ISSN (P): 3105-7071
ISSN (O): 3105-708X
INNOV STEAM RES EDU
WWW.TUFSTEAM.COM
HTTPS://DOI.ORG/10.63793/ISRE

INNOVATIONS IN STEAM: RESEARCH & EDUCATION

An International Journal

VOLUME 3 ISSUE 1 2025

ARTICLES: 25030101-25030105

Innovations in STEAM: Research & Education

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Innovations in STEAM: Research & Education
Volume 3, Issue 1, June 2025

Table of Contents

Bacteriocins Review Article 25030101
A Short Review on Multifunctional Roles of Bacteriocins
Abdul Wahab, Alina binti Abdul Rahim, Muhammad Abdullah Qadri

Keratosis Review Article 25030102
A Review on Arsenic Toxicity Induced Keratosis and its Prevalence
Noor Ul Ain, Hamna Kaleem, Zahra Batool, Arbab Zafar, Khateeba Azmat, Ramish Karamat, Hiba Siddiqui, Zobia Sohail, Ruhma Iqbal, Mahnoor Younis

Islamic Research Article 25030103
The Status of Women in Islamic Society in Light of the Prophetic Sunnah: Islamic Society in Light of the Prophetic Sunnah
Tabassum Minhas

Business Research Article 25030104
Artificial Intelligence Adoption in Malaysian SMEs: When to Optimize and When to Transform Business Models?
Indrian Logaiswari, Umar Haiyat Abdul Kohar

Ethnobotany Review Article 25030105
Common Buckwheat: A Neglected Plant with Great Health Benefits
Nabeel Shaheen, Saher Nawaz, Atia Nazir

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Innovations in STEAM: Research & Education
ISSN (print): 3105-7071; ISSN (online): 3105-708X
Volume 3; Issue 1; Article No. 25030101
https://doi.org/10.63793/ISRE/0021

REVIEW ARTICLE

A Short Review of Multifunctional Roles of Bacteriocins

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METADATA

Paper history
Received: 01 May 2025
Revised: 12 April 2025
Accepted: 30 April 2025
Published online: 20 May 2025

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Keywords
Bacteriocins
Innovative
Industrial Perspective
Multidimensional

Citation
Wahab A, Rahim AbA, Qadir MA (2025) A short review on multifunctional roles of bacteriocins. *Innovations in STEAM: Research & Education* 3: 25030101. https://doi.org/10.63793/ISRE/0021

ABSTRACT

Background: Rising demand for healthy food products has created the need for more innovative food preservation methods. One such method involves the use of bacteriocins, which are natural antimicrobial peptides with potential application in the food industry.
Objective: The purpose of this review is to highlight the purification processes of bacteriocins and discuss their multidimensional roles, particularly in controlling harmful pathogens.
Methodology: Information was compiled from relevant scientific literature focusing on the purification methods, properties, and applications of bacteriocins. Emphasis was given to their potential mechanisms of action against foodborne pathogens and their prospective role in food preservation.
Results: Current findings indicate that bacteriocins exhibit promising antimicrobial activity against a wide range of harmful microorganisms and enhance meat shelf-life, improve plant growth, and control skin-related diseases. However, further industrial-scale studies are still needed to fully validate their commercial applications.
Conclusion: Bacteriocins hold significant potential as innovative tools for food preservation and can potentially improve meat shelf-life, enhance plant growth, and control skin-related disease infestation. Their purification and demonstrated antimicrobial roles provide a foundation for future research aimed at integrating them into industrial applications for safer and healthier food production.

INTRODUCTION

Foodborne diseases remain one of the biggest threats to the food industry, and when outbreaks occur, they cause significant losses to a country, as a large portion of the national budget is spent on managing such disasters. To address this, the food industry has upgraded its safety systems to ensure consumer protection. This continuous improvement has also created healthy competition among food industries, driving technological advancements. Nature has blessed us with a wide variety of foods, and food lovers always expect these to be nutritious, wholesome, and safe for consumption. According to Obafemi *et al*. (2025), microbial spoilage is a major factor affecting food quality and safety. When microbes enter food products, they can cause discoloration, destroy flavour compounds, and lead to food toxicity. This not only damages public perception but may also contribute to food scarcity. Preservation is therefore essential to control spoilage-causing pathogens. Bacteriocins, the native antimicrobial peptides of bacteria, are becoming increasingly important tools in contemporary food protection. They inhibit pathogenic and spoilage bacteria quite effectively, providing a biological alternative to conventional preservatives (Le *et al*. 2016; Obafemi *et al*. 2025).

In the quest for safe, natural, and effective antimicrobial agents, bacteriocins have become a cornerstone of modern biotechnology. These ribosomally synthesized peptides, which are secreted by various strains of bacteria, have strong inhibitory action against other microorganisms, such as foodborne pathogens and spoilage bacteria. Their use includes antimicrobial function to preserve foods, promote animal health, and treat diseases (Ali *et al*. 2020). Food technologists and scientists have increasingly turned to biopreservatives, among which bacteriocins produced

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through biotechnology are of particular interest. Bacteriocins show promising antimicrobial effects against food spoilage organisms and are widely considered natural food biopreservatives (Mahindra *et al*. 2015). Bacteriocins play a vital role in overcoming food safety issues, lowering the dependence on chemical preservatives, and minimizing threats of foodborne illness. In the food sector, they provide a reliable solution for shelf-life extension and product safety. Outside of the food sector, they are investigated for their therapeutic applications, such as fighting antibiotic-resistant infections and influencing the gut microbiome (Gu 2023). This review highlights bacteriocins, their classifications, and their importance in the meat sector, plant growth, and skin care products.

BACTERIOCINS

The extensive use of conventional medicines in the treatment of human and animal diseases has become a concern in recent years (Roy 1997; Yoneyama and Katsumata 2006). The emergence of resistant strains has complicated the treatment of many diseases, making the development of new antimicrobial agents an important goal (Kumar and Schweiser 2005; Fisher *et al*. 2005). Bacteriocins have gained attention as alternatives to antibiotics because they are non-toxic, active at nanomolar concentrations, and produced naturally by lactic acid bacteria (Parada *et al*. 2007). They are proteinaceous compounds with antimicrobial activity, produced by bacteria to inhibit or kill other bacterial strains (Parada *et al*. 2007). Although they are bacterial products, they are not classified as antibiotics to avoid confusion with therapeutic drugs (Deraz *et al*. 2005). For the food industry, bacteriocin production is highly beneficial, as it helps inhibit and eliminate pathogens. Many bacteriocins are effective against closely related bacteria, often displaying a narrow host range (Deegan *et al*. 2006). It is used predominantly in canned foods and dairy products and is especially effective when utilized in the production of processed cheese and cheese spreads, where it protects against heat-resistant spore-forming organisms such as those belonging to the genera *Bacillus* and *Clostridium* (Tarelli *et al*. 1994).

CLASSES OF BACTERIOCINS

Bacteriocins are broadly divided into four main classes. Class I includes lantibiotics, which are small peptides of less than 5 kDa in size and are heat-stable. They act mainly by disrupting bacterial membranes, and nisin is the most well-known example (Broadbent *et al*. 1989). Within this class, subclass-Ia- Ia consists of positively charged, elongated, and flexible peptides, while subclass-Ib includes peptides that are more rigid, globular in shape, and either uncharged or negatively charged (Parada *et al*. 2007). Class II bacteriocins, often referred to as non-lantibiotics, are heat-stable peptides composed of amino acids and show variability in molecular weight. This class is further divided into three groups: Class-IIa, which contains peptides active against *Listeria* species and is represented by pediocin PA-1; Class-IIb, which includes bacteriocins that require two different peptides to achieve antimicrobial activity; and Class-IIc, which is characterized by small, heat-stable peptides transported by leader sequences (Venema *et al*. 1997; Holo *et al*. 2002; Mauriello *et al*. 1999; Parada *et al*. 2007). Class-III bacteriocins are larger in size, with molecular weights exceeding 30 kDa, while Class-IV bacteriocins are complex molecules containing carbohydrate or lipid moieties in addition to protein components (Parada *et al*. 2007; Holo *et al*. 2002; Mauriello et al. 1999).

EFFECT OF PURIFICATION METHODS, pH AND TEMPERATURE ON BACTERIOCIN PRODUCTION

Different purification methods have been developed depending on the class of bacteriocin (Table 1). These include protein precipitation, chromatography, and electrophoretic techniques, which allow isolation and characterization of bacteriocins for food and pharmaceutical applications. The production and activity of bacteriocins vary with environmental conditions. Studies have shown that each bacterial strain has an optimum pH range and temperature at which bacteriocin production is maximized (Table 2 and 3).

BENEFITS OF BACTERIOCINS

Application of bacteriocins in the food industry is valuable for extending shelf life and protecting against harmful pathogens. Their use reduces the risk of disease transmission and economic losses associated with food spoilage. Growing consumer demand for natural, minimally processed foods further supports the role of bacteriocins as natural antimicrobial agents (Soltani *et al*. 2021). When tested individually or in combination, bacteriocins show promising results against foodborne pathogens (Rendueles *et al*. 2022). In the dairy and poultry sectors, they have been applied successfully to control *Clostridium* spp. (Arqués *et al*. 2015; Le *et al*. 2016). However, bacteriocins that are applied commercially as biopreservatives must fulfill specific requirements (Holo *et al*. 2002; Mauriello *et al*. 1999), such as being non-toxic, accepted by recognized authorities, remaining sufficiently stable during storage, and not negatively affecting the quality of the product to which they are applied.

APPLICATIONS OF BACTERIOCINS

Metal industry

Several bacteriocins have been applied in the meat sector to

Table 1: Purification of bacteriocins according to their classes

Class	Purification Method	Procedure	Result	Reference
Class I Bacteriocins	Expanded bed ion exchange chromatography	Through processing of the *Lactococcus lactis* subsp diluted culture broth of A164 obtained, and further, this broth was processed by using this method	31-fold purification was achieved with a yield of 90%	Cheigh *et al.* 2004
	Ion exchange, Hydrophobic Interaction	20% of ammonium sulphate was used with the precipitate of the cell-free supernatant	Through the use of *Lactobacillus sake* L45, its strain Lactocin S, a 3,7 kDa bacteriocin, was created and then refined to uniformity	Mørtvedt *et al*. 1991
	Combinations of different chromatographic methods	Hydrophobic and Cation exchange principles were applied during the use of these methods	Purification of Acidocin CH5 manufactured by using *L. acidophilus* in lab	Chumchalova *et al.* 2004
Class II Bacteriocins	Ethanol precipitation	In the first step, ampholytes, Tween 20, and glycine were mixed, followed by ultrafiltration to achieve a pure sample. Lastly, the sample was moved to tricine SDS-PAGE	*Pediococcus acidilactici* was used to produce purified pediocin PA-1, with a yield between 30 and 40%	Venema *etal.* 2004
	Saturation with ammonium sulfate (35%)	In an FPLC system, purification includes Gel filtration chromatography, and then is moved to methanol-chloroform extraction, followed by three methods. Firstly by ion-exchange, then by hydrophobic interaction, and lastly through reverse-phase chromatography	Lactobin A, produced by *L. amylovorus,* was purified	Contreras *et al.* 1997
	ion-exchange chromatography, ultrafiltration, and successive gel filtrations	One of these methods can be used in the presence of two experimental consituents, 8 M urea followed by sodium dodecyl sulfate 0,1% sodium dodecyl sulfate	Lactacin B produced from *L. acidophilus* was purified	Barefoot *et al*. 1984
Class III Bacteriocins	Ammonium sulfate precipitation	In sodium acetate buffer, the pellet was placed and then dialysed against sodium acetate buffer.	*Lactobacillus helveticus* 481 produced Helveticin J, a peptide was purified	Joerger and Klaenhammer 1986

Table 2: Effect of pH on bacteriocin

Bacteriocin producing strain	Optimum pH	Reference
Leuconostoc MF215B	pH 6.0	Blom *et al.* 1999
L. gelidin	pH 6.5	Stiles and Hasting 1991
amylovorin L471	pH 6.5	Callewaert *et al*. 1999)
C. piscicola	7.0	Herbin et al. 1997

Table 3: Effect of temperature on bacteriocin

Bacteriocin /Strain	Suitable Temperature for Bacteriocin Production	Observation	Reference
Strain D53	10°C to 37°C	--------	Uhlman *et al.* 1992
Brevibacterium linens	25°C	No growth found at 37°C	Diep *et al*. 2000
L. sake	25–30°C	At 33.5°C decline in production occurs, and zero production is observed at 34.5°C	Diep *et al*. 2000
L. plantarumY21	30°C	At 37°C, especially in milk products, bacteriocin was produced during incubation	Tarelli *et al*. 1994

control pathogens, thereby improving food safety and extending shelf life. Classes of meat-preservation bacteriocins are present in Table 4. Partially purified or purified bacteriocins may be applied as a food additive and for active packaging. Moreover, bacteriocin-producing cells may be incorporated as starter or protective cultures for meat fermentation.

Veterinary use

Nisin has been investigated for the prevention of bovine mastitis caused by *Staphylococcus aureus* and Streptococcus agalactiae. Injectable formulations containing nisin have shown up to 99.9% effectiveness in controlling

Table 4: Role of different bacteriocins against different pathogens in meat sector

Type of meat	Meat product	Strains of bacteriocin	Action against pathogens	Other changes	References
Meat Salami	Ostrich meat salami	Lactobacillus curvatus DF126	Anti-Listeria activity	-----	Dicks *et al*. 2004
	Salami from ostrich, beef, mutton	Lactobacillus plantarum 423		----	Dicks *et al*. 2004; Todorov *et al*. 2007
		Lactobacillus curvatus DF38		----	Todorov *et al*. 2007
Fermented Meat	Fermented pork sausage	Pediococcus pentosaceus BCC 3772	Anti-Listeria activity	No changes in sensory properties, as well as in consumer acceptability of the product	Kingcha *et al.* 2012
	Fermented pork sausage	Lactobacillus sakei C2	nti-Listeria and Anti-Enterobacteriacae activity,	Both the ratio of malondialdehyde and The nitrite content in the product was reduced	Gao *et al.* 2014
Raw Meat	Raw beef	Lactobacillus curvatus CWBI-B28	Anti-Listeria activity	--------	Dortu *et al.* 2008
Packed Meat	Vacuum-packed fresh beef	Lactobacillus curvatus CRL705	Anti-Listeria activity	-------	Castellano *et al.* 2010; Castellano and Vignolo *et al.* 2006

these pathogens. If these pathogens are not controlled, they cause significant economic losses in the livestock industry (Perez *et al*. 2014; Le *et al*. 2016).

Skincare

Scientific evidence suggests that certain probiotics help maintain the skin's lipid barrier and microflora, supporting skin immunity and homeostasis (Munir *et al*. 2025). In one study, a lotion containing ESL5, a bacteriocin from *Enterococcus faecalis* SL-5, significantly reduced pimples and inflammatory acne lesions caused by *Propionibacterium acnes* (Kang *et al*. 2009), suggesting their potential role in skin care products.

Plant growth promotion

Bacteriocins such as thuricin 17, bacthuricin F4, and bacteriocin C85 have been shown to enhance plant growth. When applied with their producing bacteria on tomato, soybean, and corn, they improved leaf area, increased photosynthesis rates by up to 6%, and raised plant dry weight by 15%. Additionally, root nodulation increased by 21% compared to control plants (Smith *et al*. 2008).

CONCLUSIONS

In the 21st century, the preparation of various food products requires knowledge and integration of multiple scientific fields, with the primary objective of ensuring food safety. Bacteriocins are associated with the control of harmful pathogens in the food and pharmaceutical industries, although further research is needed to fully understand their hidden roles in food safety. At present, consumers are paying greater attention to food safety, and to address their concerns, so industries are developing strong research-based models that ensure food safety. However, more research is needed to explore the use of bacteriocins in food and other industries.

AUTHOR CONTRIBUTIONS

Conceptualization and data collection were carried out by AW; manuscript drafting was performed by AbAR; review and editing were undertaken by MAQ. All authors read and approved the final version of the manuscript.

CONFLICT OF INTEREST

The authors affirm that they possess no conflicts of interest.

DATA AVAILABILITY

The data will be made available on a fair request to the corresponding author

ETHICS APPROVAL

Not applicable to this paper

FUNDING SOURCE

This project is not funded by any agency.

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www.tufsteam.com
Innovations in STEAM: Research & Education
ISSN (print): 3105-7071; ISSN (online): 3105-708X
Volume 3; Issue 1; Article No. 25030102
https://doi.org/10. 10.37723/ISRE/0022

REVIEW ARTICLE

A Review on Arsenic Toxicity Induced Keratosis and its Prevalence

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METADATA

Paper history
Received: 2 Jan 2025
Revised: 27 February 2025
Accepted: 25 April 2025
Published online: 12 June 2025

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Keywords
Arsenic
Keratosis
Hyperpigmentation
Precancerous
Lump

Citation
Noor Ul Ain, Kaleem H, Batool Z, Zafar A, Azmat K, Karamat R, Siddiqui H, Zobia S, Iqbal R, Younis M (2025) A review on arsenic toxicity induced keratosis and its prevalence. *Innovations in STEAM: Research & Education* 3: 25030102. https://doi.org/10.37723/ISRE/0022.

ABSTRACT

Background: Rapidly increasing discharge of arsenic (As) is a major health concern due to its cancer-causing effects. Excessive exposure of As causes the cancer of many organs including skin, liver, kidney, lungs. Precancerous skin condition due to the exposure of As is called As-keratosis, which is marked by hyperpigmentation and plaques and lump formation. The article focal point is the skin cancer which is the most concerning one.
Objective: The purpose of this review article is to synthesize an up-to-date knowledge of As induced keratosis including its prevalence, diagnosis, treatment.
Methodology: This review was conducted by using major database including Google Scholar and PubMed.
Review findings: Toxicity due to As is a global health related issue which affect people globally. As-keratosis is inveterate clinical or subclinical deadly harmful because of the presence of As metalloid in the body at higher level. A cross-sectional analysis was held to investigate the exposure of As is due to the number of reasons which includes contaminated water and sanitary landfills, etc. Diagnosis is based on the laboratory examination and histopathological examination. It is also diagnosed by the measuring the amount of As in blood, urine and hairs sample. Pathophysiology of the keratosis describe that the trivalent arsenide and methylation of As cause hyperpigmentation.
Conclusion: For the prevention of As keratosis make sure the usage of As treatment plant for the availability of As free water for drinking purposes. Options for the treatment purpose include the use of the oral and topical medications and surgical excision. For the management of As keratosis nanotechnology use to remove As from ground water.

INTRODUCTION

Contamination and the filthy pollutants caused due to Arsenic (As), which is a heavy metal is a universal considerable challenge, it becomes a major issue, a health hazard to humans who are being exposed to this heavy metal. As is known for its cancer-causing properties, called as King of poisons, which shows the acuteness of its toxicity (Li *et al*. 2025). As-keratosis is a precancerous causing skin cancer, pigmentation changes, and neurological changes by long-term chronic exposure to heavy metal. As is carcinogenic metalloid which is present in groundwater, soil, rock and air (Tao and Wang 2024). Due to high illiteracy rate and lack of knowledge among people living in such areas and being exposed through As poisoning and peak level of extremities of detrimental health related issues due to As by drinking such polluted water is ambiguous and inadequately evidenced, which carries a high risk of proceeding into cutaneous squamous cell carcinoma and can be represented with clinical and subclinical lesions (Ibrahim *et al*. 2006). Humans have had a very long, hysterical and chaotic relationship with heavy metals. Their prevalent nature and human's dependency on heavy metals for production, have outgrowth consequences that causes systemic toxicity. In spite of clinical knowledge and related experience more than a decade ago, toxicity and poisoning effects caused due to heavy metals have now become representative and most problematic point of interest and

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perverted outcome in clinical toxicology is potentially fatal and it is a notion that is mainly and primarily aided by studies and performing experiments on animals and collecting data. Due to restricted research and experiments performed on animals may escalate the rate of heavy metal excretion, their curative effectiveness regards to morbidity and mortality is large (Kosnett 2010).

This article scrutinizes the clinical exemplar and pathophysiology of As poisoning, a heavy metal. The term "arsenic" is a derivative word from the Latin, "*Arsenicum*" that usurp from a Syriac word "(al)zarniqa", which means "yellow orpiment". Antecedently, As is thought as a metalloid due to its dual properties such as they consider to possess metallic and non-metallic characteristics, for time bein in accordance to the reference book of toxicology, As accounts as a toxic metal, which is translucent, odorless, and tasteless (Hall, 2002; Rajiv *et al.* 2023). As metal possess two compounds having chemical-valences of three and five. The chemical compound of As (As_2O_3), which possess tri-valent property, has high level of toxicity than the compound which is penta-valent. As is metabolized by the liver and excreted mainly through the kidneys about 90–95% (Sy, Salud-Gnilo *et al.* 2017). The purpose of this review article was to synthesize an up-to-date knowledge of As induced keratosis including its prevalence, diagnosis, treatment and prevention.

HEAVY METAL EXPOSURE

Exposure due to heavy metal and their core root are natural sources and industrial as well as medicinal. It can invade in humans through absorption, nasal route, and ingestion. As contamination due to natural source involves soil, water, rocks, of which the most common is by drinking tap water comes from underground sources (Lee 2017; Demissie *et al.* 2023). Peak level of As metal stratum was noticed and then reported in deep aquifers. As can endow in industry for manufacturing pesticides, dyes, HED, and semiconductors. It is suggested that the surplus As amount in cosmetic product's preparation should be within the specified limit and must be less than 5 ppm (Tao and Wang 2024). Research have proclaimed that As is present in color pigments used as a cosmetic product in eye-shadows, leads to dermatitis of eyelid and even promote cancers of skin on its long-term use. As metal is broadly classified as and used in striated medicinal preparations as an ingredient of many natural preparations, by use of herbs and allopathic formulations, in various diseases treatment such as asthma, psoriasis, eczema, and Hodgkin's disease, leprosy, squamous cell carcinoma, followed by long-term administration of conventional medicinal therapy which contains As metal for chronic psoriasis (Rajiv *et al.* 2023).

KERATOSIS CAUSED BY ARSENIC

Keratosis due to heavy metal As is a pre-malignant and venomous plague in human beings that shows chronic exposure due to As has become an outgrowth effect. Toxicity of As is the most acute and primitive biomarker (Ganie *et al.* 2024). Lesions erupt as firm, punctate, symmetric papules corn-like in appearance fuse to form scaly, hyper pigmented, warts on skin (Huang *et al.* 2019; Table 1). They are on areas of body which prone to produce friction like soles of feet and palm of hands, moreover they can be enact on the dorsum of extremities, genitalia, eyelids. There is no specific grading level and severity classification for toxicity induced by As metal (Pratt *et al.* 2016). It can be acute, sub-acute and chronic. Severity of As poisoning depends upon the various elements, whichincludes the type and grade of As compound, state of valence chemical compounds, toxic dose, rate of exposure of heavy metal, duration of exposure and underlying disease illness (Çöl *et al.* 1999).

PATHOPHYSIOLOGY

After exposure to As, it absorbs in the body and goes to different organs. During transit from blood to tissues, it metabolizes into reactive trivalent arsenite. Trivalent arsenite have ability to bind to sulphahydral group present in keratin filament, skin, hair, nails (Sarma, 2015). After binding to sulphahydral group of proteins, it activates transcription factors, alters the level of growth factors and cytokeratin's. Due to alteration of cytokeratin's and p53, As affect differentiation and proliferation of keratinocytes, which are the cells of epidermis (Rossman *et al.* 2004). In the cells demand of energy, DNA damage and mutation of mitochondria due to As exposure cause differentiation of epidermal keratinocytes. As up-regulates interleukin 1 & 2, beta factors and keratin. Abnormal proliferation of keratinocytes starts to form, and lesions develop in skin, which may coalesce to form hyper pigmented plaques (Palma-Lara *et al.* 2020). Keratosis mostly occur in areas prone to friction and trauma such as palm of hands and soles of feet. Lesions may develop squamous cell carcinoma (Fig. 1). Abnormal differentiation of keratinocytes, apoptosis and aberrant inflammation cause carcinogenesis. In liver As is methylated into mono-methyl arsenic acid and it is further reduced to mono-methylarsonous acid (Paul *et al.* 2015). Methylation increases the oxidative stress, this stress cause DNA repair, altered chromosomal abnormalities i.e. sister chromatid changes and gene expression. As acts on P53 compromised cells to cause chromosomal abnormality this cause carcinogenesis of skin (Tao and Wang 2024).

PREVALENCE

The prevalence rates of As keratosis across the world and countries of South-Asia such as Pakistan, India, Bangladesh, narrative for the highly polluted domain of the world due to As prevalence. Inorganic As has demonstrated gene amplification, a major potential finding, since gene

Table 1: Level of grading of As-keratosis according to papule size

Severity	Papule sizes	Characteristics
Grade-1; Mild level	<2 millimeter	Thickened and gritty papules, apparent
Grade-II; Moderate level	2–5 millimeter	Papules corn-like in appearance, apparent
Grade-III; Severe level	>5 millimeter	Warts or papules with fissures

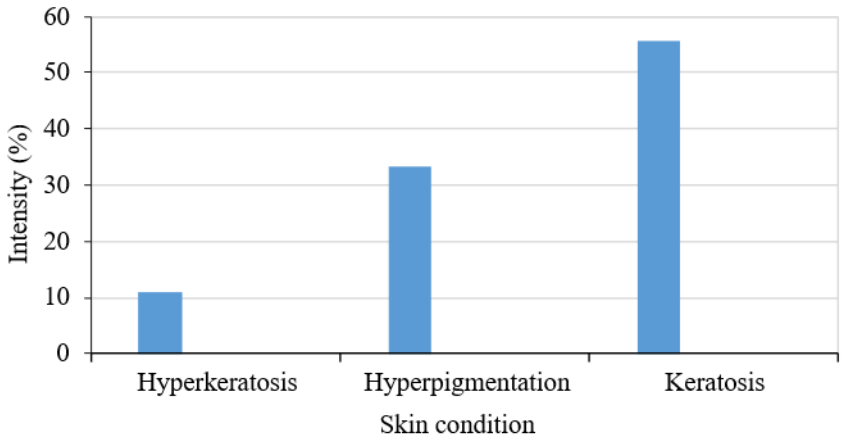


Fig. 1: Prevalence of keratosis in comparison to hyperkeratosis and hyperpigmentation

amplification of oncogenes has been seen in number of human tumors with epidemiologic work (Rajiv *et al.* 2023). Heavy metal poisoning is interlinked with a number of occupations. It is directly linked by drinking contaminated tap water, washing in ground water without any use of filters and potential soil exposure. A major concern is that the safe disposal of waste of heavy metals include As, lead, copper, etc. The concentration of these heavy metals is higher than the prescribed limit as set by the United States Food and Drug Administration and World Health Organization (Somé *et al.* 2012).

To guarantee compliance with regulatory limits, quality control measures should be implemented to monitor metal concentrations. Of the 116 residents surveyed, 81 had clinically diagnosed As keratosis and pigmentation changes. Among them were 52 males and 29 females in the age ranging between 4–82 years (Lonergan *et al.* 2010). Two cases of squamous cell carcinoma were detected through skin biopsy in situ. High grades of As in the groundwater and topsoil aided the prevalence of chronic As poisoning. A revelatory quota of groundwater in Pakistan is contaminated with As noticed. As contaminated wells were found around Indus River, suggest that poisoning is due to heavy metal. The very first noticed and reported epidemiological case of experimental data based on clinical evidence of As metal causing lesions on skin's surface and into deep tissues carried out alongside Indus River (Chakrabarty 2015). A case in point with cluster of multi stage survey was conducted and documented among people (3874) ≥ age of 15 years, is to conclude the prevalence of arsenicosis, based on its relation with increasing level of drinking contaminated groundwater in urban as well as in rural areas (population ratio: 1.8 million of people) in Pakistan due to lack of awareness programs. Pakistan has low levels of As metal exposure in tap water compared with India, Philippines, Bangladesh and China. A large population in West of Bengal, India and Uttar Pradesh, susceptible to inorganic As through their drinking contaminated water (Singh *et al.* 2007). A survey was conducted involving 7683 study population of all ages in an affected As territory, noticed skin keratosis, pulmonary effects and pigmentation alterations between April 1995 and March 1996. Recently, disease prevalence odd-ratio estimates evidently raised the sample population who take part in clinical experimental studies and have had high grades of As in their sources of drinking contaminated water (≥500 mcg/L) as compared with such individuals who had normal skin appearance and exposed to low levels of As (<50 mcg/L) (Table 1). Such territories are exaggerated due to the As-rich sediments grounds in the Gangetic River of Brahmaputra (Ganga-Jumna) sink, which flows orderly millions of years ago (Rahman and Hasegawa 2011; Järup 2003).

DIAGNOSIS

Skin signs are specific for diagnosis. Reports show that chronic As toxicity affects various bodily systems. Clinical evidence of chronic As poisoning depends on the dose, exposure duration, and host vulnerability (Das and Sengupta 2009). It is difficult to diagnose since its symptoms resemble those of common ailments. As the blood exits quickly, thus diagnosing long-term exposure necessitates hair or nail testing, which are not always available. Because trace levels present in food and water, even a positive test

can be difficult to interpret. Many people are unaware they have been exposed until major health conditions, such as nerve damage or cancer, arise years later, making diagnosis even more difficult. Concentration of As in the urine used as an indicator for the exposure of As (Fatmi *et al.* 2013). Route for the elimination of As from the body is urine. As concentration in urine has been shown to compare with presence of As in tap water (groundwater) concentration. As concentration present in seafood also affect As measurement in urine.

Organic As have no toxicity on mammals. If the seafood has been taken from last 2 days then it affects the laboratory As measures that's why laboratories only measure inorganic As or its metabolites. Urine sample should be collected over 24 h time period. More presence indicates the maximum exposure of As. Typically, human hair and nails contain higher levels of As than other body parts due to keratin content. Levels of As metal in hair give important point of interest which gives meaningful information about chronic poisoning induced by As exposure to skin (Singh *et al.* 2007). There is only a very rough correlation among As concentration in hairs and As toxicity, which presents a number of challenges for the toxicologist utilizing this test. Thus, hair concentrations in patients with chronic As poisoning can range from 10 parts per million deaths linked to As have been documented to have levels of about 45 ppm. Chances of variation of hairs from inside and outer-side due to As content could be significant, which makes results of a single hair less accurate than from larger hair samples. Therefore, samples should be taken from multiple locations on the head, containing only one gram of hair clipped near the area of scalp, the entire sample should be examined (Son *et al.* 2008; de Luzuriaga *et al.* 2011). To evaluate toxicity using hair As concentrations, contamination outside of the hair should be eliminated.

The majority of inorganic and organic As in human blood is removed quite quickly. As in blood will only reflect exposure for a brief period, making it highly time dependent. Continuous and consistent exposure, such as drinking water, can lead to steady state As levels in the blood, allowing for a correlation between As exposure and As blood levels (Vahter 2008; Ali *et al.* 2013). However, there is no quantitative evidence linking As exposure to blood As concentrations in humans. The half-life of As in the body in comparison to its half-life in the blood makes it challenging to determine the link between body As concentrations and total concentration of As in blood and organs. The pigmentary and keratotic alterations observed in arsenicosis can be mimicked by a variety of disorders (Khan *et al.* 2015). The study of pathology Hyperkeratosis, parakeratosis, acanthosis, and papillomatosis are epidermal alterations associated with As keratosis (Fig. 1). Basal pigmentation and dysplastic alterations are also infrequently observed. Both benign and malignant forms of arsenical hyperkeratosis are distinguished by the presence or lack of cellular atypia. There are no distinct histological characteristics that distinguish As-induced cutaneous cancers from their non-As-induced counterparts. Diagnostics in laboratories, the primary method of determining the environmental burden is to test the amounts (Ahamed *et al.* 2006; Ghosh 2013).

TREATMENT APPROACH

In China, As poisoning was commonly treated using As removal agents i.e. sodium thiosulphate and Dimercaptopropyl sulfonate. Concentration of As in blood and urine were reduced after these drugs were given to 18 (43.90%) patients who were cancer free and 6 (14.6%) patients who were cancerous (Camaclang *et al.* 2019). Two patients received sodium thiosulphate noticed a drop in blood As levels, whereas 4 patients received dimercaptopropyl sulfonate saw their levels return to normal. Following treatment with dimercaptopropyl sulfonate, two cancer patients had higher urine As levels (Balali-Mood *et al.* 2025; Islam *et al.* 2025).

Leaves of Drumstick tree (*Moringa oleifera*) and leaves of spinach (*Ipomea aquatica*) and the raised parts of them, had increased effects in the toxicity due to As. *Silybum marianum*, Garlic (*Allium sativum*), Turmeric (*Curcuma longa*), and some algae along with fibers was the most beneficial herbs for the intoxication treatment due to As. Chelating agents work by attaching themselves to the metal ion, making it more soluble in water and facilitate quicker kidney elimination. As a result, it lowers the body's total As load and lowers the risk of cancer (Verma *et al.* 2025; Zahra *et al.* 2025). The clearance of skin lesions is accelerated by keratolytic treatment like 20% of urea and 6–10% of salicylic acid in combination with agents which forms chelates and complex compound formulation. Retinoid have anti-keratinizing properties, their therapy has been utilized to treat As keratosis. By influencing the gene expression, which may impact cell distinction, proliferation, multiplication and induction of apoptosis, they also aid in the chemo-prevention of malignancies linked to As (Ullah *et al.* 2024). Drinking contaminated groundwater tanned with As, people who take a high calorie, antioxidants rich meals had lessened effects of As toxicity (Das and Sengupta 2009). Numerous studies have demonstrated that polyphenols, black tea and leaves of green tea, Vitamin A (Retinol), Vitamin C (Ascorbic acid), Vitamin E (Tocopherol) all reduced the effects of As toxicity. After six weeks of topical treatment with 5% imiquimod cream once daily, the neoplasms completely resolved clinically and didn't reappear throughout more than three years of clinical observation. In order to identify and eradicate cancer cell, it activates immune cells like T-cells and dendritic cells (Tang *et al.* 2023).

PREVENTION STRATEGIES

Prevention is the core step in lowering chronic As toxicity. The best way is the prevention rather to cure. The health

impacts and prevention of As have been the attention of many nations. Acknowledge the severity of the arsenicosis epidemic, which affects a sizable portion of the global population and for which there is currently no cure (Rajiv *et al.* 2023). Increased prevention measures are of importance to us because to the substantial impact on the population at risk as well as the additional conditions linked to ongoing drinking water exposure to As. Filtration is the most used clean up method (Hye 2018). SONO filters, iron filters, membrane filters and nanoparticle filters are the common techniques used to remove the As from water. Different filters work better at different water pH level. It is important to understand that As cannot be removed by boiling the water (Tao and Wang 2024). It offers a promising solution for removing As from water and soil. It is the natural and cheap way to remove As. Plants can remove As regardless of water pH, it clears the contaminated area of As. In reality, these plants are hyper accumulating (Hassan 2018). It doesn't eliminate contaminations from polluted areas instead, it reduces the contaminated mobility, As which prevents plants from absorbing it. As can be absorbed by certain hyper accumulating plants, which then move it to their aerial parts and release it into the atmosphere as arsine (Saha 2003). This should not be attempted form an environmental perspective. Using plant metabolism, this is a combination of phytodegradation and phytostabilization. As is absorbed by hyper accumulating plants in watery environments (Shajil *et al.* 2024).

CONCLUSION

As keratosis can cause variable incorporations. Its prevalent nature and their huge presence globally, makes it a difficult chore to prevent these aspects of poisoning. The outcome of this experimental study and limited research on keratosis revealed that the contemporary prevalence of skin lesions caused by As in the community was 2.21%. Moreover, beside the cases of arsenicosis, the primarily clinical manifestation was keratosis, which is then followed by hyperpigmentation and then comes the hyperkeratosis, were observed. There must be checkpoints to evaluate the As exposure and related poisoning in between the population in the area under-study by using body biomarkers. A global epidemic, global agencies i.e. World Health Organizations and the UNEP (United Nations Environment Program) can help the communities by encouraging hyperawareness, and the surroundings global etiquette for acceptable limits of As exposure in periodic history. People who are affected by these heavy metals and have had previously developed history of keratosis should must pay attention to decrease improbability of malignant modification and they must hold identical preventive steps. Lesions are cancerous in nature and these cancerous cells may invade into other body tissues and can also cause damage to them, so they should be closely monitored, and surgical treatment strategies should be followed and implemented to affected individuals.

AUTHOR CONTRIBUTIONS

NUA: Topic decision in publication, Journal approach, publication process, data defining, writing and data collection; HK: Introduction to Arsenic, Heavy metal poisoning, Prevalence; ZB Intervention traditional and modern strategies; AZ: Abstract and diagnosis; KA: Introduction to arsenic keratosis and conclusion; RK Pathophysiology; HS: Diagnosis; ZS: Pathophysiology; RI: Intervention traditional and modern strategies; MY: Introduction to arsenic keratosis and conclusion, data collection and in writing.

CONFLICTS OF INTEREST

No conflict of interest among the authors to declare

DATA AVAILABILITY

Not applicable to this paper

ETHICS APPROVAL

Not applicable to this paper.

FUNDING SOURCE

Not applicable to this paper.

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www.tufsteam.com
Innovations in STEAM: Research & Education
ISSN (print): 3105-7071; ISSN (online): 3105-708X
Volume 3; Issue 1; Article No. 25030103
https://doi.org/10.63793/ISRE/0023

REVIEW ARTICLE

Status of Women in Islamic Society and Light of the Prophetic Sunnah

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METADATA

Paper history
Received: 31 December 2024
Revised: 30 January 2025
Accepted: 25 April 2025
Published: 07 May 2025

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Keywords
Women rights
Islamic Principles
Social practices
Gender differences

Citation
Minhas T (2025) Status of women in Islamic society and light of the prophetic sunnah. *Innovations in STEAM: Research & Education* 3: 25030103. https://doi.org/10.63793/ISRE/0023

ABSTRACT

Background: The Hadith and Sunnah of Prophet Muhammad play a crucial role in Islamic theology, jurisprudence, and daily life. While the Quran is the primary source of Gods direction, the Sunnah complements and contextualizes it, providing practical applications and thorough explanations.
Objective: This study review investigates the varied roles of Hadith and Sunnah in developing the Islamic way of life, including legal, ethical, social, and spiritual dimensions. The article emphasizes the Prophet Muhammad ﷺ legislative authority, the Sunnah's role in understanding the Quran, and its impact on the development of Islamic principles. This assessment was supported by Quranic verses and authentic Hadith references and underlines how ancient and contemporary Islamic research maintains the interdependence of the Quran and Sunnah.
Methodology: The information and concepts included in this article were gathered from the Holy Quran, the Sayings of the Prophet, Islamic literature books, and literature available in different online sources.
Results: A critical assessment of Quranic and Hadith texts demonstrates that, while there are potential interpretations that favour gender equality, social and religious practices, but not completely represent these egalitarian principles.
Conclusion: This research confirms that ignoring the Prophetic legacy results in a fragmented perception of Islam, whereas devotion to the Prophet's Sunnah assures a complete and authentic Islamic identity. This study emphasizes that education and inclusive interpretations of sacred texts are key to overcoming patriarchal norms. These findings emphasize that increasing gender equality in Muslim communities necessitates both structural adjustments to social and religious practices as well as changes in how religious texts are interpreted.

INTRODUCTION

Societies, in one sense, are moving fast towards development and modernity, yet on the other hand, incidents that are proof of the downfall of human values and civilizations are taking place regularly. The Prophet ﷺ put special focus on the best treatment of the weak, and himself treated women with compassion, and put a lot of focus on good manners, kindness, and goodness towards women (Bano *et al*. 2025). Islam has determined the equality of men and women in areas where equality can be attained, and to what extent equality can be established. But Islam does not have faith in equality against the law of nature. As a human, women are equal to men in rights. But since the husband is active, the man possesses the personal virtue (not honor but mastery) which Allah has granted to the man with complete justice "الرِّجَالُ قَوَّامُونَ عَلَى النِّسَاءِ" (Al-Baqarah, 228) "*Men are the protectors and maintainers of women*". This is a natural difference between men and women, accepted by the family system according to the laws of organization. The position of women in the time of the Prophet ﷺ can be observed by the position accorded to Hazrat Khadija, who was an exemplary figure, as were Fatima, daughter of the Prophet of Islam, and Ayesha, his second wife (Erwani and Siregar 2025). These were intellectual women who were politically involved and who had a very significant role to play in the propagation of Islam. Not like passive onlookers, women were instead active participants in studying, teaching, relating Hadith, and aiding in the promotion of Islam. Leading personalities like Hazrat Khadijah (RA), Hazrat Ayesha (RA), and Hazrat Umm Salama (RA) played a key role in constructing the early Islamic. Their houses

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turned into schools, and their narrations and legal views became standards for generations. Female personalities like Hazrat Fatimah (RA), Hazrat Safiyyah (RA), and Hazrat Umm Ammarah (RA) integrated spiritual devotion with social activism and even war activities. Women companions made contributions to studies, medicine, memorization of the Quran, and calligraphy, highlighting Islam's support of women's intellectual development (Azam and Afzal 2025). Islam is an ideal religion that has directed mankind in all aspects, including social, educational, moral, and religious.

The teachings of Islam have placed not only men but also women. The Sunnah of the Prophet ﷺ gives us knowledge, understanding, awareness, and honor. If we study the Seerah of the Prophet taht raelc semoceb ti ,ﷺ during the Prophet's era, women were not merely confined to domestic life; rather, they stood shoulder-to-shoulder with men in religious and educational fields. This article delves into the important religious, educational, and social functions that Muslim women held in Prophetic times and their important contributions to Seerah al-Nabi.

THE PLACE OF WOMEN IN SOCIETY

Women make up half of the human population, and their contribution is fundamental to the moral, social, and economic health of any community. When women are valued, respected, and allowed to develop their abilities, society flourishes. When they are ignored or treated unjustly, the entire social structure suffers. History is filled with examples. Nations rise when justice, compassion, and equality prevail, and they fall when oppression and ignorance dominate (Anyango *et al*. 2025). In every successful society, each person, whether man or woman, understands their rights and duties and lives free from cruelty or tyranny. This principle is not a modern discovery; it is a truth that Allah's guidance has been established since the beginning of humankind. The place of women in Islam differs among Muslim nations, which differently perceive the Islamic religion and law, particularly in their perception of women's rights. The majority of these Islamic nations have certain conceptions regarding women and have prohibitions related to them.

Gender stereotypes of women in Islam trace their roots in the development of the Muslim religion (Sechzer *et al*. 2024). But it cannot be said that the Muslim woman's role is only in her home and family. It is a natural component of the employment of her inborn talents and an expression of female nature. Muslim women can establish their businesses or engage in the social and political life of society, work for the Muslim ummah (community) in various areas like medicine, education, fashion, and cooking. The wife of the Prophet Muhammad ﷺ ran a successful business and provided the Prophet with reliable material and spiritual support during the most difficult times to help him achieve his goal. Therefore, Islam does not make a woman stay at home or be discriminated against, but instead equates her daily work at home and childcare with a hard and responsible occupation, which is superior to an expensive male job. A lot of emphasis is laid upon the education and training of other people. Perhaps education is more of a duty than a privilege. The initial responsibility of a woman in the household, as quoted earlier, is to raise a good child. It is a known fact that children pick up good habits at a young age. This was best expressed by our ancestors in the following words: "A tree bends when it is young". It is necessary that the woman who brings up the children is devout and educated. Husbands are likely to love educated, godly, and virtuous women. Indeed, during the heyday of Islam, the Ambassador of God strongly advised women to learn to read and write, as well as to know what they needed in everyday life: "*Learn from the cradle to the grave and seek knowledge! If you must travel to China, seek knowledge! Seeking knowledge is the responsibility of all Muslims women and men*" (Surah An-Nisa; Ayah 51). In Islam, it is a firmly established truth that a woman, according to Islamic law, possesses the same soul and human value as a man. The religion recognizes the natural role of women, especially as the foundation of family life through motherhood. A mother has the power to nurture and build a strong society or to weaken it, for the future of any community depends largely on the upbringing she gives her children. She stands as one of the key pillars of society, shaping its values and directions. A woman's deepest sense of fulfillment often begins with the blessings of motherhood. The Prophet Muhammad ﷺ greatly honored mothers, saying, "Paradise lies at the feet of your mothers," highlighting their immense status and importance as mothers.

ISLAM'S REVOLUTIONARY APPROACH TO WOMEN'S RIGHTS

Before the coming of Islam, women in many cultures were denied even the most basic human rights. In some societies, daughters were considered a burden, leading to cruel practices such as burying newborn girls alive. Islam ended these injustices and replaced them with mercy, respect, and fairness.

وَإِذَا بُشِّرَ أَحَدُهُم بِٱلْأُنثَىٰ ظَلَّ وَجْهُهُۥ مُسْوَدًّا وَهُوَ كَظِيمٌ ۝ يَتَوَارَىٰ مِنَ ٱلْقَوْمِ مِن سُوٓءِ مَا بُشِّرَ بِهِۦٓ أَيُمْسِكُهُۥ عَلَىٰ هُونٍ أَمْ يَدُسُّهُۥ فِى ٱلتُّرَابِ أَلَا سَآءَ مَا يَحْكُمُونَ

(Surah An-Nahl; Ayahs 58–59)

"*And when one of them is informed of the birth of a female, his face becomes dark, and he suppresses grief. He hides himself from the people because of the ill of which he has been informed. Should he keep it in humiliation or bury it in the ground? Unquestionably, evil is what they decide*."

Marriage is one of the oldest social institutions in all known forms of history. For Islam, marriage is neither an intellectual and spiritual concept nor a secret; marriage is a social contract that assigns certain rights and responsibilities upon men and women:

وَأَنكِحُوا ٱلۡأَيَـٰمَىٰ مِنكُمۡ وَٱلصَّـٰلِحِينَ مِنۡ عِبَادِكُمۡ وَإِمَآئِكُمۡۚ إِن يَكُونُواْ فُقَرَآءَ يُغۡنِهِمُ ٱللَّهُ مِن فَضۡلِهِۦۗ وَٱللَّهُ وَٰسِعٌ عَلِيمٞ

"*Marry off the singles among you and the righteous among your male and female servants. If they are poor, Allah will enrich them from His bounty. And Allah is All Encompassing, All Knowing.*"

Marriage is a social obligation from society's perspective, designed for the preservation of human life, and for the individual, it is an exercise of compassion between a man and a woman:

وَمِنۡ ءَايَـٰتِهِۦٓ أَنۡ خَلَقَ لَكُم مِّنۡ أَنفُسِكُمۡ أَزۡوَٰجٗا لِّتَسۡكُنُوٓاْ إِلَيۡهَا وَجَعَلَ بَيۡنَكُم مَّوَدَّةٗ وَرَحۡمَةً

"*And of His signs is that He created for you from yourselves mates that you may find tranquility in them, and He placed between you affection and mercy*."

The Quran provides a beautiful picture of the natural affinity between a man and a woman:

هُنَّ لِبَاسٞ لَّكُمۡ وَأَنتُمۡ لِبَاسٞ لَّهُنَّ

"*Your wives are a garment for you, and you are a garment for them*."

Marriage has been described as a source of love, compassion, and understanding by the Quran. In particular, men are encouraged to treat their wives with care and kindness, as stated in the words of the Prophet Muhammad ﷺ. They each .ehT selpuoc sdnimer naruQ nemow dna nem taht eed each other. To a man: a woman is part of your very being, without whom you cannot live. To a woman: you were created from a man, who is your origin, and you cannot live without him. The Quran also emphasizes that normal family relationships involve agreement between husband and wife. While they are two distinct halves, they are united in essence, body, and soul. As per Islamic law, a married woman cannot be treated as a servant in her husband's home, and likewise, her husband is not her employer.

Marriage is a special area of human relations with certain characteristics concerning the rights and responsibilities of the couple, in which the husband holds the position of the head of the household, while the wife is a helper and advisor. However, a Muslim woman must attend to the needs and well-being of her family members, show love, and perform household work with sincerity. A wife should not hesitate to fulfill her household responsibilities, assist her husband, and bring happiness to him. For a Muslim woman, her home and family are the joy and fulfillment of her life. She is entrusted with the household, manages it as her own, and strives to maintain it in the best way she can.

In all the verses of the Holy Quran that command obedience to parents, the mother comes first by being mentioned first. A Hadith is reported that one day a man came to the Prophet ﷺ and inquired, "Which of the people is to be respected and heard more than anyone else?" *The Prophet answered, "Your mother!" The man repeated his question, "Who comes after her?" The Prophet replied, "Your mother!" The man repeated his question once again, "Who comes after her?" For the third time, the Prophet replied, "Your mother!" The man repeated his question one more time, "Who comes after her?" The Prophet replied, "Your father!"* (Sahih al-Bukhari; Book of Manners, Hadith 5971).

This Hadith clearly states that a mother is three times more likely to educate a child than a father is. In Islam, a woman holds a central role in the upbringing and development of a child. She is responsible for guiding the child's moral, spiritual, and intellectual growth from an early age. The values, habits, and knowledge that a child acquires at home largely depend on the mother's influence. This emphasis highlights the importance Islam places on women as nurturers, educators, and moral guides in the formation of generations to come. In an Islamic family, a woman is mainly addressed as the rightful wife of her husband and the administrator of the household.

EQUALITY AND HONOR

Islam teaches that men and women come from the same origin and are equal in their humanity. Neither gender is superior simply by birth. True honor lies in piety and righteousness.

يَٰٓأَيُّهَا ٱلنَّاسُ إِنَّا خَلَقۡنَٰكُم مِّن ذَكَرٖ وَأُنثَىٰ وَجَعَلۡنَٰكُمۡ شُعُوبٗا وَقَبَآئِلَ لِتَعَارَفُوٓاْۚ إِنَّ أَكۡرَمَكُمۡ عِندَ ٱللَّهِ أَتۡقَىٰكُمۡۚ إِنَّ ٱللَّهَ عَلِيمٌ خَبِيرٞ

"*O mankind, indeed We have created you from male and female and made you peoples and tribes that you may know one another. Indeed, the most noble of you in the sight of Allah is the most righteous of you. Indeed, Allah is Knowing and Acquainted*."

Islam promises equal spiritual rewards and responsibilities to men and women. Good deeds are valued regardless of gender, and sins are judged by the same standard for everyone.

مَنۡ عَمِلَ صَٰلِحٗا مِّن ذَكَرٍ أَوۡ أُنثَىٰ وَهُوَ مُؤۡمِنٞ فَلَنُحۡيِيَنَّهُۥ حَيَوٰةٗ طَيِّبَةٗۖ وَلَنَجۡزِيَنَّهُمۡ أَجۡرَهُم بِأَحۡسَنِ مَا كَانُواْ يَعۡمَلُونَ

"*Whoever does righteousness, whether male or female, while they are a believer, We will surely cause them to live a good life, and We will surely give them their reward according to the best of what they used to do*."

Islamic society is based on cooperation between men and women in building a life based on justice and obedience to Allah.

وَٱلۡمُؤۡمِنُونَ وَٱلۡمُؤۡمِنَٰتُ بَعۡضُهُمۡ أَوۡلِيَآءُ بَعۡضٖۚ يَأۡمُرُونَ بِٱلۡمَعۡرُوفِ وَيَنۡهَوۡنَ عَنِ ٱلۡمُنكَرِ وَيُقِيمُونَ ٱلصَّلَوٰةَ وَيُؤۡتُونَ ٱلزَّكَوٰةَ وَيُطِيعُونَ ٱللَّهَ وَرَسُولَهُۥٓۚ أُوْلَٰٓئِكَ سَيَرۡحَمُهُمُ ٱللَّهُۗ إِنَّ ٱللَّهَ عَزِيزٌ حَكِيمٞ

"*The believing men and believing women are allies of one another. They enjoin what is right and forbid what is wrong and establish prayer and give zakah and obey Allah and His Messenger. Allah will have mercy upon them. Indeed, Allah is Exalted in Might and Wise*."

It is narrated that the Messenger of Allah :dias ﷺ

عَنْ أَبِي هُرَيْرَةَ رضي الله عنه قَالَ: قَالَ رَسُولُ اللَّهِ ﷺ: "اسْتَوْصُوا بِالنِّسَاءِ خَيْرًا"

(رواه البخاري (5186) ومسلم 1468

"I advise you to be kind to women."

Abu Hurairah (RA) reported that the Prophet ﷺ said:
عَنْ أَبِي هُرَيْرَةَ رضي الله عنه، عَنِ النَّبِيِّ ﷺ قَالَ: "أَكْمَلُ الْمُؤْمِنِينَ إِيمَانًا أَحْسَنُهُمْ خُلُقًا، وَخِيَارُكُمْ خِيَارُكُمْ لِنِسَائِهِمْ"
رواه الترمذي (حديث 1162) وقال: حديث حسن صحيح
"*The most complete of the believers in faith are those with the best character, and the best of you are the best to their women*".

THE PROPHET'S EXAMPLE IN VALUING WOMEN

The determinants of women's empowerment are numerous, including both the material and psychological dimensions of rights, power, and perception. The expression "women's empowerment" blends between women's perception of themselves as worthy persons, management of their options, their rights to benefit from the use of resources, and the power to control their lives. The corpus of Islamic doctrines, perhaps, has numerous pillars of women's empowerment that may be accessed by investigating the parts of the Prophet Muhammad's ﷺ biography. The Islamic importance of empowering women may be exemplified by studying his vision on the topic of women's rights. Moreover, the Prophet's vision for women's empowerment can be best understood by focusing on the status of the nearest women members of his own family. Amongst the female relatives of Prophet Muhammad ﷺ with whom he had a chance to repeatedly interact for a significant amount of time were his wives and daughter. Prophet Muhammad ﷺ was a model of compassion, respect, and fairness in his treatment of women, both in his family life and within the wider community.

In his own home, he shared household duties, mending his clothes and helping with chores. With his wives, he showed deep affection and care as he would speak kindly, listen attentively, and engage in moments of joy such as racing playfully with Ayesha (RA) or drinking from the same spot on a cup she had used. He upheld the dignity of women by safeguarding their rights to property, inheritance, and education. He strongly condemned any form of oppression, declaring that the best man is the one who is best to his wife. His love for Khadijah (RA) endured even after her passing, as he would often speak of her virtues and maintain ties with her friends. Towards mothers, he placed extraordinary honor, repeating three times that a mother is most deserving of her children's good companionship before mentioning the father. In public matters, he listened to women's voices seriously, addressing their concerns and granting them authority in decision-making. In every role as husband, father, leader, and teacher, he embodied mercy and fairness, setting a timeless example for how women should be valued and treated with respect.

The Prophet Muhammad ﷺ was a living example of how Islam elevates women.

مَن عَالَ جَارِيَتَيْنِ حَتَّى تَبْلُغَا جَاءَ يَوْمَ القِيَامَةِ أَنَا وَهُوَ وَضَمَّ أَصَابِعَهُ
"*Whoever raises two daughters until they mature, he and I will come on the Day of Resurrection like this, and he joined his fingers together*."

Islam's measure of worth is not gender, wealth, or status. It is contribution and sincerity. A woman may surpass many men in her service to her family, society, and humanity, just as a man may surpass many women.

CONCLUSIONS

From all the above, a Muslim woman is not merely the most active member of socio-political life, but also a supporter of a man, a necessary assistant in the family, and a prudent adviser. Women in Islam performed many duties, including the propagation of Islam. Thus, in Islam, the principle of femininity (mother, wife, sister, daughter) is honoured. The life of Prophet Muhammad ﷺ stands as a timeless example of dignity, respect, and empowerment for women. At a time when women were denied basic human value, he ended practices like female infanticide, restored their right to inherit, and recognized their voice in public matters.

DATA AVAILABILITY

The data will be made available on a fair request to the corresponding author.

ETHICS APPROVAL

Not applicable.

FUNDING SOURCE

No specific funding was acquired for this work.

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www.tufsteam.com
Innovations in STEAM: Research & Education
ISSN (print): 3105-7071; ISSN (online): 3105-708X
Volume 3; Issue 1; Article No. 25030104
https://doi.org/10.63793/ISRE/0024

RESEARCH ARTICLE

Artificial Intelligence Adoption in Malaysian SMEs: When to Optimize and When to Transform Business Models?

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METADATA

Paper history
Received: 10 February 2025
Revised: 20 March 2025
Accepted: 12 May 2025
Published online: 25 May 2025

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Keywords
Gut microbiota
Probiotics
Fecal microbiota
Transplant

Citation
Indiran L, Kohar UHA (2025) Artificial intelligence adoption in Malaysian SMEs: when to optimize and when to transform business models?. *Innovations in STEAM: Research & Education* 3: 25030104. https://doi.org/10.63793/ISRE/0024

ABSTRACT

Background: Artificial Intelligence (AI) has become an essential driver of innovation, operational efficiency, and competitive advantage in business settings. Despite national efforts to promote digitalisation, its adoption among small and medium-sized enterprises (SMEs) in Malaysia remains limited and inconsistent. One of the core challenges lies in deciding whether to deploy AI for optimising existing processes or to leverage it for broader transformation in business models and value delivery.
Objective: To examine how Malaysian SMEs make strategic choices between process optimisation and business transformation in adopting digital technologies.
Methodology: A qualitative methodology involving ten in-depth interviews was conducted with owners and managers from four key sectors: retail, education and skills training, home-based food services, and personal health services.
Results: The findings show that AI is primarily used for operational convenience, such as automating scheduling, responding to customer queries, and content generation. These decisions were often shaped by peer influence, affordability, and perceived usefulness, rather than formal planning or strategic foresight. Notably, businesses in the education sector displayed greater willingness to explore AI for service innovation and personalised learning delivery, reflecting a higher degree of digital openness. Sectoral differences, owner mindsets, and contextual readiness significantly shaped AI adoption patterns.
Conclusion: The study concludes that while AI optimisation remains the dominant approach among Malaysian SMEs, there is a growing awareness and readiness for transformation, underscoring the need for policy frameworks and digital support systems that are contextually responsive and practically aligned with SME realities.

INTRODUCTION

Artificial Intelligence (AI) is increasingly becoming a central feature in the digital transformation journey of businesses around the world. From large corporations to emerging enterprises, the ability to harness AI has been linked to improved operational efficiency, enhanced customer engagement, and the discovery of new business models (Denic *et al*. 2024). However, the application of AI is not simply about acquiring new technology; it involves making informed strategic decisions that align with an organisation's long-term goals, capabilities, and market context. Globally, SMEs are often seen as crucial drivers of innovation and employment. Yet, many of them face substantial challenges when it comes to adopting emerging technologies such as AI. These include limited access to capital, insufficient digital talent, and the lack of clear frameworks to guide adoption strategies (OECD 2021). The AI landscape for SMEs, therefore, is markedly different from that of larger corporations, necessitating tailored strategies that are sensitive to their unique constraints and opportunities. In Malaysia, SMEs account for approximately 97.4% of total business establishments and contribute over 38% to the national GDP, making them an essential pillar of the economy (SME Corp Malaysia 2023). Despite their significant role, many SMEs in the country still find

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themselves at an early stage of digital adoption. While basic digital tools such as point-of-sale systems and social media marketing are widely used, the uptake of more advanced technologies like AI remains relatively low and inconsistent across sectors (Manap and Abdullah 2020). Two main approaches have emerged: AI optimization and AI transformation. Though both depend on AI technologies, they differ substantially in their objectives, scope, and the depth of impact on business operations and value delivery. While AI optimization is centred around improving existing workflows and enhancing operational efficiency, AI transformation involves more radical changes that could redefine business models and restructure how value is created. Understanding these distinctions is essential for organisations, particularly SMEs, to align AI strategies with their readiness levels, risk appetite, and long-term aspirations. The lack of strategic clarity on how and when to adopt AI further complicates this issue.

One of the most pressing decisions facing Malaysian SMEs is whether to adopt AI incrementally, through AI optimization and enhancing existing processes, or to pursue AI transformation, which involves a more fundamental shift in business operations and value delivery. This decision is far from straightforward. It requires SMEs to consider multiple factors such as their current digital readiness, resource availability, industry trends, and long-term strategic objectives (Jalil *et al*. 2024; Tajudeen *et al*. 2025). Making the wrong choice could result in wasted investments or missed opportunities for innovation and growth. This study is therefore positioned to examine this critical decision-making process. By conducting in-depth interviews with SME owners and managers across four key sectors, retail, education and training, home-based food services, and personal health and wellness, this research explores how these businesses navigate the challenges and opportunities presented by AI. The goal is to develop a contextualized decision-making framework that can guide Malaysian SMEs in choosing the most suitable AI pathway, whether through optimization or transformation. In doing so, this study aims to contribute towards more informed, strategic, and sustainable AI adoption among SMEs in Malaysia. The integration of AI into business practices has become increasingly central in shaping strategic direction across industries.

MATERIALS AND METHODS

This study adopts a qualitative approach to explore how MSEs in Malaysia are engaging with AI, with a particular focus on whether their efforts are aimed at improving existing processes or shifting towards new business models. The main objective was to understand the motivations, practices, and challenges faced by small business owners when navigating AI adoption within their respective industries. A qualitative methodology involving ten in-depth interviews was conducted with owners and managers from four key sectors: retail, education and skills training, home-based food services, and personal health services. Participants were selected through purposive sampling to ensure relevance to the study. All businesses involved met the criteria of having fewer than thirty employees and generating annual revenues of less than RM3 million, in line with the Malaysian definition of micro and small enterprises. The interviews were semi-structured, allowing for flexibility while still maintaining focus on the key research questions. They were conducted in a mix of Bahasa Malaysia and English, depending on the comfort level of each participant, and lasted between thirty to forty-five minutes. The discussions explored current use of AI tools, perceived benefits, practical challenges, and whether their adoption efforts leaned more towards process optimization or business transformation. All interviews were transcribed and coded manually. A thematic analysis was then carried out to identify emerging patterns, with particular attention given to sectoral differences, owner motivations, and the depth of AI integration within business operations.

RESULTS

Retail sector

In the retail sector, which included three micro and small businesses such as a local mini market, a preloved item shop, and an online reseller, the adoption of AI was primarily geared towards basic optimization rather than full-scale transformation. Most of these businesses incorporated simple AI tools such as WhatsApp chatbots to manage customer inquiries, inventory restocking applications, and lightweight analytics to track popular products. For these small business owners, AI was seen as a practical solution to everyday challenges, especially when they had limited manpower and time to handle repetitive tasks. As one owner explained, “I use a chatbot, so I don’t have to reply to every question myself. It’s a time saver, not a game changer.” This statement reflects the mindset shared by many, where AI was useful for operational convenience but not something they viewed as a driver for major innovation. Interestingly, the decision to adopt AI was often influenced by word of mouth, peer recommendations, or exposure through social media, rather than through formal training or strategic planning. Most preferred ready-made tools were affordable, easy to install, and required little to no technical expertise (Fig. 1). However, there are several limitations; financial constraints remained the most common barrier, followed by uncertainty about the actual return on investment. As a result, AI usage in the retail sector stayed within a narrow scope, mostly focused on saving time and effort rather than exploring its broader potential to shift business models or scale digitally. AI becomes a driver of new revenue streams or entirely new business models. This often includes AI-powered

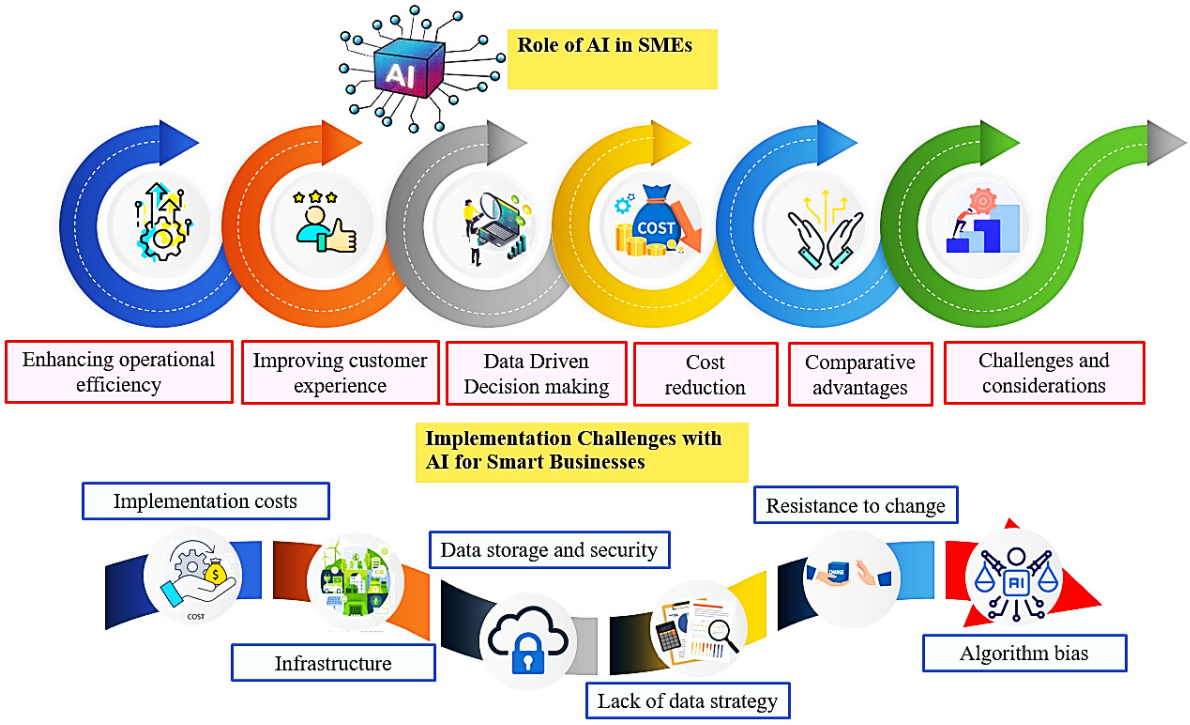


Fig. 1: Role of Ai in SMEs and challenges with its implementation

marketplaces or subscription services that deliver personalized experiences.

Education and skills training sector

In the education and skills training sector, which involved three small businesses such as a private tuition center, an online language coach, and a workshop-based training provider, the use of AI showed a slightly more progressive pattern. Compared to other sectors, these business owners demonstrated a higher level of digital openness and willingness to explore AI tools beyond basic operational tasks. AI was mainly used to support teaching and learning activities, including automating administrative tasks, designing customized learning materials, and tracking student progress. For instance, one educator shared how tools like ChatGPT and Canva helped to prepare content more efficiently, allowing her to handle a larger number of students without needing to hire additional staff. Another respondent mentioned that AI-generated feedback gave students quicker responses and allowed for more personalized guidance. These small but meaningful changes suggest a move towards rethinking service delivery methods, even if the business structure itself remained the same.

Unlike the retail and food sectors, owners in education were more experimental and proactive in searching for tools that could enhance their offerings. Most of them discovered AI applications through online communities, webinars, and peer sharing. They expressed appreciation for tools that were simple, cost effective, and compatible with their existing teaching styles. Despite their interest, some concerns still existed. These included fear of relying too much on AI to replace human interaction, and uncertainty about how students and parents would respond to AI-assisted learning. However, many saw AI as a support system rather than a threat. As one educator noted, "AI does not replace me as a teacher, but it helps me become a better one. Overall, the adoption of AI in this sector indicated a gradual shift from optimization towards modest transformation, especially in how learning is delivered and how value is created for learners. These early steps, although small in scale, highlight the potential for AI to play a transformative role in micro and small education-based businesses.

Home based food services

In the home-based food services sector, which included two small businesses, a home maker and a frozen food supplier, the use of AI was limited to simple tools that supported daily operations. These entrepreneurs operated with minimal staff and managed most tasks on their own, so any digital tool that could save time or reduce repetitive work was seen as valuable. AI was mainly applied in areas such as social media marketing, basic demand forecasting, and cost calculation. For example, one home baker used AI-generated captions to promote her products more creatively on Instagram, while another business owner relied on template-based apps to predict weekly demand for frozen items and manage stock

accordingly. These tools were not integrated into core processes but served as light support systems that made daily tasks more manageable. The overall approach in this sector was clearly focused on practical optimization, rather than transformation. Most owners had no formal digital background and expressed hesitation in adopting tools that seemed too technical or complex. Their decisions were shaped more by personal comfort and affordability than by long term business strategy. One of the owners explained, "I use AI to help me write better posts and plan ingredients, but I still cook everything myself. It is more of a helper than a big change." This statement reflects a common sentiment among home based food entrepreneurs, they welcomed tools that enhanced efficiency but were not ready or able to explore deeper digital transformation, such as automated kitchens or smart delivery systems.

Challenges such as limited financial resources, lack of digital skills, and concerns about losing the "personal touch" of their brand were frequently mentioned. As such, while AI was appreciated for its convenience, it was not yet viewed as central to the growth or evolution of the business. AI adoption within the home-based food services sector remained limited in scope, primarily centered on operational efficiency and content creation. There was minimal evidence of broader structural changes or transformative shifts in service delivery.

Personal and health services sector

In the personal and health services sector, which included two small businesses, a freelance physiotherapist and a home-based beauty and wellness service provider, AI was used primarily to support customer engagement and streamline service coordination. While these businesses operated in very personalized settings, they still found value in using simple AI tools to improve efficiency and client experience. The most common applications of AI in this sector were automated appointment scheduling, reminder notifications, and basic client profiling. For example, both business owners used AI powered apps to manage bookings without manual back and forth communication, allowing them to focus more on delivering their services. In one case, a physiotherapist noted that she could reduce missed appointments by using an AI system that automatically reminded clients through WhatsApp. Another practitioner used AI tools to keep track of client preferences, making it easier to personalize treatment sessions. Despite operating on a small scale, these entrepreneurs showed an openness to integrating AI when it was easy to use and directly beneficial to their workflow. One owner explained, "AI helps me keep track of everything without needing an assistant. It's small things, but it makes a big difference." This comment highlights how even basic AI tools can support better service delivery in people focused businesses. However, their adoption remained within the boundaries of optimization, rather than full transformation. While there was interest in more advanced features like AI based skin analysis or customized health monitoring, most felt such tools were out of reach financially or technically. Some also expressed concern about relying too much on technology in services where personal trust and human interaction were central. Overall, AI in this sector played a supportive role, enhancing operational convenience and client satisfaction, but did not fundamentally change how the businesses operated. These early steps, while modest, suggest a readiness to explore more transformative uses of AI in the future if tools become more accessible, affordable, and tailored to the unique nature of personal care services.

DISCUSSION

This study set out to explore how MSEs in Malaysia are approaching AI, and more specifically, how they decide between using AI for process optimization versus business model transformation. The findings suggest that while AI adoption is taking place across different sectors, the depth and purpose of that adoption vary significantly depending on the nature of the business, the digital mindset of the owner, and the practical constraints faced. Across most of the sectors studied, particularly retail, home-based food services, and personal health services, AI was used primarily to simplify daily tasks and save time, rather than to redefine the business model. This form of AI use aligns with what scholars describe as AI optimization, where technology is applied to existing systems without altering the core of how the business operates (Rakova *et al*. 2021). For instance, AI-powered chatbots, appointment reminders, and demand forecasting tools were commonly mentioned, suggesting a focus on task automation rather than innovation. This outcome is not surprising given the operational realities of Malaysian MSEs, as many of these businesses are owner-managed, with limited staff and tight financial margins. In such environments, tools that can reduce workload and streamline operations are naturally more appealing than high-risk, large-scale digital transformations. Similar patterns have been observed in other studies, where SMEs in developing countries tend to favor incremental digital adoption due to cost sensitivity and lack of technical skills.

While most sectors leaned towards optimization, the education and skills training sector demonstrated a slightly more progressive orientation towards AI adoption. The business owners in this group were more open to exploring AI tools that could enhance not only internal efficiency but also the value delivered to clients. Examples included AI-generated learning materials, feedback tools, and adaptive content delivery, all of which reflect early signs of AI transformation, where technology enables new methods of engagement and service delivery (Hewage 2024). What distinguishes this sector is the greater digital exposure and a willingness to experiment, possibly due to the nature of education as a service that increasingly depends on digital platforms. Additionally, the informants in this group were

more likely to have learned about AI through webinars, peer networks, or online communities, reflecting the role of informal learning in shaping digital adoption among small businesses. One common thread across all sectors was the informal way of AI adoption decisions, rather than being part of a structured digital strategy or formal trainings. Most business owners discovered and adopted AI tools through word of mouth, social media exposure, or trial-and-error. This points to a broader issue in the Malaysian SME ecosystem: the lack of accessible, sector-specific guidance or advisory services to support AI adoption (Bader and Kaiser 2019). Despite the absence of formal strategy, many owners displayed pragmatic thinking. They adopted tools based on immediate relevance, affordability, and ease of use. However, this also meant that AI adoption remained surface-level. Without clear understanding of AI's full capabilities, business owners are likely to underutilize the technology, missing out on opportunities for longer-term growth or transformation. Financial constraints were consistently cited as the most significant barrier across all sectors. For small businesses operating on tight budgets, the cost of advanced AI systems, software subscriptions, or even training can be prohibitive. This was followed by concerns over technical complexity and fear of losing the "personal touch", especially in sectors like food services and wellness, where customer trust and human interaction are key differentiators. These concerns reflect the findings of previous studies that emphasize the importance of contextual sensitivity in digital adoption frameworks. For Malaysian MSEs, digital readiness cannot be measured solely by technological infrastructure, it must include cultural readiness, owner confidence, and sector-specific suitability.

While full-scale AI transformation was not evident in most businesses, the findings suggest there is a latent interest among some owners to explore more transformative uses of AI, provided tools become more affordable, intuitive, and relevant to their context. Statements like "AI helps me become a better teacher" or "It's a small thing, but it makes a big difference" show that perceived value is already present, even if adoption is still at a basic stage. This aligns with Brătucu *et al*. (2024) concept of "digital maturity progression," where organizations evolve from using digital tools for convenience, innovation, and differentiation once they have gained enough confidence and support. With appropriate government incentives, training programmers, and ecosystem support, Malaysian MSEs could gradually shift from AI as an enabler to AI as a strategic core of their business.

CONCLUSIONS

This study set out to explore how Malaysian SMEs are adopting AI, with a particular focus on the strategic distinction between AI optimisation and AI transformation. The findings reveal that AI optimisation is the more dominant approach among small businesses. Entrepreneurs largely adopted AI tools that are affordable, easy to use, and directly relevant to daily operational challenges. This study also identified early signs of transformation in some contexts, particularly in the education sector. Business owners in this domain showed more interest in exploring AI to reshape service delivery, enhance personalisation, and improve learner engagement. It also highlights the importance of digital mindset and informal learning networks in shaping innovation trajectories among small firms. This includes affordable AI tools, accessible training in local languages, and clearer guidance on how AI can align with specific business goals. If such support is extended, it is possible for more Malaysian MSEs to transition from simply "using AI to save time" to leveraging AI as a strategic tool for growth and innovation. This study affirms that the journey towards effective AI adoption among Malaysian MSEs is not binary, but rather situated along a spectrum, from practical optimisation to gradual transformation. While most businesses remain at the optimisation stage, their growing interest and adaptive use of digital tools point to a readiness for deeper change, if given the right environment. As Malaysia moves forward in its national digital agenda, recognising and nurturing this readiness at the MSE level will be essential to ensuring that the benefits of AI are inclusive, sustainable, and locally meaningful.

AUTHOR CONTRIBUTIONS

Both the authors contributed equally to the write up.

CONFLICTS OF INTEREST

The authors affirm that they possess no conflicts of interest.

DATA AVAILABILITY

Not applicable

ETHICS APPROVAL

Not applicable

FUNDING SOURCE

No funding was acquired for this work.

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Innovations in STEAM: Research & Education
ISSN (print): 3105-7071; ISSN (online): 3105-708X
Volume 3; Issue 1; Article No. 25030105
https://doi.org/10.63793/ISRE/0025

REVIEW ARTICLE

Common Buckwheat: A Neglected Plant with Great Health Benefits

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METADATA

Paper history
Received: 14 Jan 2025
Revised: 23 February 2025
Accepted: 27 March 2025
Published: 02 April 2025

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Keywords
Grain vitamins
Crude fiber
Pseudocereal
Gluten sensitivity
Functional food

Citation
Nawaz S, Nazir A (2025) Common buckwheat: a neglected plant with great health benefits. *Innovations in STEAM: Research & Education* 3: 25030105. https://doi.org/10.63793/ISRE/0025

ABSTRACT

Background: Sustainable food security is dependent upon finding and improving food crops. Buckwheat (*Fagopyrum esculentum* Moench) has been neglected but is regaining popularity due to its short duration and low input for growing. Its flour has characteristics closely related to bread wheat.
Objectives: This extension article aims to review the specific nutritional and health features of buckwheat grain for the benefit of public health
Methodology: The information included in this article was gathered from different literature resources, including Google Scholar, Scopus, Web of Science, Springer Link, ResearchGate, Taylor & Francis, and related databases.
Results: The buckwheat is a short-duration crop compared to bread wheat. Its grain is used as a nutritional and functional food as it is rich in essential nutrients, dietary fibres, and vitamins. It is a pseudocereal and gluten-free crop. It has a low glycaemic index and has the insulin-sensitizing agent, D-Chiro-Inositol, which regulates blood plasma glucose level. It is also used in the treatment of polycystic ovary syndrome. However, despite all these benefits, our consistent food habits are a major deterrent to its adoption.
Conclusion: Buckwheat has numerous nutraceutical and health benefits. It remained a neglected crop due to non-adaptability of the crop and farmers perspective, but it is gaining popularity due to increased awareness of the people.

INTRODUCTION

Food security and nutrition form the foundation of human life, serving as essential pillars that not only sustain health and well-being but also catalyse progress in multiple developmental domains, including environmental sustainability, education, economic growth, and employment opportunities, thereby ensuring a resilient and prosperous society. The world population is steadily increasing, and with this growth, food insecurity is becoming a more pressing concern. According to the UN Population Division (2024), the global population may reach up to 16 billion by 2100, which will significantly increase food demand and put additional pressure on already limited food resources. Therefore, it is crucial to explore, diversify, and cultivate alternative food crops. Out of approximately 80,000 edible plant species, only 150 are actively cultivated, and just a few of these crop's supply around 84% of our caloric intake. Many crops have been neglected or lost due to monoculture and the green revolution. Among these neglected crops, common buckwheat (*Fagopyrum esculentum* Moench) stands out for its high nutritional and medicinal value. (Babu *et al*. 2021. In Pakistan, the buckwheat is known by local names Bro, Baroo, Baravo, Balti, Khowar, Satho, etc. It is grown at a limited scale in the inner valleys of the Himalaya, Hindukush, and the Korakaram mountain ranges. The major area of its cultivation in Pakistan is Gilgit-Baltistan, but its production is on a limited scale. However, due to increasing awareness about its health benefits, the area under buckwheat cultivation is increasing in the plains of Punjab. Adaptability trials have revealed that buckwheat has a great potential for growing in diverse environments in the relatively cool season (Luitel *et al*. 2021). Its average grain yield goes up to 2 tons/ha under ordinary field conditions, but under well-managed conditions, it may yield up to 3 tons/ ha (Unal *et al*. 2017). Buckwheat is a pseudocereal of immense economic and nutritional value for people who

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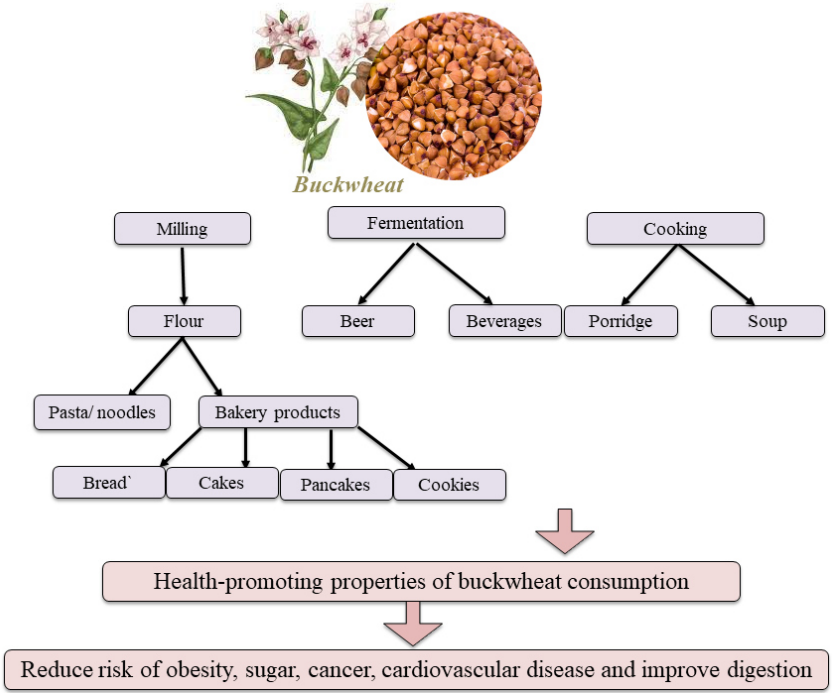


Fig. 1: Buckwheat and end-use products

follow a controlled diet. It has 70–75% carbohydrates, 12–15% proteins, and 3–4% lipids and 1.5–2.0% ash content, indicating high nutrient content together with several medically important bioactive compounds (Fujimura *et al*. 2003; Sofi *et al*. 2022). An excellent dough quality of buckwheat flour makes it a preferred choice for food-conscious people (Collar and Angioloni 2014). This review gives an updated overview of the medicinal and nutraceutical importance of buckwheat.

BUCKWHEAT SPECIES DESCRIPTION

There are two main types of buckwheat: common buckwheat (sweet) and Tartary buckwheat (bitter). Generally, consumers prefer common buckwheat due to its better palatability, whereas Tartary buckwheat is less favoured. Common buckwheat is a pseudocereal and is utilized similarly to wheat. The term "buckwheat" is derived from “buck,” reflecting the triangular shape of its seeds, which resemble the larger seeds of the beech tree, and “wheat,” indicating its use analogous to wheat (Luitel *et al*. 2021).

Buckwheat is native to Asia and is naturally distributed in Central Asia, including China and the Himalayan regions of Pakistan and India. Despite limited attention, common buckwheat is cultivated in countries such as Japan, China, Russia, Ukraine, and Kazakhstan. In Pakistan, it is grown in northern regions including Gilgit, Ghizer, Skardu, Hushe, Hunza-Nagar, and Kande along the Indus River. Locally, buckwheat is known by various names depending on the region and language, such as Baravo/Broofy in Gilgit, Baroo/Bali in Hunza-Nagar, and Jawas in Baltistan (Ahmed *et al*. 2014).

BIOCHEMICAL COMPOSITION

As shown in Fig. 1, buckwheat grains contain 60–70% carbohydrates, which are biochemically similar to cereal starch. The starch granules are also a potential source of nutrients, including carbohydrates, proteins, and lipids, as well as bioactive compounds such as trypsin inhibitors (Wang *et al.* 2007), antitumor proteins (Guo *et al.* 2010), hypotensive peptides (Zhu 2021), and antidiabetic peptides (Koç *et al*. 2025).

HEALTH BENEFITS OF BUCKWHEAT

Regarding health benefits and nutraceutical importance, buckwheat is considered a functional food. Ancient Chinese wisdom states, “people who love buckwheat live long” and “people who love buckwheat are healthy.” The seeds of common buckwheat resemble wheat in appearance and taste but are gluten-free, making them suitable for individuals with celiac disease or gluten sensitivity (Yurtseven *et al*. 2015). Buckwheat is a rich source of dietary fibre, providing approximately 6 g per cup, with coarse-grain flour containing ten times more fibre than refined flour. Its low glycaemic index allows carbohydrates to be absorbed gradually, and it contains the insulin-sensitizing agent D-

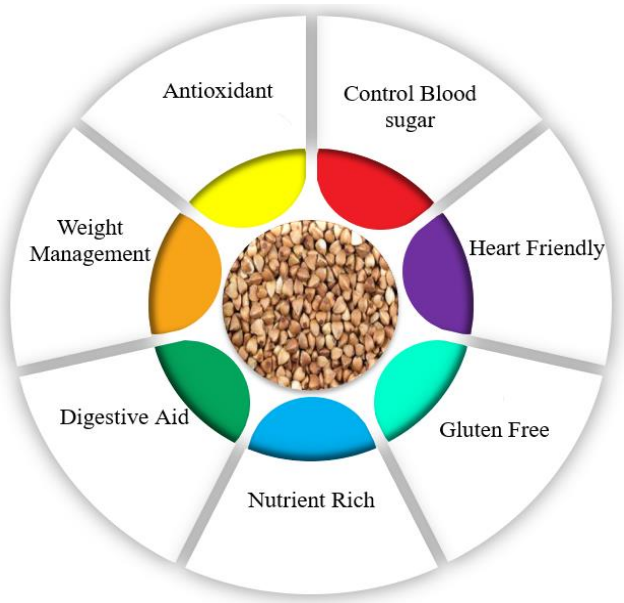


Fig. 2: Overview of buckwheat health benefits

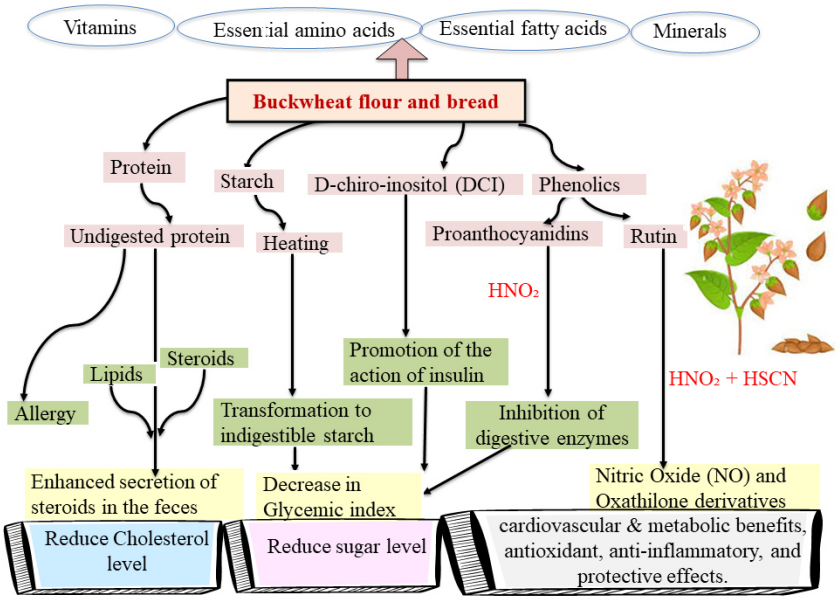


Fig. 3: Buckwheat nutrients and health benefits

chiro-inositol, contributing to improved blood glucose regulation. Consequently, buckwheat is beneficial for patients with diabetes, metabolic disorders, and polycystic ovary syndrome. Additionally, its high dietary fiber content and low glycemic index support weight management (Guo *et al*. 2025). Protein malnutrition is a major concern in developing countries, causing conditions such as poor growth, marasmus, and kwashiorkor in children, and reduced work efficiency in adults. Common buckwheat provides a valuable source of high-quality protein (13–21%), containing all essential amino acids, a rare attribute among crops. It also exhibits hypotensive effects and supports mental health; for instance, tryptophan in buckwheat contributes to positive mood, happiness, and depression prevention. Buckwheat is rich in minerals, including magnesium, iron, phosphorus, manganese, and copper, as well as vitamins, which collectively improve cardiovascular function, reduce low-density lipoprotein

cholesterol, control blood pressure, enhance circulation, prevent heart disease, and increase high-density lipoprotein cholesterol (Fig 2). Consumption of whole-grain buckwheat has also been associated with a roughly 50% reduction in asthma risk, likely due to its magnesium and vitamin content (Fujimura *et al*. 2003; Sofi *et al*. 2022; Koç *et al*. 2025). Furthermore, common buckwheat contains potent antioxidants, particularly flavonoids such as rutin, which are effective in managing low hemoglobin, cold, and flu. Skin health is influenced not only by genetics but also by environmental factors, including pollution, stress, and lifestyle.

Nutrient-rich buckwheat contributes to skin health by preventing premature aging, promoting skin firmness, and offering natural sun protection. Vitamins C (particularly in sprouts/microgreens), B, and E improve blood vessel function, circulation, and skin radiance. Hair health is also supported by nutrients abundant in buckwheat, including zinc, omega-3 and -6 fatty acids, and vitamins A, B6, and E, which can mitigate hair loss, thinning, split ends, and dandruff. Collectively, these properties position buckwheat as a highly valuable functional food and nutraceutical (Liţoiu *et al*. 2024; Bani *et al*. 2024; Koç *et al*. 2025). Although buckwheat is cultivated only on a limited scale in Pakistan, it is used in traditional local dishes such as Prapoo, Marzaan, Bro-skating, and Kisir, which are prepared from buckwheat flour. However, entrenched dietary habits limit the wider adoption of buckwheat. Gradual incorporation into daily meals is recommended to fully benefit from its health-promoting properties.

CONCLUSIONS

Common buckwheat is an extremely valuable pseudocereal with essential nutritional, medical, and biochemical features. It contains carbohydrates, high-quality proteins with all the necessary amino acids, dietary fibre, lipids, vitamins, and minerals, that's makes it a wonderful food for human health. Buckwheat is gluten-free by nature and possesses a low glycaemic index, making it a beneficial food for patients with coeliac disease, diabetes, and other metabolic disorders. Its bioactive constituents, such as rutin, trypsin inhibitors, hypotensive and antidiabetic peptides, are responsible for cardiovascular health, mental health, and disease prevention. Furthermore, antioxidants in buckwheat promote skin health, retard aging, and enhance hair quality. Though it has advantages, buckwheat farming and consumption are limited in most parts of the world because of the conventional food culture. Encouraging its productivity and incorporation into normal diets may enhance food security. Further studies are required to investigate its phytochemical constituents and underlying genetic basis.

AUTHOR CONTRIBUTIONS

All authors contributed equally to the conception, design, and preparation of this manuscript.

CONFLICT OF INTEREST

The authors declared no conflict of interest.

DATA AVAILABILITY

The data will be made available upon request to the author

ETHICS APPROVAL

Not applicable

FUNDING SOURCE

This project is not funded by any agency

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