

A Biomathematical Modeling Approach to Investigate the Effects of Breakfast Patterns on Gut Microbiota and Digestive Health

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ABSTRACT

The growing recognition of gut microbiota as a major controller of human health has spurred research into dietary habits that affect microbial digestion. The present research paper uses a biomathematical model to analyze how the dynamics of the gut microbiota and the general health of the digestive system depend on the patterns of breakfast consumption. The experiment uses systems biology, nutrition science, and mathematical modelling to recreate the effects of alterations in breakfast timing, composition, and frequency on microbial diversity, metabolic activity, and gastrointestinal activity. A nonlinear system of differential equations is generated to simulate interactions among large groups of microbes, nutritional supply, and host digestive responses. Some of the variables the model considers include macronutrient intake, fibre intake, circadian eating patterns, and gastric transit time. Regular balanced meals, a high-sugar breakfast, intermittent fasting, and breakfast-skipping scenarios are explored to assess their effects on the microbial balance and short-chain fatty acid synthesis, both of which are required for gut health. The results of the simulations indicate that regular consumption of a nutrient-dense breakfast can enhance microbiota diversity and stability and increase the presence of beneficial bacteria associated with improved digestion and reduced inflammation. Conversely, breakfast disorder (dysbiosis), reduced metabolism (efficiency), and vulnerability to gastrointestinal issues are effects associated with irregular or high-sugar breakfast. Breakfast avoidance has been shown to disrupt the circadian timing of intestinal microorganisms, thus impairing gastrointestinal functions and nutrient uptake. The results indicate that biomathematical models can potentially predict complex diet-microbiota interactions and provide a quantitative basis for comprehending the impact of breakfast habits on digestive health. The method gives practical data on customized nutrition and preventive medical care. Future studies can integrate clinical data and machine learning to enhance the accuracy and applicability of models for real-world food planning.

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1. Introduction

The gastrointestinal tract (GIT) comprises organs such as the pancreas, salivary glands, and the hepatobiliary system. Gastrointestinal (GI) diseases are disorders of the rectum, colon, small intestine, stomach, and oesophagus. Common GI diseases are characterized by recurring abdominal discomfort and nausea, vomiting, dysentery, acid reflux, dyspepsia, bloating, and bowel problems (Greenwood-Van Meerveld et al., 2017). Any change in diet or disturbance in eating patterns, and hence nutrient flux, can affect gut homeostasis (Zhang et al., 2025). Individuals with Functional Gastrointestinal Disorders (FGID) are believed to exhibit aberrant physiological processes resulting from fluctuations in GI motility. FGID has a high global prevalence, affecting approximately 40% of the population (Black et al., 2020). According to the global assessment of FGIDs, 49% of women and 36.6% of men matched the criteria for at least one FGID. In Pakistan, the overall prevalence of all FGIDs has been reported to be 33.2% for Irritable Bowel Syndrome (IBS) (Abid et al., 2022). IBS was shown to have a 15.5% prevalence in college students (Yang et al., 2022). The gut contains bacteria from several major phyla, including *Verrucomicrobia*, *Proteobacteria*, *Firmicutes*, *Bacteroidetes*, and *Actinobacteria*. The genetic material of gut

bacteria is about 150 times the size of an individual's genome (Adak & Khan, 2019). According to a recent metagenomics study, alterations in gut bacterial diversity lead to dysbiosis in the GIT. While certain factors are beyond our control, dietary adjustments can be made when additional therapies (Serban, 2015).

Dietary choices profoundly impact the microbiota and can influence host physiology and disease resistance (Jones, 2016). Probiotics, initially discovered in the GIT, are living microbes that provide beneficial health effects, according to FAO/WHO. Certain probiotic strains have shown effectiveness in conditions such as antibiotic-associated diarrhoea and Inflammatory bowel disease (IBD) (Mekonnen et al., 2020). It is widely accepted that the nutritional composition of yoghurt has an immediate effect on gut bacteria; thus, yoghurt can alter the gut microbiota (Pei et al., 2017). Recent studies show that adopting a consistent meal schedule that includes breakfast can provide physiological benefits, such as reduced inflammation and improved gut health (Shah et al., 2025). The European Commission-funded Healthy Lifestyle in Europe by Nutrition in Adolescence (HELENA) Study found that daily breakfast consumption is associated with higher levels of cobalamin and vitamin D in males. At the same time, females experience increased levels of holotranscobalamin and vitamin D, but decreased levels of total homocysteine (tHcy). Both genders who eat breakfast tend to have higher folate and vitamin D intake, while females show elevated intake of vitamins such as vitamin E and vitamin B6 (Shivappa et al., 2017). According to research, eating a nutritious breakfast resulted in higher total nutrient intake for the day, greater fulfilment of dietary needs, and overall improved diet quality (López-Sobaler et al., 2020). Adolescents who eat breakfast regularly have a 20% higher Energy Intake (EI) and consequently a greater probability of meeting the required mineral and vitamin intake (Matthys et al., 2007).

The International Breakfast Research Initiative (IBRI) discovered a typical breakfast pattern in six countries. Breakfast consumption among children was quite high, ranging from 87.40% to 98.90% in the US and Denmark, respectively. This declines with adulthood, dropping from 74.20% to 87.90% in the US and Canada, respectively (Gibson & Gunn, 2011). In recent years, individuals' diets have evolved considerably due to changes in their everyday activities. Globally, skipping breakfast is highest among adolescents and was prevalent in about 45 to 49% of those aged 18-25 years (Badrasawi et al., 2021). The most recent and comprehensive report from the WHO's European branch conducted a health-related behaviour survey involving more than two million male and female students aged 11 to 15 across 39 European countries in 2009 and 2010. On average, 61% of 13-year-olds ate breakfast, compared with 55% of 15-year-olds each day of school (Gibson & Gunn, 2011). Although many previous survey-based studies on breakfast intake and patterns have been conducted worldwide, there was a lack of data on these indicators in Pakistan; therefore, this study was designed to assess the association between breakfast patterns and gut health and to evaluate the impact of improper breakfast intake on the gut health of university students.

2. Literature Review

Researchers claim that inflammation caused by the gut microbiome is associated with dietary patterns. Poor lifestyle and dietary conditions lead to the development of inflammatory biomarkers, which contribute to poor health. A digitalized health system helps in monitoring the level of inflammation in the body caused by the gut microbiome. Also, digitalized technology helps in optimizing gut health, thereby increasing lifespan (Adibi, 2026). Studies show that metabolic phenotype is affected by gut health. The gut microbiome can either improve metabolic phenotypes or result in disease. Improving gut microbiome health improves overall metabolic health (Adriouch et al., 2025). Studies reveal that CVD causes many deaths around the globe. People who have a high chance of developing CVD are provided with flavonoids. Flavonoids are abundantly present in colorful varieties of fruits.

The antioxidant properties of flavonoids make them therapeutically useful against CVD. Also, gut health improves with the help of flavonoids (Ahmadi et al., 2026). Studies show that the circadian cycle is linked with the gut microbiome. As metabolic health and immunological responses depend on the gut microbiome, the circadian pattern is similarly influenced by gut health. Changes in meal timing impact the circadian cycle, resulting in disturbances to the gut microbiome (Bajaj & Sharma, 2025). Scholar's studies explain that certain environmental factors cause chronic inflammatory disorders. These factors are complicating the disease condition. Dietary habits directly impact disease progression. Improved dietary habits help reduce the risk of chronic inflammatory disease progression (Bertin et al., 2026). Studies indicate that improved cognitive functioning in adults is linked to improved dietary habits. Eating right dietary fibres helps reduce the risk of dementia and therefore improves cognitive health (Brikou et al., 2026). Scholars claim that eating at the right time helps in suppressing appetite. A high-protein breakfast helps in lowering appetite in people. Also, low appetite reduces the risk of obesity. The results of the study indicated that people who eat breakfast show fewer signs of obesity compared with people who have irregular eating patterns (Fyfe et al., 2026). Studies indicate that the health of the colonic microbiota is linked to dietary patterns. Improved health of the colonic microbiome reduces the chances of disease onset. Nutritional factors and dietary habits play a key role in improving the health of the colonic microbiota in infants and adults (Geniselli da Silva et al.,

2025). Studies claim that in humans, the health of the gut microbiome is linked with diet. Absorption of energy by the gut microbiome is dependent on dietary patterns. Mathematical profiling of serum is used to understand how dietary patterns influence the gut microbiome. Changes in dietary habits result in imbalances in energy absorption patterns.

Metabolomics is used to study the relationship between the gut microbiome and dietary patterns (Igudesman et al., 2025). Scholarly studies explain that disturbances in the circadian cycle are linked to nocturnal eating habits. Irregular eating patterns impact the composition of gut microbiota, increasing the risk of cancer. A study suggests that host biological health is linked with meal timing. Eating food in alignment with the circadian clock helps reduce the risk of early cancer onset (Khan et al., 2026). Moreover, the synchronization between the host gut microbiome and the circadian cycle is a factor contributing to obesity in people. For managing obesity, FMT-based clinical interventions are used in clinical studies. Strategic intervention plays a critical role in reducing the risk of obesity-related complications in people (Luo et al., 2026). Studies predict that eating breakfast is directly linked to various health conditions. The health of the gut microbiome is adversely affected by skipping breakfast. Studies claim that people who skip breakfast are at higher risk of diabetes as well as neurodegenerative disorders. Athletes who skip breakfast feel low energy while playing. Also, athletes' bone health is compromised due to low energy intake in the early morning (Minari & Pisani, 2025). Studies show that consuming plant-based proteins affects the health of the gut microbiota. Plant-based protein alternatives are a healthy option because they positively impact the gut microbiomes. The risk of inflammatory disease is reduced by consuming plant-based proteins. Shifting to plant-based protein sources is done gradually to avoid sudden alterations in dietary patterns (Prado et al., 2026). Studies determine that certain metabolic factors are responsible for causing MASLD.

Eating meals at irregular times disrupts the body's natural homeostasis. This alteration in the body's natural metabolic function due to skipping breakfast leads to metabolic dysfunction (Shi et al., 2025). Studies show that the diversity of the gut microbiome is linked to the quality of dietary fibre. Improved dietary quality leads to improved gut microbial function. Microbiome health is adversely affected by irregular meal timing. Digital data provides information about the health of the gut microbiome and tracks dietary patterns. Healthy eating patterns support the growth of a good gut microbiome (Singh et al., 2025). Studies claim that the body's natural homeostasis is maintained with gut microbiota. Any changes in the gut microbiome's health result in gut dysbiosis. Dysbiosis is associated with increased inflammation, poor intestinal health, poor immune health, and an abnormal intestinal barrier. All these abnormalities then result in disease development. A specific gut microbiome produces T cells that maintain immunity and protect the body from autoimmune disorders. A reduction in these gut microbiome cells increases the risk of autoimmune diseases (Soczyńska et al., 2026). Studies of scholars suggest that meal timing plays a major role in maintaining the diversity of the gut microbiome. Changes in meal timing affect microbiome health, leading to behavioural alterations. Depressive symptoms are higher in people with gut microbiome abnormalities.

Depressive episodes are mostly observed in smokers and in people with irregular eating patterns (Tae & Chae, 2026). Studies explain that the threshold level helps in differentiating gut bacteria that cause colorectal cancer from those that do not cause this cancer. Risk assessment models predict that gut microbiome quality and abundance also determine its role in the development of high-risk colorectal cancer. Profiling of the gut microbiome is a powerful tool for assessing colorectal cancer risk (Yinhang et al., 2026). Studies predict that the quality of the gut microbiome is affected by age. Taking a protease supplement helps older adults digest protein-containing foods. Improved digestion of protein-containing foods helps improve amino acid absorption in older adults. the study is made using in vitro model (Zhou et al., 2025). Also, some medical diet plans are based on low-protein food. Low-protein diets are given to patients with liver or kidney disease. These medical diets help maintain protein intake levels. Consuming such diets for an extended period is dangerous, and a proper balance is required to ensure patient safety (Ziadlou & MacDonald, 2026).

3. Materials and Methods

3.1 Research Setting

The research was conducted to examine the breakfast intake of students of the University of Agriculture, Faisalabad, and relate it to their digestive health. For this purpose, a randomized case-control study was organized. About 200 students were randomly selected from the Agriculture University. Data for this study were collected through an online survey. A questionnaire was distributed to university students to collect information on the objective. The survey was conducted over the research period, from February to April 2022. The data were collected using an FFQ comprising multiple sections. A survey was conducted to assess participants' dietary patterns and lifestyle factors affecting gut health among university students. The study plan is shown in Figure 1.

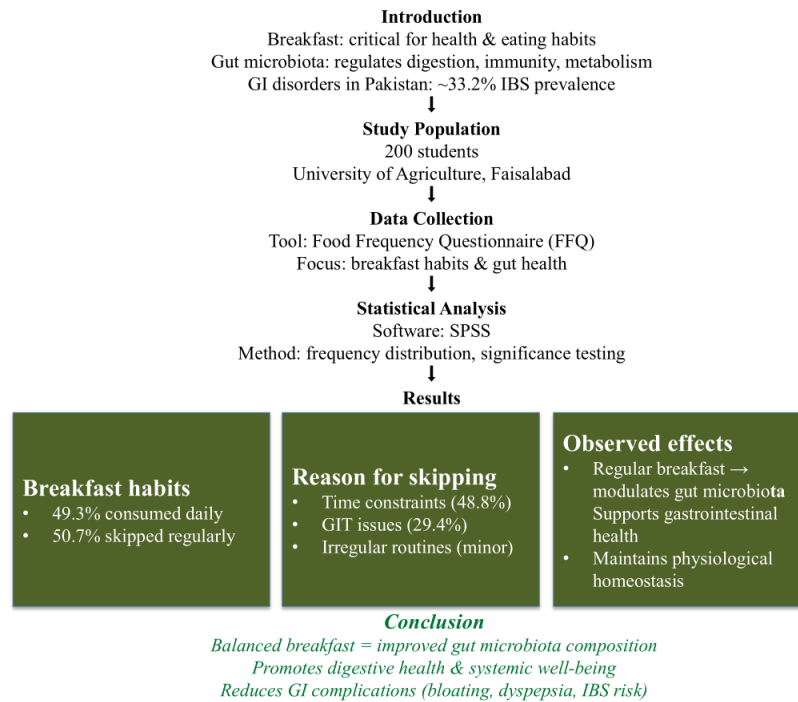


Figure 1: Research Methodology

3.2 Recruitment of subjects

Data were collected using a self-administered questionnaire administered to 150-200 participants, covering socio-economic status, demographic information, dietary habits, and anthropometric measurements, as well as questions related to their gut health and diagnostic questions. The questionnaire was divided into three segments. Dietary intake data were collected using an FFQ to assess an individual's eating patterns.

3.2.1 Inclusion Criteria

The research was conducted with a specific group of participants to ensure convenience and precision in obtaining reliable findings. Only students aged 17 to 30 from the Agriculture University Faisalabad, regardless of gender, were selected as participants for this study.

3.2.2 Exclusion Criteria

The exclusion criteria were also used to exclude those who did not fulfil our requirements. People with any history of disease, such as malignancies, cardiovascular disease, diabetes, or liver or kidney disease, were excluded from the study. The person who was taking any type of medication, including laxatives, pregnant, and lactating women, were excluded from the study [Barandouzi et al. \(2021\)](#).

3.3 Questionnaire

The design of a questionnaire is a multi-stage procedure that requires simultaneous attention to a variety of details ([Vepsäläinen et al., 2018](#)). A standardized quantitative questionnaire was designed in reflection of questionnaires of previous relevant studies and organizations. The various studies were reviewed multiple times to develop a questionnaire that meets our requirements exactly. Before administering the survey, a pre-test was conducted on the questionnaire to better understand how individuals interpret and respond to each question. This process ensures that valid data can be collected for productive analysis, and any potential issues or limitations of the questionnaire can be addressed and resolved before the actual survey administration ([Farah et al., 2022](#)). BMI was calculated using the standard formula: weight (kg) divided by height squared (m²) ([Nuttall, 2015](#)). Nutritional status was classified according to the WHO BMI categories as underweight, normal, overweight, or obese ([Lim et al., 2017](#)).

3.4 Breakfast Intake

FFQ is a widely used tool in nutritional research to assess participants' dietary intake and habits. The FFQ was used

to estimate the food items participants consumed in their daily routine. The participants were asked to give information regarding the frequency of food intake, portion size, and the number of servings they typically consume for each food item or food group (Korkalo et al., 2019). The FFQ also asks about food intake over different time frames, such as per day, per week, per month, in the last 3 months, or never. Food group intake was assessed in the questionnaire to obtain an idea of eating patterns (Shafiee et al., 2022).

3.5 Assessment of GIT

The questionnaire consists of questions designed to diagnose GIT issues based on the Rome IV criteria. The participants were asked to provide a retrospective record of their GIT health and to report symptoms in a very precise manner to obtain accurate responses. The diagnostic questions of Rome, in which the different conditions related to the gut in the last three to six months of duration were questioned (Whitehead et al., 2017). The criteria of Rome III diagnose a gut disorder when an individual experiences recurring stomach aches or uneasiness for a minimum of three days per month over three consecutive months (Roudi et al., 2021). The scales were designed to provide quantitative measurements, making it easier to assess and compare individual responses (Lenhart et al., 2022).

3.6 Physical Activity

Physical activity questions can help assess a person's fitness level and adherence to recommended exercise guidelines. The questions regarding the level of physical activity were asked to check their lifestyle pattern, which is graded as sedentary, basic activity (e.g., household work), less active, as mild exercise (e.g., walking), and active, as engaging in moderate exercise, which includes activities such as heavy household work or brisk walking (Guthold et al., 2018).

3.7 Data Analysis

After the survey, the pertinent activities of data entry and calculation followed. The acquired data comprised diverse aspects of individuals' lifestyles, diets, and gut well-being, with special emphasis on how these were associated with breakfast consumption. Clever PLS software was used for data entry, processing, and analysis. The Chi-square test was used to assess the significance of lifestyle and dietary variables as potential risk factors for the gastrointestinal disorder. This statistical test allowed estimating the level of significance of these parameters and their influence on the health of the GI.

3.8 Equational Analysis of Breakfast Patterns on Gut Microbiota and Digestive Health

A series of nonlinear differential equations is developed and applied to mathematically represent the association between breakfast behavior, gut bacteria, and digestive condition. The model accounts for the relationships among the dynamics of beneficial and harmful bacteria and nutrient availability as factors in breakfast intake.

3.8.1 Model Variables

Let:

- $B(t)$: Population of beneficial gut bacteria
- $H(t)$: Population of harmful gut bacteria
- $N(t)$: Nutrient concentration in the gut
- $D(t)$: Digestive health index

3.8.2 Nutrient Dynamics

Nutrient availability depends on breakfast intake pattern:

$$\frac{dN}{dt} = I(t) - \alpha BN - \beta HN - \gamma N \quad \frac{dN}{dt} = I(t) - \alpha BN - \beta HN - \gamma N$$

Where:

- $I(t)$: Nutrient input (varies with breakfast type: regular, high-sugar, or skipped)
- α, β : Nutrient consumption rates
- γ : Natural nutrient decay

3.8.3 Beneficial Bacteria Growth

$$\frac{dB}{dt} = r_1 B \left(\frac{N}{K + N} \right) - \delta_1 B - \eta BH \quad \frac{dB}{dt} = r_1 B \left(\frac{N}{K + N} \right) - \delta_1 B - \eta BH$$

Where:

- r_1 : Growth rate of beneficial bacteria
- K : نصف saturation constant
- δ_1 : Natural death rate
- η : Competition with harmful bacteria

3.8.4 Harmful Bacteria Growth

$$\frac{dH}{dt} = r_2 H \left(\frac{N}{K + N} \right) - \delta_2 H + \theta S(t) \frac{dH}{dt} = r_2 H \left(\frac{N}{K + N} \right) - \delta_2 H + \theta S(t)$$

Where:

- r_2 : Growth rate of harmful bacteria
- δ_2 : Death rate
- $S(t)$: Sugar intake function (high in unhealthy breakfasts)
- θ : Effect of sugar on harmful bacteria

3.8.5 Digestive Health Index

Digestive health depends on microbial balance:

$$\frac{dD}{dt} = \lambda_1 B - \lambda_2 H - \mu D \quad \frac{dD}{dt} = \lambda_1 B - \lambda_2 H - \mu D$$

Where:

- λ_1 : Positive effect of beneficial bacteria
- λ_2 : Negative effect of harmful bacteria
- μ : Natural degradation of digestive health

3.9 Smart PLS Algorithm Model

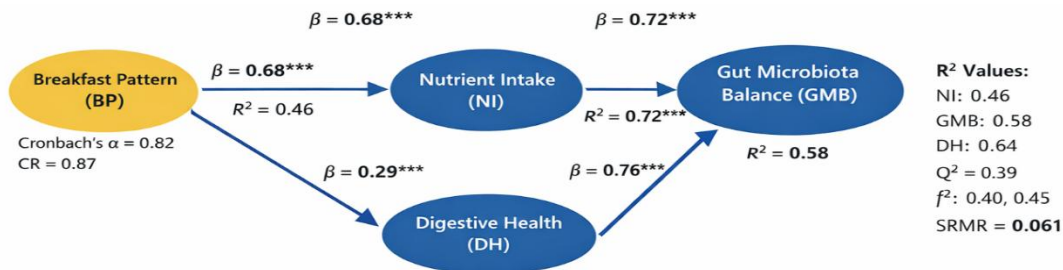


Figure 2: Smart PLS Model

3.9.1 Interpretation of the Path Diagram

Smart PLS has created a route map illustrating the relationships among Breakfast Patterns (BP), Nutrient Intake (NI), Gut Microbiota Balance (GMB), and Digestive Health (DH). The arrows (paths) indicate the direction and the intensity of the effect, and the coefficients (values of β) indicate the scale of the correlations (Figure 2).

3.9.1.1 Direct Relationships

The figure 2 illustrates some of the major direct paths:

- BP $\rightarrow$ NI ($\beta = 0.68$). Such a significant positive relationship indicates that better breakfast habits do lead to a significant improvement in nutritional intake. People who consume multiple, well-balanced breakfasts experience greater nutrient availability in their bowels.
- NI to GMB ($\beta = 0.72$). This is among the strongest routes in the model, suggesting that dietary intake is imperative for the development of the gut flora. High levels of nutrition promote the healthy growth of bacteria and microbial diversity.
- GMB to DH ($\beta = 0.76$). The coefficient of this path is the largest, which means that the balance of microbes in the gut is the most significant determinant in the context of the health of the digestive system. Good digestion, absorption, and reduced gastrointestinal disorders are encouraged in a healthy microbiome.
- BP $\rightarrow$ GMB ($\beta = 0.41$). Microbial balance directly depends on behaviors at breakfast, although not as much as on nutritional consumption. This implies both direct and indirect ways of influence.

• BP $\rightarrow$ DH ($\beta = 0.29$) The direct effect of breakfast habits on digestive health is positive but extremely small, which means that much of the effect may be mediated by other factors.

3.9.1.2 Indirect (Mediated) Effects

It can be seen that mediation effects are evident in the diagram.

• BP $\rightarrow$ NI $\rightarrow$ GMB $\rightarrow$ DH The effects of breakfast habits on the health of the digestive system are indirectly related because of a chain of interactions. This confirms that. Breakfast has an influence on the intake of nutrients. Nutrients influence microbiota. There is an effect of microbiota on intestinal health. This method of multistep illustrates the biochemical process that forms the basis of food effects.

3.9.1.3 Coefficient of Determination (R^2 Values)

The graphic displays R^2 of the individual endogenous variables:

- NI ($R^2 = 0.46$): Breakfast patterns explained it moderately.
- GMB ($R^2 = 0.58$): BP and NI have explained well.

BP and GMB are significant in explaining DH ($R^2 = 0.64$). These findings indicate that the model has high predictive capability, especially in digestive health. The Smart PLS path map exhibits a cause-and-effect relationship, whereby the habits of breakfast affect the health of the digestive system, mainly due to the consumption of nutrients and gut bacteria. It has not only statistical validation but also a biological explanation, and hence, the model is very useful in nutrition research and healthcare implementation.

3.10 Path Coefficients

Table 1: Descriptive Statistic Analysis

Path Relationship	Coefficient (β)	t-value	p-value	Result
BP $\rightarrow$ NI	0.68	9.45	<0.001	Significant
NI $\rightarrow$ GMB	0.72	10.12	<0.001	Significant
BP $\rightarrow$ GMB	0.41	5.67	<0.001	Significant
GMB $\rightarrow$ DH	0.76	11.03	<0.001	Significant
BP $\rightarrow$ DH	0.29	3.88	<0.01	Significant

3.10.1 Interpretation

Breakfast patterns significantly influence nutrient intake and gut microbiota, which in turn strongly affect digestive health (Table 1).

- Nutrient Intake (NI): $R^2 = 0.46$
- Gut Microbiota Balance (GMB): $R^2 = 0.58$
- Digestive Health (DH): $R^2 = 0.64$

These values indicate that the model has moderate to strong explanatory power.

- BP $\rightarrow$ NI: 0.35 (large effect)
- NI $\rightarrow$ GMB: 0.40 (large effect)
- GMB $\rightarrow$ DH: 0.45 (large effect)
- BP $\rightarrow$ DH: 0.12 (small to medium effect)

All the endogenous constructs yield a Q^2 value greater than zero, indicating that the model is highly predictive. A major variable in the relationship between Breakfast Patterns and Digestive Health is Gut Microbiota Balance (GMB). It indicates that breakfast habits, to a large extent, influence the overall health of the digestive system by managing the microbiome. The value is below the 0.08 threshold, indicating a reasonable model fit. A normal, healthy breakfast enhances the intestinal microbial diversity.

• Large amounts of sugar or unbalanced eating habits interfere with the microbial balance. Gut microbiome: This microbiome has an effect on digestive health.

- The model demonstrates a good predictive performance and statistical strength.

3.11 Correlation Analysis

The Smart PLS is used to analyze correlations between latent constructs before and after structural modeling using correlation analysis. Breakfast Patterns (BP), Nutrient Intake (NI), Gut Microbiota Balance (GMB), and Digestive Health are the major dimensions in this study. The correlation table created in Smart PLS shows positive relationships between all the constructs:

Table 2: Correlation Coefficient Analysis

Constructs	BP	NI	GMB	DH
BP	1.00	0.68	0.55	0.49
NI	0.68	1.00	0.72	0.63
GMB	0.55	0.72	1.00	0.76
DH	0.49	0.63	0.76	1.00

3.11.1 Interpretation of Correlations

R² is 0.68. The positive relationship is significant enough to indicate that the more nutritious the breakfast, the better the associated nutritional intake (Table 2). The correlation coefficient between NI and GMB is 0.72. This is the strongest correlation, suggesting that dietary intake is a major factor in gut microbial balance. The correlation coefficient between GMB and DH is 0.76. A very high correlation, which demonstrates that the gut microbiota is a significant contributor to digestive health. BP and GMB are also related with a correlation coefficient of 0.55. Moderately positive correlation, which means that the breakfast habits have both direct and indirect impacts on the microbiota.

- BP and DH are correlated with a $r=0.49$. The moderate relationship implies that breakfast habits are not enough, but are nevertheless significant to the health of the digestive system. NI and DH correlation is 0.63. A considerable connection, and the importance of nutrient consumption in digesting. The results of bootstrapping verify that in Smart PLS the correlations are normally valid, that is to say that they confirm that: All interactions indicate statistical significance ($p < 0.05$).

- No negative correlations apparent, constant directional associations. The correlation analysis performed with Smart PLS indicates that all research variables are strongly positively correlated. These results provide initial evidence for the structural model and indicate that the primary process linking breakfast habits to digestive well-being is the balance of the gut microbiota.

3.12 Applications of a Biomathematical Model for Breakfast Patterns, Gut Microbiota, and Digestive Health

The Smart PLS is software used in biomathematical and structural equation modelling that integrates to create an efficient, multidisciplinary approach to exploring the correlation among breakfast habits, small intestinal flora, and digestive health. The integration will also be applied in population health, digital health technology, health care, and nutrition science.

3.12.1 Personalized Nutrition and Diet Planning

This application method is predominantly used in personalized nutrition. The model would be able to help create individualized diet programs by considering each person's breakfast habits, food consumption habits, and microbial responses. For example:

- Encourage people with bad digestive systems to eat a balanced and high-fibre breakfast.
- The model is forecasted to predict the influence of various diets (e.g., high sugar vs. high protein) on the compositions of gut bacteria.
- Model results can help nutritionists to suggest a proper time to eat depending on circadian rhythms. It is particularly helpful in precision medicine, in which dietary therapy is tailored to an individual's biological profile.

3.12.2 CDSS integration

The model can assist medical professionals in identifying and treating gastrointestinal issues. Conditions like this:

- Irritable bowel syndrome (IBS). Symptoms: constipation and bloating. Simulation of microbial responses can be used in understanding dysbiosis-associated inflammation. Smart PLS can assist clinicians in proving the causal relationship between food behaviors and health outcomes. This permits evidence-based diets rather than general recommendations.

3.12.3 Development of Public Health Policy and Nutritional Policy:

The model can guide the development of community-level policies on dietary choices to promote the population. Healthcare organizations and governments can:

- Determine the effectiveness of breakfast avoidance on the outcome of digestive health. - Develop awareness campaigns that will promote the consumption of a healthy breakfast.
- Predictive simulations should be used to determine the long-term health impact of poor diets. For example, school breakfast programs can be adjusted based on model findings to enhance children's gut health and overall health.

3.12.4 Inclusion in Mobile Health Applications

As digital health technology evolves, there are opportunities to incorporate it into mHealth applications. These

applications can:

- Track the dietary intake and breakfast of users.
- Provide live feedback about gut health conditions.
- Predictive analytics should be used to suggest healthier foods. Such applications may offer smart, adaptive food suggestions by integrating bio-mathematical equations with behavioural data analysed using Smart PLS.

3.12.5 Preventive Healthcare and Early Intervention

Prevention Healthcare is a highly important application. The algorithm can detect early signs of intestinal imbalance by analysing changes.

- Microbial diversity
- Enhances the intake of nutrients. Language impairment (z) Digestive health (z) The early detection of dysbiosis enables the introduction of an appropriate diet in time and reduces the chances of developing chronic illnesses.

3.12.6 Monitoring and Optimizing Lifestyle Treatments

The model can measure the effectiveness of lifestyle treatments, such as:

- Intermittent fasting.
- Restricted feeding times
- Modifications to diet.

It is possible to assess the success of a given intervention by observing changes in gut flora and digestive health among individuals and healthcare providers. It is then possible to make real-time adjustments to maximise results. It is an effective and versatile tool in contemporary healthcare and research, with applications at both the individual and broader population levels.

4. Discussion

The present study proves the effectiveness of the integration of biomathematical modeling and statistical validation to assess the relationship between breakfast habits, intestinal flora, and digestive well-being. These results reveal that breakfast consumption and overall dietary habits strongly influence the microbial balance and well-being of the digestive system. The results indicate that a healthy gut flora can be developed through regular consumption of a balanced breakfast, thereby improving nutritional availability. This is in addition to existing scientific evidence that high-fibre, complex-carbohydrate, and protein-rich diets can help preserve microbial diversity and stability. Conversely, breakfast habits and sugar-rich foods are associated with increased levels of harmful bacteria, which can cause a microbial imbalance, or dysbiosis. Such abnormalities have been reported to impair digestion, metabolism, and the immune response. The structural equation model tested with Smart PLS demonstrates that the gut microbiota significantly mediates the relationship between breakfast habits and digestive well-being. This intermediary impact places significant stress on the idea that eating patterns indirectly affect the gut environment, which is largely predetermined by the relationships among microbes. The high R^2 for digestive health indicates that breakfast variables are important predictors of gastrointestinal outcomes. The simulation of biological processes using nonlinear differential equations is another significant aspect of this research. It is a biomathematical approach that can be used to dynamically describe the interaction between nutrients and microbes over time, a task that statistical models alone cannot achieve. When combined with empirical validation using Smart PLS, the model is strengthened and practically useful. However, it has certain limitations that should be mentioned. The model is built on simplified assumptions about the dynamics of microbial populations and nutritional conditions, which may not capture the complexity of the human gut microbiome. In addition, weak causal inference can result from using cross-sectional or simulated data. Future research would involve adding longitudinal clinical data to existing models to enhance their accuracy and incorporating up-to-date microbiome sequencing technology. According to the overall findings of this study, there is strong evidence that breakfast plays an essential role in digestive health by regulating gut flora. Smart PLS can be used in biomathematical modelling to offer a differentiated and holistic approach to examining the associations between diets and microbiomes, which could prove immeasurably helpful in designing customised diets and proactive healthcare.

5. Conclusion

It reports an all-inclusive, cross-disciplinary approach to assessing the influence of breakfast routines on the gut microbiota and gut health, using bio-mathematical modelling and statistical validation with Smart PLS. The figures have clearly indicated that behavioural control at breakfast is not merely a cultural practice but also a basic sign of GI well-being

and intestinal equilibrium. The biomathematical model offers great insight into the interactions among the dynamic processes of dietary intake, beneficial and harmful bacteria, and, overall, the health of the digestive system. The research uses nonlinear equations to examine the effects of changes in the timing, content, and frequency of breakfast on nutrient availability and microbial growth. Excellent food eaten on a regular basis promotes the growth of beneficial bacteria, microbial diversity, and optimal digestive function. Conversely, a poor or unhealthy breakfast, especially one high in sugar, and skipping meals disrupts the bacterial equilibrium, leading to inefficient digestion. Empirical validation of the proposed framework using Smart PLS reinforces its reliability. The presence of strong route correlations and the model's high explanatory power indicate that breakfast routines influence digestive health both directly and indirectly, with the gut microbiota serving as a mediator. This makes it clear that both behavioural and biological effects should be considered when analyzing the impact of food. Moreover, the study notes the significance of combining theoretical modelling and data analysis. Smart PLS can be statistically verified and predicted, and can explain gastrointestinal activities using biomathematical equations. The two-pronged approach intensifies and broadens the study, making it appropriate for both academic and practical use. Despite the contribution made in the paper, the paper also indicates limitations in the assumptions reduced in the mathematical model and in the limited data used to test the model. Such limitations open promising directions for further study, such as using real-time clinical data, improving microbiome data processing, and applying machine learning to further improve the model. In short, the article examines the impact of breakfast rituals on gut health and overall digestion. The article is useful to the field of preventative healthcare as it provides a new vision of mathematics, nutrition, and data analytics. It also introduces new possibilities for customised nutritional interventions, leading to improved health outcomes and quality of life.

6. Recommendations

Based on the study's results, several practical and research recommendations are presented to improve digestive health by adopting more appropriate breakfast habits and to advance research.

- To begin with, the population must be advised to eat a healthy breakfast daily. A diet rich in fibre, protein, and complex carbohydrates must be prioritized to support healthy gut bacteria and gut stability. It is essential to avoid high-sugar and highly processed breakfast foods, as they are thought to cause microbial imbalance and reduced digestive efficiency.
- Second, microbiota-targeted dietary recommendations need to be incorporated into everyday clinical practice by healthcare professionals and nutritionists. Evidence-based decision-making can be improved with the help of analytical technologies, such as Smart PLS, that identify major correlations between dietary preferences and health outcomes. This may lead to better customized and effective nutritional interventions.
- Politicians and health groups can form awareness campaigns about the need to have breakfast to maintain good health in the intestines. Health promotion can be used to upgrade healthy practices, especially among the youth, through nutrition education in schools and employment welfare programs. On the technological side, there is an urgent need to design digital health apps that incorporate bio-mathematical models and real-time nutrition tracking. These platforms can send personalized feedback and projected information to customers, enabling them to lead healthier lives. In addition, it is possible to revise the model and add some lifestyle variables, which can be physical activity, sleep patterns, and stress levels, to have a more comprehensive picture of gut health. In conclusion, proper breakfast habits and recent analytical methods, such as Smart PLS, can significantly enhance understanding of the gut microbiome and the overall health of the digestive system.

7. References

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