.96 ± 0.54	3.22 ± 1.37
Pentadecanoic acid	**C15:0**	1.06 ± 0.13	1.12 ± 0.10	0.99 ± 0.19	0.33 ± 0.47	2.57 ± 0.83	–	0.39 ± 0.01	0.24 ± 0.00
Palmitic acid	**C16:0**	28.69 ± 3.23	30.69 ± 2.17	29.70 ± 2.62	25.24 ± 0.97	26.45 ± 5.76	14.65 ± 10.06	20.51 ± 0.30	13.12 ± 2.80
Heptadecanoic acid	**C17:0**	0.56 ± 0.16	0.64 ± 0.18	0.69 ± 0.08	0.21 ± 0.30	0.35 ± 0.37	0.30 ± 0.10	0.38 ± 0.02	1.01 ± 0.46
Stearic acid	**C18:0**	11.05 ± 1.09	12.13 ± 1.29	9.07 ± 1.18	9.78 ± 0.36	15.00 ± 4.18	12.77 ± 8.91	1.26 ± 0.06	7.24 ± 5.89
Myristoleic acid	**C14:1 (c9)**	0.81 ± 0.50	0.56 ± 0.21	0.29 ± 0.15	0.22 ± 0.02	0.48 ± 0.66	0.36 ± 0.00	0.39 ± 0.00	0.02 ± 0.02
Palmitoleic acid	**C16:1**	1.29 ± 0.53	1.59 ± 0.36	1.09 ± 0.44	1.04 ± 0.12	9.47 ± 3.53	2.49 ± 0.20	5.41 ± 0.19	0.69 ± 0.13
Oleic acid	**C18:1**	21.76 ± 1.49	20.79 ± 1.52	20.52 ± 1.83	21.15 ± 3.22	25.44 ± 5.39	33.37 ± 2.66	20.86 ± 1.06	18.07 ± 6.06
Linoleic acid	**C18:2**	2.20 ± 0.73	1.29 ± 0.29	2.07 ± 1.25	2.98 ± 0.66	2.55 ± 1.15	12.07 ± 2.54	14.63 ± 3.33	1.45 ± 1.45
Linolenic acid	**C18:3**	0.95 ± 0.55	0.69 ± 0.52	0.35 ± 0.07	0.80 ± 0.07	1.69 ± 0.12	1.04 ± 0.88	8.53 ± 3.38	0.74 ± 0.01
CLA	**c9 t11 C18:2**	0.80 ± 0.35	0.83 ± 0.06	0.81 ± 0.11	1.47 ± 0.32	–	0.02 ± 0.00	0.07 ± 0.00	0.03 ± 0.00
Reference		[24–26]	[24–26]	[25,26]	[27–29]	[30–32]	[33–35]	[36,37]	[38,39]

Note: The values are average of the reported values in different publications and represented as Mean ± SD.

studies were carefully reviewed to assess their eligibility based on pre-determined inclusion criteria. These criteria consisted of original and review articles, animal studies, human intervention trials, case studies, randomized controlled trials, in-vitro and epidemiological studies. The literature search produced 246 articles out of which 83 duplicate articles were removed, and an additional 54 papers were deemed irrelevant after thorough evaluation of their title and abstract. Finally, 109 studies that met the selection criteria were included in this review.

Further, to draw the complementarity and to identify gaps between classical ayurveda and modern literature, percentage mentions under each benefit cluster in Ayurveda literature search and the number of studies for each benefit cluster in modern literature were compared.

Comparing the number of references for each benefit in Ayurveda texts with PubMed show that the lead interests in the two are very different. The most studies in PubMed are for cardiovascular health, wound healing and skin health. None of these are in the top three list of Ayurveda texts which leads with cognitive benefits, gastrointestinal health and nourishing properties (Table 3).

The review of modern literature also maps the functional benefits of dietary intake of ghee or its functional components such as SCFAs and CLAs. This review has been presented under various subheads according to the functional benefit.

Table 3
Comparison of references of ghee for the 15 benefit groups between Ayurveda literature and PubMed.

S. No.	Benefit group	Percentage of mentions to ghee in Ayurveda (%)	Percentage of papers on ghee in PubMed (%)
1	CNS/Cognitive benefits	21.45	8.26
2	Gastrointestinal health	18.73	0.92
3	Nourishing properties	13.05	0.00
4	Vision/ENT benefits	10.98	8.26
5	Cleansing and purifying	7.24	0.92
6	Rejuvenation and immunity	6.59	3.67
7	Benefits to Respiratory system	4.91	0.00
8	Excretory system benefits	3.23	0.00
9	Voice, beauty and complexion	3.10	0.00
11	Benefits to reproductive	2.33	0.00
10	Circulatory system and heart health	2.33	27.52
12	Curing skin diseases	2.20	17.43
13	Healing properties	1.81	23.85
14	Anti-tumor properties	1.16	5.50
15	Bone health	0.90	3.67

4.1. Cognitive benefits of ghee

This is the most mentioned benefit group in Ayurveda literature with every 5th mention (~22 %) of ghee being in context of cognitive health. It has been referenced in context of enhancing memory, brilliance, intellect, and even in management of diseases like epilepsy and insanity. However, only 9 studies were found on cognition in PubMed and comprised less than 10 % of all the PubMed articles on therapeutic benefits of ghee. Of these, 5 were animal studies, 2 were human clinical studies and another 2 studies were review articles on cognitive aspect of ghee-based formulations. The results of many of these studies are not conclusive [40].

While studies on effect of ghee on brain health are limited, there are many studies on individual components found in ghee like Short Chain Fatty Acids (SCFAs), omega-3 fatty acids and Conjugated Linoleic Acids (CLAs) that show promising role in improving brain health. Research suggests that SCFAs released by gut microbes have potential anti-inflammatory effects on impaired microglia in Alzheimer's disease [41]. Other beneficial fatty acids in ghee like DHA, EPA, and CLAs have been found beneficial for cognitive functions and anti-inflammatory effects in the brain [42]. Although n-3 fatty acids and CLAs are minor components of ghee, the presence of SCFAs and other minor fatty acids together may contribute to the cognitive benefits associated with ghee mentioned in Ayurvedic literature [43]. Exploring ghee's potential in cognitive health research could offer novel solutions, considering the growing importance of cognitive health particularly in an aging global

population.

Besides pure ghee, studies on some herbal formulations made with ghee have been reported and have shown promising results. Studies on *Kalyanaka Ghrita* show its positive effects on cognitive abilities and memory skills. *Kalyanaka Ghrita* also reduces acetylcholinesterase levels, oxidative stress, and inflammatory cytokines in the brain [44]. Similarly, *Jyotismati* oil along with ghee showed significant enhancement in spatial and fear memory in rats [45]. *Sarasvata Ghrita* exhibits neuroprotective activity by reducing malondialdehyde levels, increasing antioxidant enzyme levels, inhibiting acetylcholinesterase activity, and promoting the release of brain-derived neurotrophic factor [46]. *Kushmanda Ghrita* significantly improved the psychometric parameters and clinical symptoms in clinically diagnosed cases of depressive illness [47]. Similarly, *Brahmi Ghrita* along with yoga potentially enhance cognitive abilities like learning, attention, processing speed, and working memory among elderly persons with Mild Cognitive Impairment [48]. These studies indicate that the use of ghee as base in the herbal formulations possibly enhance bioavailability & bio-assimilation.

4.2. Gastrointestinal health benefits

Ayurveda emphasizes the gastrointestinal (GI) health benefits of ghee, which account for approximately 11 % of its mentions, while modern scientific literature focuses on this benefit area in less than 1 % of studies. Ayurveda highlights that camel ghee has higher gastrointestinal (GI) benefits as compared to ghee from other animal species. Only one study found on PubMed was in the context of effect of ghee on GI health. Studies on the absorption of glucose and glycemic response of rice indicate that ghee may control the postprandial glycemic response when used in the cooking and stir frying of rice [49]. While studies on ghee and its effects on GI health are limited, the significance of fatty acids found in ghee have been studied in terms of improving digestion and GI health. SCFA improve digestion, enhance the integrity of the intestinal wall and boost the immune system in the gut [50]. Medium Chain Triglycerides (MCTs), CLA, SCFAs, and n-3 PUFAs not only provide energy but also show satiating effects and hence help limit energy intake [51]. Synergistic effects of FAs also improve gut health as in case of CLAs that help produce higher amounts of SCFAs by the gut microbiota [52]. While the amount of dietary fatty acids reaching to GI tract remains uncertain, research studies focusing on the impact of individual fatty acids on GI health suggest the importance of studying the potential effects of ghee on various aspects of GI health and digestion.

4.3. Rejuvenating and immunomodulatory properties

In Ayurveda, approximately 13 % of the mentions highlight the rejuvenating and immunomodulatory properties of ghee. In contrast, less than 4 % of studies in PubMed focus on these specific properties of ghee. Ghee is recognized as a '*Rasayana*' in Ayurveda, a Sanskrit term meaning to nourish and distribute nutrients throughout the body. '*Rasayana*' therapy is utilized for enhancing immunity, lengthen life, rejuvenation and retard ageing in Ayurveda [53]. While Ayurveda places significant emphasis on the immunomodulatory benefits of ghee, the number of studies in modern literature specifically investigating these properties remains limited.

Studies have demonstrated that ghee and its individual constituents have beneficial role in modulating immune responses. While ghee as such is considered to have rejuvenating and immunomodulatory properties in Ayurveda, many lipid-based poly-herbal formulations have also been used for thousands of years for promoting cardiovascular, pulmonary, brain, and immune health. These formulations, particularly those utilizing ghee or sesame oil as carriers, have a special significance in modulating immunity due to their absorption through the lymphatics, which are lipid-rich. Recent research on lipid absorption pathways and immune cell receptors supports the use of these lipid-based formulations in targeting the cardiovascular, pulmonary, and immune systems [54]. *Swarna Bindu Prashana*, a ghee-based gold nanoparticle complex show immunity enhancing effects in children [55]. *Āmalaki Rasāyana*, an Ayurvedic formulation containing *Āmalaki* (*Emblica officinalis*), show significant immunostimulant activity and moderate cytoprotective activity in rats [56]. Many ghee-based herbal formulations have also been found effective in producing anti-stress effect with immunosuppressing activity [57]. In Ayurveda, products derived from cow are used either singly or in combination with botanicals and herbs for treatment of various diseases [58,59].

Components of ghee such as Butyric acid help in producing killer T cells in the intestinal tract, and strengthen the immune system [60]. Linolenic fatty acids (omega-3 fatty acids) have proven useful in the management of allergic, inflammatory and auto-immune diseases [61]. A clinical trial indicated that administering 3 g/d CLAs to 25–50 year-old individuals had a considerable positive impact on their immune response [62].

In conclusion, ghee, its components, and multiherbal ghee-based formulations known as "*ghritas*" are potentially helpful in boosting the immune system and possibly reducing the severity and likelihood of many diseases. The traditional practice of using ghee in Ayurvedic medicine for its immune-boosting properties has been supported by several scientific studies. While more research is needed to fully understand the mechanisms behind ghee's immunomodulatory properties, it is clear that incorporating ghee into one's diet could potentially improve immune function and reduce the risk of diseases.

4.4. Ghee and cardiovascular health

While ghee finds lesser mention in context of cardiovascular health in Ayurveda literature, it finds the most mentions in PubMed articles on ghee with nearly 27 % of all references on ghee being in the context of cardiovascular health. Most of these articles highlight concerns associated with consumption of ghee, though a few points to the cardiovascular health benefits of ghee as well.

Much of the negative focus has been from ghee's compositional perspective, arising from the fact that ghee contains cholesterol and is very rich in saturated fat content and both of these have been linked with the risk of cardiovascular diseases (CVDs) in the past [63]. Another concern with ghee has been the potential formation of cholesterol oxidation products (COPs) upon heating and cooking, and a possible association of these COPs with high risk of atherogenicity [64]. However, a study by Nath and Murthy (1988) reported that COPs were not detected in fresh ghee clarified at 120 °C [65]. Ghee intake has been shown to reduce serum prostaglandin levels and inhibit the formation of inflammatory leukotrienes in rats indicating its non-atherogenic nature [66]. Zeb and Uddin (2017) found that the negative effects of oxidized ghee on serum lipid profile is reduced by unoxidized or normal ghee in rabbits. The study concluded that ghee upto 10 % levels may alter blood lipid profile but does not elevate the risk of CVDs [67].

Though ghee was linked with CVDs due to high SFAs and COPs, studies suggested that several functional components in ghee may help in lowering its atherogenic index [68]. In a study, ghee at 2.5 % of total energy levels showed dose dependent decrease in LDL, VLDL, cholesterol, and TG levels. It also reduces fatty streak formation and cholesterol levels in coronary artery of rabbits [69]. Kumar et al. (2000) suggested that the cholesterol lowering effect of ghee occurred possibly through the increased secretion of cholesterol in bile [70]. Nirmala et al. (2018) compared curd ghee and cream ghee and found that intake of 5 % curd ghee led to slower weight gain, low LDL, VLDL, total cholesterol, and TGs than cream ghee [71]. Ghee based formulations have also been studied for their effect on biomarkers of cardiovascular health. A study focusing on the efficacy of *Guggulutikthaka gritha* (GTG), an Ayurvedic ghee-based formulation used for treating dyslipidemia, demonstrated significant reductions in serum lipids and blood glucose levels in rats [72].

There are very few epidemiological studies that have looked at ghee

consumption and biomarkers of cardiovascular health. In an epidemiological survey conducted in Rajasthan, India, it was found that men who consumed more than 1 kg of ghee/month had significantly lower prevalence of coronary heart disease (CHD) compared to those consuming less than a kg of ghee/month [73]. However, Manna et al. (2016) did not find any correlation between ghee consumption and the history of CHD [74]. A recent case-control study conducted in Lahore, Pakistan, involving 500 subjects (250 with coronary artery disease and 250 healthy controls) also concluded that daily ghee consumption is not associated with an increased or decreased risk of coronary artery disease [75]. Some epidemiological studies have found a negative correlation between ghee consumption and biomarkers of cardiovascular health. An epidemiological study conducted in Kolkata, India suggested that the consumption of ghee and vegetable oil are associated with high BMI, waist circumference, and HDL cholesterol [76]. Mishra et al. (2010) also indicated that intake of Saturated Fatty Acids (SFAs) from sources like animal fats and clarified butter (ghee) is one of the causative factors for developing obesity and type-2 diabetes among people in developing countries particularly in South Asia and South-East Asia [77]. A study in Pakistan based on the National Health Survey of Pakistan (NHSP) (1990–1994) data revealed that ghee and saturated fat intake are associated with increased prevalence of CVD risk factors. The overall prevalence of the coexistence of risk factors for CVD was 13.0 % in men and 20.9 % (19.8–22.0 %) in women [78]. Similarly, a case-control study associated ghee as one of the risk factors for premature acute myocardial infarction among young South Asians [79].

Human clinical trials have also studied the correlation between ghee consumption and biomarkers of cardiovascular health. Again, the results paint a mixed picture. While some studies indicate a reduction in risk factors, other studies show no effect, positive or negative, while still others indicate an increase in the biomarkers. Shankar et al. (2005) suggested that including 10 % ghee in the diet could improve the serum lipid profile by increasing high-density lipoprotein (HDL) levels and reducing triglycerides (TGs), potentially lowering the risk of cardiovascular diseases (CVDs) [80]. A randomized clinical trial involving 206 healthy participants aged 20–60 years suggested that ghee consumption resulted in a significant decrease in total cholesterol and TGs, along with a significant increase in Apo-A and HDL-cholesterol levels compared to oil [81]. The findings of Kumar, Sambaiah and Lokesh (1999) found that ghee consumption reduced prostaglandin levels and production of inflammatory leukotrienes in rats and suggested that ghee may not increase the risk of cardiovascular diseases [66]. Sserunjogi et al. (1998) suggest that the natural antioxidants present in ghee such as vitamin A, vitamin E, carotenoids and phospholipids possibly aid to reduce the risk of CVDs [4].

However, other studies have failed to find any benefit of ghee on CVDs or its biomarkers. A study by Mulay (2021) showed that short term escalating administration of large amount of sneha (fat) did not increase blood lipids, but found significant reductions in TGs, very-low-density lipoproteins (VLDL), body weight, and abdominal circumference [82]. In a clinical trial with 24 young and healthy volunteers on a lactovegetarian diet, consuming ghee at a 10 % energy level for 8 weeks showed no significant impact on the serum lipid profile, indicating that ghee may not have a substantial effect on cardiovascular health [83]. While the above studies suggest that ghee may have beneficial effects on serum lipids, contributing to improved cardiovascular health or at worst no effect, there are others that show a negative effect.

Elshafei (1992) and Al-Othman (2000) report that ghee fed at 10 % of total energy levels increases triglycerides (TGs), LDL-C, total cholesterol and glucose levels as compared to normal diet. However, the increase in all these biomarkers were less as compared to vegetable oil [84,85]. Another study reported that TG and VLDL levels were increased due to consumption of cow ghee but this may not affect serum cholesterol levels [86]. Soelaiman (1996) reported that ghee is more atherogenic than coconut oil as it increases oxidative stress due to more production of conjugated dienes in liver and serum after 4 and 9 months of intervention in rats [87]. Certain types of ghee like Eve's ghee (*Avika Ghrita*) may increase the risk of CVDs as it raises QTc [88]. Another study reported that consumption of high levels of ghee along with carbohydrate rich diet resulted in altered inflammatory homeostasis and impaired glucose tolerance [89]. High fat along with carbohydrate rich diet also resulted in development of metabolic syndrome and negatively impacted the lipid profile in glucose-intolerant mice [90]. A recently conducted two-period crossover randomized trial indicated that ghee consumption had a more significant impact on increasing apo B and non-HDL-cholesterol levels compared to olive oil and may increase the risk of CVDs [91]. However, all these studies have small sample sizes and are short duration and these results have to be looked at with caution.

Despite conflicting scientific findings regarding the association between ghee consumption and cardiovascular health, ghee continues to be a popular food item in various cultures and holds a significant place in traditional medicinal practices such as Ayurveda. Furthermore, there is a rising interest in investigating the potential therapeutic advantages of ghee for many conditions, particularly in relation to cognitive and gut health. Given the wide-ranging potential health benefits associated with ghee, it is important to know whether ghee is good, neutral or bad in the context of cardiovascular health. Comprehensive, large sample size, long duration studies are needed to understand the effects of ghee consumption on cardiovascular health and establish clear guidelines regarding its inclusion in the diet.

4.5. Anti-tumor properties

5.5 % of the papers found on PubMed focus on anti-tumor properties of ghee. Studies with positive annotations reported that ghee is potentially beneficial in reducing the risk of certain cancers. Constituents in ghee such as vitamin A, E, and K potentially lower the risk of cancers by preventing cell damage and reducing the effects of free radicals [92–94]. Ghee also reduces the progression of mammary carcinogenesis by reducing the expression of cyclooxygenase-2 and increased expression of peroxisome proliferators activated receptor-γ (PPAR-γ) in mammary gland tissues [95,96]. Moreover, cow ghee suppresses the activity of liver enzymes involved in activating carcinogens, enhances the detoxification processes in the liver and mammary tissues. These findings suggest that cow ghee has potential benefits in regulating enzyme activities associated with carcinogen metabolism [97]. Ghee solid lipid nanoparticles show excellent carrier properties and drug diffusion for carrying temozolomide (TMZ) used for the treatment of glioblastoma cells [98]. However, two studies indicated negative annotation linking ghee with an increased risk of lung and prostate cancer [99,100]. Considering the multifactorial nature of cancers and tumors, further studies should be carried out investigating the metabolic pathways that can potentially prevent cancer development and aid tumor treatment. Exploring these pathways will provide insights into how ghee may contribute to cancer prevention and treatment.

4.6. Skin healing properties

While not in the top 5 based on frequency of mentions in Ayurvedic texts, ghee and ghee-based formulations are commonly prescribed for management of various skin diseases in Ayurveda. Our literature review on PubMed revealed that ghee and skin health are one of the top five focus areas of 'ghee' research in modern science with 17 % of the 'ghee' publications on PubMed being in the context of skin health. All PubMed studies have shown positive annotations for ghee or ghee-based formulations in the management of skin ailments. While one study did not show any benefits of ghee alone, others did find a positive effect when ghee was infused with botanicals [101].

Cow ghee's stability even in the presence of infused botanicals, and its suggested ability to carry active components of herbs to target tissues in Ayurveda also contributes to its popularity in formulations for treatment of skin diseases [102]. We now also know that ghee has

antioxidant, antibacterial, and antiseptic properties, all of which may be contributing ghee's effectiveness in managing skin diseases thus making it a good base for the more complex botanical formulations [103]. Ghee blended with honey in alginate hydrogel help scarless cutaneous wound repair with excellent antibacterial efficacy and cell viability [104]. *Jatyadi ghrta* was found to aid in wound healing on irradiated skin tissue by faster re-epithelialization and collagen fibers deposition [105]. Ghee based turmeric formulations showed promising results in wound healing in dogs with periodontal treatment consequences after surgery [106]. Local application of ghee and *Dashanga Lepa* along with *Kaishore Guggulu* and *Sanjivani Vati* in a case study demonstrated healing of dry gangrene [107]. Ghee, honey along with *Apamarga Kshara Yoga Lepa* was found to be effective in treatment of Vitiligo (*shvitra*) [108]. Ghee along with *Guduchi* and *Bhringaraja* powder showed promising results in treatment of Eczema [109]. These findings highlight the potential functional benefits of ghee and Ayurvedic approach of using functionalized herbal ghee as lipid-based formulations for management of various skin diseases. Further research and clinical trials to explore the potential of ghee and its polyherbal infusions could result in novel formulations for dermatological applications.

4.7. Wound healing and anti-inflammatory properties

About 24 % papers on PubMed were in the context of healing properties. Due to its lipid-based nature, ghee serves as a carrier for various herbs, allowing their active components to be effectively applied for wound treatment, enhancing their spreadability, extrudability, and solubility [110]. The review on wound healing properties of ghee shows mostly positive annotations. The only negative annotation found in the review of ghee was its association with neonatal tetanus as a result of its application on the umbilical cord wound [111]. Studies have shown that ghee exhibits anti-inflammatory effects in acute pancreatitis, reducing inflammation in pancreatic and lung tissues [112]. Additionally, ghee promotes cell proliferation and enhances migration of keratinocytes, indicating its positive influence on wound healing processes [113]. *Jyatyadi ghrta* has demonstrated significant wound contraction, faster closure and improved tissue regeneration highlighting its efficacy in wound healing [114,115].

In a randomized control clinical trial involving 45 patients, "*Manjishthadi Ghrita*" demonstrated superior wound healing properties [116]. Hydrogel containing honey and ghee exhibited antibacterial effects and promoted cell viability that help in scarless wound healing [117]. A medicated ghee with *Tinospora cordifolia* leaves and fumigation therapy resulted in complete healing of burn wounds [118]. Wound dressings with honey and ghee show promising results in treating various chronic infected wounds, and improving the patients' quality of life [119]. Additionally, use of ghee on excision wounds in rats demonstrated over 90 % wound healing, with rapid epithelialization and increased vascularity compared to control groups [114]. These studies collectively highlight the positive impact of ghee as an effective agent in wound healing.

4.8. Use in ocular health, vision and eye diseases

Approximately 8 %, of the studies in PubMed focused specifically on the topic of eye health. Similarly, in Ayurveda review, the references to ghee in the context of vision or eye health was relatively less (about 4 %). Research studies have explored the use of ghee as a medication for various eye diseases [120]. Gupta et al. reported that 12 % of participants in their study used ghee as a traditional remedy for ophthalmic diseases [121]. Cow ghee has been found beneficial in to enhancing the permeation of fluocinolone acetonide medication in rats [122]. Another study showed that cow ghee and vitamin E effectively treated cataract induced by glucose in sheep eye lenses [123]. Nasal administration of cow ghee oral intake of *Triphala Ghrita* improves retinal sensitivity in glaucoma patients [124]. *Mahatriphaladya Ghrita* used for *Tarpana* relieved signs and symptoms of myopia [125]. *Jeevantyadi ghrita* applied through *Akshitarpana* demonstrated promising outcomes in reducing myopia symptoms [126]. Additionally, a study comparing *Triphala Ghrita* and *Goghrita Manda Tarpana* in managing dry eye syndrome showed moderate to marked relief in patients [127]. Overall, these studies suggest that ghee may have potential benefits in promoting eye health as well as facilitating drug delivery to the deeper tissues of the eye. However, more research is needed to explore these potential benefits and determine the optimal dosages and methods of use.

4.9. Bone health

4 % of PubMed articles focus on bone health, in contrast to less than 1 % in Ayurveda. Though all the annotations were positive in the modern review on bone health, ghee individually was rarely mentioned as a therapeutic for bone health. A study on *Panchatikta Ghrita* (PG) stated its anti-osteoporotic properties in rats. PG administration in osteoporosis induced rats demonstrated better serum calcium and inorganic phosphate levels, reduced urinary calcium and phosphate levels, decreased osteoclasts, and increased bone hardness compared to the diseased group [128]. Later another study be the same authors show promising effects of PG in protecting against postmenopausal osteoporosis [129]. Administration of PG also resulted in enhanced bone mineral density (BMD) scores, bone-specific biomarkers and quality of life [130]. These results suggest the potential of PG as a preventive therapy for osteopenia.

5. Conclusion

Ayurvedic literature and modern scientific studies have low complementarity, though both sheds light on the diverse pharmacological and therapeutic profiles of ghee. While, important benefits areas in Ayurveda are in the context of cognitive health, nourishment, rejuvenation & immunity and gastrointestinal health, studies in modern literature are limited in these areas. Modern scientific literature on ghee has largely focused on cardiovascular health risk of consumption of ghee and that too primarily due to its saturated fatty acid composition. The benefit areas associated with ghee in Ayurveda literature has been largely overlooked in recent research, with only limited interest in areas such as cognitive health, GI health, wound healing, dermatological applications, and eye health. A few studies in these areas, though limited in number and quality, show directionally positive results meriting further research. They indicate the potential of ghee as functional food in preventing and treating various diseases, including tumors/cancers, skin conditions, eye health, and wound healing and merit further research and comprehensive interventional trials are necessary to fully understand the mechanisms behind these benefits and establish definitive guidelines for ghee consumption. Many fatty acid constituents of ghee may have potential in treatment of various diseases and promoting health. These could be studied as single molecule or fractions as functional lipid blocks. Ghee's potential as a carrier of medicinal ingredients is another promising area of research. These areas present promising directions for further research and lay the ground for collaboration between Ayurveda and biomedicine to design and conduct clinical trials necessary to optimize the use of ghee and developing new formulations for managing and improving health outcomes.

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Author contribution

DK- Writing original draft, investigation, Writing-review and editing, methodology, formal analysis.

GS- Conceptualization, Supervision, Writing-review and editing, methodology, formal analysis funding acquisition.

Declaration of competing interest

The authors of this paper declare that there is no conflict of interest regarding the publication of this paper.

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Appendix A. Supplementary data

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