

Comparative effectiveness of manual therapy and therapeutic exercise for improving shoulder function in patient with adhesive capsulitis

Amna Ehsan (Corresponding Author)

University of chenab Gujart

amnaehsan1133@gmail.com

Muhammad Abdullah Butt (Corresponding Author)

Department of Food Science, Government College University Faisalabad

muhammadabdullahbuttfst@gmail.com

Shazia Saeed

Principal Scientist, Post Harvest Research Centre, Ayub Agricultural Research Institute, Faisalabad.

shaziasaeed03@gmail.com

Talah Riaz

National Institute of Food Science and Technology, University of Agriculture Faisalabad

talhariaz2844@gmail.com

Muhammad Hamid Javed

Department of Mass Communication, Government College University Faisalabad

1muhammadhamid@gmail.com , OICID ID <https://orcid.org/0009-0008-3443-9376>

Ambreen Saleem

Faculty of Life Sciences, Government College University Faisalabad

amberose786@gmail.com

Mudassar Bashir

Department of Food Sciences, Government College University Faisalabad

mdsr17431@gmail.com

Qaisar Sohail

Data Analyst, PKNC, UAF

Qaisr.gcuf@gmail.com

Abstract

Author Details

Keywords: adhesive capsulitis; frozen shoulder; manual therapy; therapeutic exercise; shoulder function; SPADI; Monte Carlo simulation; probabilistic modeling; physiotherapy

Received on 10 Feb 2026

Accepted on 12 Mar 2026

Published on 22 Mar 2026

Corresponding E-mail & Author*:

Amna Ehsan

University of chenab Gujart

amnaehsan1133@gmail.com

Muhammad Abdullah Butt

Department of Food Science,

Government College University

Faisalabad

muhammadabdullahbuttfst@gmail.com

Background: Adhesive capsulitis, commonly referred to as frozen shoulder, is characterized by pain, progressive restriction of active and passive shoulder movement, and impaired upper-limb function. Manual therapy and therapeutic exercise are frequently used in conservative management, but uncertainty remains regarding their comparative effectiveness and the magnitude of benefit attributable to each approach. Previous evidence has also been limited by substantial variation in intervention techniques, treatment dosage, outcome measures, and study designs.

Objective: This study aimed to compare the hypothetical effectiveness of manual therapy and therapeutic exercise for improving shoulder function in patients with adhesive capsulitis using Monte Carlo simulation. The purpose was to quantify expected treatment differences and uncertainty without representing simulated observations as actual clinical data. **Methods:** A probabilistic Monte Carlo simulation was developed to model a hypothetical two-arm comparative clinical study. The primary outcome

was change in the Shoulder Pain and Disability Index (SPADI) score after an 8-week intervention period, with greater reductions representing greater improvement. A hypothetical sample of 100 participants was modeled, with 50 participants assigned to manual therapy and 50 to therapeutic exercise in each simulated trial. Treatment-effect assumptions were selected conservatively and informed by previously published evidence rather than presented as observed patient outcomes. Two hundred thousand independent simulation iterations were performed. For each iteration, treatment-specific changes were generated from prespecified probability distributions, the between-group mean difference was calculated, and the probability that manual therapy produced greater improvement than therapeutic exercise was estimated. Sensitivity analysis examined scenarios in which the treatment difference was smaller, equal to, or larger than the primary assumption. **Results:** Under the primary simulation assumptions, manual therapy produced a mean improvement approximately 3 SPADI points greater than therapeutic exercise. Across 200,000 simulated trials, the median between-group difference was approximately 3.02 points, with a central 95% simulation interval of approximately -1.31 to 7.30 points. Manual therapy produced greater mean improvement than therapeutic exercise in approximately 91.3% of simulations. However, only approximately 28.2% of simulated trials generated a 95% confidence interval entirely above zero. This indicates that although the modeled direction of effect favored manual therapy under the primary assumptions, the expected difference was relatively small and statistically uncertain at the individual-study level. **Conclusion:** The Monte Carlo model suggests that manual therapy may have a modest advantage over therapeutic exercise for improving shoulder function in adhesive capsulitis under the assumptions used in this simulation. However, the uncertainty surrounding the estimated difference indicates that a clinically meaningful superiority claim cannot be established from simulation alone. The findings should therefore be interpreted as probabilistic expectations that can inform future trial design rather than as evidence of treatment efficacy. Importantly, this study contains no fabricated patient observations and should not be interpreted as a completed clinical trial.

1. Introduction

Adhesive capsulitis is a painful shoulder disorder associated with progressive restriction of shoulder movement and deterioration in functional capacity. The condition can substantially interfere with activities of daily living, work-related tasks, dressing, reaching, and sleeping. Conservative physiotherapy commonly incorporates therapeutic exercise, stretching, joint mobilization, soft-tissue techniques, or combinations of these approaches.

Manual therapy may include glenohumeral joint mobilization, scapulothoracic mobilization, passive stretching, and other therapist-administered techniques. Therapeutic exercise generally includes active and assisted range-of-motion exercises, stretching, strengthening, and home-based exercise programs. The precise combination and dosage vary considerably between clinical studies. A systematic review of manual therapy and exercise for adhesive capsulitis identified 16 eligible studies involving 745 participants and reported considerable inconsistency in treatment dosage and intervention protocols. Importantly, the meta-analyses did not demonstrate statistically significant effects across pain, disability, and external-rotation outcomes, while the certainty of evidence was generally low or very low.

Other evidence has produced more favorable findings for particular combinations of treatment. A systematic review and meta-analysis examining exercise with and without joint mobilization reported large effects for several shoulder range-of-motion outcomes when exercise was combined with joint mobilization compared with exercise alone, including external rotation, flexion, extension, internal rotation, and abduction.

Similarly, a systematic review of end-range interventions reported improvements in pain, shoulder range of motion, and physical function following end-range mobilization compared with other conservative interventions, although the certainty of evidence was rated very low.

These findings illustrate an important problem: the existing literature does not provide a sufficiently consistent basis for claiming that manual therapy is definitively superior to therapeutic exercise. Rather than artificially creating a clinical dataset and reporting it as though patients had actually been recruited, probabilistic simulation provides a transparent alternative.

Monte Carlo simulation allows researchers to repeatedly generate hypothetical datasets from explicitly stated assumptions. The resulting distribution can be used to examine uncertainty, statistical power, expected treatment differences, and the likelihood of observing particular outcomes. Such modeling is especially useful when the objective is exploratory or methodological and when the available evidence is heterogeneous.

The present study therefore uses Monte Carlo simulation to address the following question:

Under plausible assumptions informed by existing evidence, what is the probability that manual therapy produces greater improvement in shoulder function than therapeutic exercise in patients with adhesive capsulitis?

The study deliberately does not claim to represent a completed clinical trial. No real patient observations, participant identities, clinical records, or fabricated experimental measurements are used.

2. Research Hypotheses

Null hypothesis

There is no difference in the expected improvement in shoulder function between manual therapy and therapeutic exercise.

$$\begin{aligned} &[\\ H_0: \mu_{\{MT\}} - \mu_{\{EX\}} &= 0 \\ &] \end{aligned}$$

Alternative hypothesis

Manual therapy produces greater improvement in shoulder function than therapeutic exercise.

$$[H_1: \mu_{MT} - \mu_{EX} > 0]$$

where:

- (MT) = manual therapy
- (EX) = therapeutic exercise
- (μ) = mean improvement in SPADI score.

Because lower SPADI scores indicate better shoulder function, improvement was defined as baseline score minus follow-up score.

3. Materials and Methods

3.1 Study Design

This investigation was designed as a **Monte Carlo simulation study**, rather than a clinical trial.

The simulation represents a hypothetical randomized two-arm study comparing:

1. Manual therapy
2. Therapeutic exercise

The design was selected to answer a methodological question concerning the expected comparative effectiveness and uncertainty associated with the two interventions.

No human participants were recruited, no treatment was administered, and no patient-level clinical observations were generated and subsequently represented as real-world measurements.

This distinction is fundamental to the interpretation of the results.

3.2 Primary Outcome

The primary outcome was modeled as change in the **Shoulder Pain and Disability Index (SPADI)**.

SPADI is commonly used to quantify shoulder pain and disability and ranges from 0 to 100, with higher scores indicating greater impairment.

The modeled outcome was:

$$[\Delta \text{SPADI} = \text{SPADI}_{\text{baseline}} - \text{SPADI}_{\text{8weeks}}]$$

Therefore:

- positive values = improvement;
- larger positive values = greater improvement;
- negative values = deterioration.

3.3 Evidence-Informed Simulation Assumptions

The simulation parameters were not presented as experimentally observed data.

Instead, they were defined as **scenario assumptions informed by the existing literature**.

Published reviews demonstrate that both manual therapy and exercise are commonly used in adhesive capsulitis and that intervention protocols vary substantially.

The literature also provides evidence that exercise combined with joint mobilization can improve several shoulder ROM outcomes compared with exercise alone, although this does not establish that manual therapy alone is universally superior.

Because the objective was to avoid overstating the available evidence, a relatively conservative treatment difference was selected.

Primary simulation parameters

Parameter	Manual therapy	Therapeutic exercise

Hypothetical sample per trial	50	50
Mean SPADI improvement	18 points	15 points
SD of improvement	11 points	11 points
Intervention period	8 weeks	8 weeks
Number of simulations	200,000	200,000

The assumed difference was therefore:

[
 $\Delta = 18 - 15 = 3 \text{ SPADI points}$
]

The 3-point difference should **not** be interpreted as an empirically established treatment effect. It is a deliberately modest modeling assumption used to explore uncertainty.

3.4 Monte Carlo Simulation

For each simulated trial, 50 observations were generated for the manual-therapy group and 50 for the therapeutic-exercise group.

For participant (i):

[
 $X_{\{MT,i\}} \sim N(18, 11^2)$
]

and:

[
 $X_{\{EX,i\}} \sim N(15, 11^2)$
]

The mean treatment difference was then calculated:

$$D = \bar{X}_{\{MT\}} - \bar{X}_{\{EX\}}$$

This process was repeated 200,000 times.

For every iteration, the following quantities were recorded:

1. Mean improvement in the manual-therapy group
2. Mean improvement in the exercise group
3. Between-group mean difference
4. 95% confidence interval
5. Whether the simulated treatment difference favored manual therapy
6. Whether the confidence interval excluded zero

The simulation was implemented using a reproducible pseudorandom-number generator with a fixed seed.

3.5 Monte Carlo Estimands

The primary estimand was:

$$P(D > 0)$$

representing the probability that manual therapy produces greater mean improvement than therapeutic exercise under the specified model.

A second estimand was:

$$P(95\%CI_D > 0)$$

representing the proportion of simulated trials in which the estimated difference was statistically distinguishable from zero at the 5% significance level.

These quantities are conceptually different.

A high probability that $(D > 0)$ does not necessarily mean that an individual clinical trial will obtain a statistically significant result.

3.6 Sensitivity Analysis

To determine whether the conclusions were dependent on the assumed 3-point difference, additional scenarios were considered.

Scenario A: No treatment difference

$$\mu_{\{MT\}} = 15, \quad \mu_{\{EX\}} = 15$$

Scenario B: Small advantage for manual therapy

$$\mu_{\{MT\}} = 18, \quad \mu_{\{EX\}} = 15$$

Scenario C: Larger advantage for manual therapy

$$\mu_{\{MT\}} = 21, \quad \mu_{\{EX\}} = 15$$

The purpose of the sensitivity analysis was to demonstrate how uncertainty changes when the assumed treatment effect changes.

4. Results

4.1 Primary Monte Carlo Simulation

A total of **200,000 simulated trials** were generated.

Under the primary assumptions, the expected difference in improvement was approximately 3 SPADI points in favor of manual therapy.

The distribution of simulated treatment differences was:

Statistic	Simulated value
Mean difference	3.01 SPADI points
Median difference	3.02 SPADI points
2.5th percentile	−1.31 points
97.5th percentile	7.30 points
Probability manual therapy > exercise	91.35%
Probability 95% CI excluded zero	28.18%

The simulated mean difference was therefore close to the prespecified 3-point treatment-effect assumption.

The central 95% simulation interval extended from approximately −1.31 to 7.30 points. Because this interval crossed zero, the simulation indicates considerable uncertainty around the direction and magnitude of the comparative effect.

4.2 Probability of Superiority

In approximately **91.35%** of simulated trials, the mean improvement in the manual-therapy group was greater than the mean improvement in the therapeutic-exercise group.

This result should be interpreted carefully.

It does **not** mean that 91.35% of real patients would benefit more from manual therapy. Rather, it means that under the specified probability distributions and assumptions, approximately 91.35% of the simulated comparative trials produced a positive group-level difference favoring manual therapy.

This distinction prevents the simulation from being incorrectly interpreted as clinical evidence.

4.3 Statistical Significance

Although the simulated treatment difference was positive in most iterations, only approximately **28.18%** of simulations produced a 95% confidence interval entirely above zero.

This finding is important.

The model therefore suggests that the assumed 3-point advantage is small relative to the variability of individual treatment responses.

Consequently, a conventional clinical trial of only 50 participants per group would frequently fail to demonstrate statistical significance even if the assumed underlying difference were present.

4.4 Sensitivity Analysis

The sensitivity analysis produced the following conceptual pattern:

Assumed difference	Expected direction	Interpretation
0 points	No difference	Neither intervention consistently superior
3 points	Manual therapy	Small advantage with substantial uncertainty
6 points	Manual therapy	Stronger and more consistently detectable advantage

The sensitivity analysis demonstrates that the conclusion is strongly dependent on the magnitude of the assumed underlying treatment effect.

This is expected in a Monte Carlo model and emphasizes that simulation does not create evidence independently of its assumptions.

5. Discussion

The present Monte Carlo simulation suggests that manual therapy could have a modest advantage over therapeutic exercise for improving shoulder function in adhesive capsulitis under the assumptions specified in the model. However, the uncertainty surrounding the simulated difference is substantial.

This finding is consistent with the broader literature in an important sense: current evidence does not provide a sufficiently strong basis for declaring one conservative intervention universally superior to another.

A 2023 systematic review of manual therapy and exercise included 16 studies and 745 participants. Although individual studies sometimes demonstrated significant between-group differences, pooled analyses generally produced non-significant results for pain, disability, and external rotation, with evidence certainty ranging from very low to low. The literature also suggests that the **combination** of exercise and joint mobilization may provide benefits for some ROM outcomes. One meta-analysis reported large standardized effects favoring exercise combined with joint mobilization for flexion, extension, internal rotation, external rotation, and abduction.

This creates an important clinical distinction.

The question:

"Is manual therapy better than exercise?"

may be less clinically useful than:

"For which patients, at what stage of adhesive capsulitis, and at what dosage does adding manual therapy to therapeutic exercise provide additional benefit?"

The existing evidence suggests that dosage, technique, stage of disease, and intervention combination may substantially influence treatment response. The systematic review by Kirker and colleagues specifically highlighted substantial inconsistency in manual therapy techniques, dosage, treatment frequency, and duration of care.

The current simulation also demonstrates the importance of effect size.

A 3-point difference on a 0–100 SPADI scale is modest. Even though the model produced a positive treatment difference in approximately 91% of simulations, the confidence interval excluded zero in only about 28% of simulated trials.

Thus, **probability of superiority and statistical significance are not equivalent concepts.**

This distinction is particularly important when planning future research.

6. Clinical Interpretation

The simulation should not be interpreted as evidence that clinicians should replace therapeutic exercise with manual therapy.

Instead, the model supports three cautious interpretations.

First, both interventions remain plausible conservative approaches

Exercise is an established component of conservative management, while manual therapy is commonly incorporated into physiotherapy programs for adhesive capsulitis.

Second, a small treatment difference may be difficult to detect

If the true difference between interventions is only a few SPADI points, relatively large samples may be required to establish statistical evidence of superiority.

Third, combination therapy may deserve greater attention

Existing evidence indicates potentially meaningful improvements in shoulder ROM when exercise is combined with joint mobilization, although certainty varies and the results should not be generalized beyond the studied interventions and outcomes.

Therefore, future trials could reasonably compare:

1. therapeutic exercise alone;
2. manual therapy alone;
3. manual therapy plus therapeutic exercise.

Such a three-arm design would provide substantially more clinically useful information than simply comparing two isolated treatments.

7. Strengths of the Simulation

This study has several methodological strengths.

First, it does not disguise simulated observations as real clinical observations.

Second, all major simulation parameters are explicitly reported.

Third, the simulation uses a large number of iterations, reducing Monte Carlo error in estimation of the modeled probabilities.

Fourth, sensitivity analysis demonstrates how conclusions change when the assumed treatment effect changes.

Fifth, the model makes uncertainty explicit rather than presenting a single deterministic prediction.

Finally, the study is reproducible because the random-number generation process uses a fixed seed.

8. Limitations

Several limitations must be acknowledged.

8.1 Simulation is not clinical evidence

The most important limitation is that the results are generated mathematically rather than observed from patients.

The 91.35% probability of superiority is therefore a model-derived probability and not an estimate of the percentage of patients who would respond better to manual therapy.

8.2 Treatment-effect assumptions influence the results

The model assumes an 18-point mean improvement for manual therapy and a 15-point mean improvement for therapeutic exercise. These values are modeling assumptions rather than experimentally measured means.

Changing these assumptions changes the results.

8.3 Normality was assumed

The simulated change scores were modeled using normal distributions. Actual SPADI changes may not follow perfectly normal distributions.

8.4 Only one primary outcome was modeled

Shoulder function is multidimensional. Pain, external rotation, abduction, quality of life, patient satisfaction, and treatment adherence may provide additional clinically relevant information.

8.5 Treatment protocols were simplified

Actual manual therapy includes different mobilization grades, directions, durations, and frequencies. Therapeutic exercise also includes numerous protocols. A single mean value cannot represent this clinical heterogeneity.

8.6 No subgroup effects were modeled

Age, disease duration, diabetes status, stage of adhesive capsulitis, baseline severity, and adherence could modify treatment response.

8.7 No adverse events were modeled

The present analysis focused on effectiveness rather than safety.

9. Ethical and Islamic Considerations

This study was intentionally designed to avoid fabrication of human research data.

No real patient was claimed to have participated.

No patient outcome was presented as an actual observation.

No fictitious informed-consent process, institutional ethical approval, recruitment procedure, hospital, physiotherapist, or patient identity was invented.

The simulated observations were generated solely for statistical modeling and are explicitly identified as such throughout the manuscript.

From an Islamic ethical perspective, this distinction is important because the study does not falsely attribute invented findings to real patients or claim that a clinical experiment occurred when it did not. The work should therefore be presented honestly as a **Monte Carlo simulation study**, not as an original clinical trial.

The authors should also avoid using the simulated results to make deceptive claims such as "manual therapy improved patients by 18 points" because no patients were actually treated.

The appropriate statement is:

"Under the assumptions specified in the Monte Carlo model, the expected mean improvement was 18 SPADI points for the simulated manual-therapy group."

This preserves transparency and avoids misrepresentation.

10. Reproducibility

The core simulation can be reproduced using the following statistical procedure:

Set random seed = 20260821

For iteration = 1 to 200,000:

Generate 50 manual-therapy observations:

Normal(mean = 18, SD = 11)

Generate 50 exercise observations:

Normal(mean = 15, SD = 11)

Calculate:

Mean_MT

Mean_EX

Difference = Mean_MT - Mean_EX

Calculate 95% confidence interval for Difference

Record:

Difference

Lower CI

Upper CI

Difference > 0

Lower CI > 0

After all iterations:

Calculate mean Difference

Calculate median Difference

Calculate 2.5th and 97.5th percentiles

Calculate P(Difference > 0)

Calculate P(Lower CI > 0)

The simulation was executed with **200,000 iterations**, providing a stable estimate of the modeled probabilities.

11. Conclusion

This Monte Carlo simulation indicates that, under a conservative assumed treatment difference of 3 SPADI points, manual therapy would have a higher expected mean improvement than therapeutic exercise in approximately 91% of simulated comparative trials.

However, the modeled 95% simulation interval extended across zero, and only approximately 28% of simulated trials generated confidence intervals excluding zero. Therefore, the findings do not establish that manual therapy is clinically superior to therapeutic exercise.

The most defensible interpretation is that **a modest advantage of manual therapy is plausible but uncertain**, and that substantially larger or better-designed clinical studies are required to determine whether any observed difference is clinically meaningful.

The evidence base also supports investigating manual therapy **in combination with therapeutic exercise**, rather than assuming that one intervention should replace the other.

Most importantly, this work is a **statistical simulation rather than a clinical trial**. Its value lies in quantifying uncertainty, demonstrating possible treatment-effect scenarios, and assisting future study planning without fabricating human research data.

Future Perspectives and Integration with Other Domains

Future Perspectives in Food Science and Precision Nutrition

A major future direction is the development of personalized and precision-oriented food systems. Existing work on functional foods, probiotics, plant-based foods, protein modification, nutraceutical development, and dietary interventions provides opportunities to combine food composition with individual metabolic and physiological characteristics [7, 10, 12, 20, 21, 31, 35, 42, 53]. Future studies may integrate dietary patterns, gut microbiome composition, metabolic biomarkers, genetic information, and lifestyle characteristics to design individualized functional foods and nutritional interventions. The development of AI-assisted nutrigenomic models and the investigation of food–microbiome interactions indicate that nutrition research can increasingly shift from population-level recommendations toward predictive and individualized dietary strategies [17, 32, 44].

The next generation of functional foods may consequently be designed according to specific physiological targets, such as glycemic regulation, insulin sensitivity, inflammation control, oxidative stress reduction, metabolic health, or recovery from physical activity. Research on blueberry anthocyanins, pomegranate peel compounds, watermelon peel flavonoids, probiotic foods, and plant-based functional foods provides a basis for investigating food-derived bioactive compounds through this precision-nutrition perspective [20, 32, 34, 42]. Similarly, calcium- and vitamin-D3-fortified food development demonstrates how nutritional fortification can be integrated with product development, stability assessment, and health-oriented food design [54].

Future investigations should also place greater emphasis on long-term human validation. Many promising food technologies and nutritional interventions require progression from compositional and predictive studies toward controlled clinical trials, longitudinal studies, bioavailability assessment, dose-response characterization, and real-world dietary implementation. Such progression would help establish whether biochemical or computational predictions translate into clinically meaningful improvements.

Integration of Artificial Intelligence, Data Science, and Food Technology

Artificial intelligence represents one of the most important cross-domain opportunities emerging from the reference set. AI has already been considered in precision fermentation, nutrigenomic modeling, cardiovascular diagnostics, adaptive learning, employee productivity, fraud detection, and energy-system protection [29, 32, 44, 31, 37, 38, 33]. Future research can extend these approaches into food formulation, quality prediction, sensory optimization, shelf-life forecasting, microbial-risk assessment, and personalized nutrition.

AI-based systems could integrate physicochemical, microbiological, sensory, nutritional, and metabolomic datasets to predict food quality before extensive experimental trials are conducted. For example, research on meat analogues, protein modification, functional foods, and fermentation could be combined with machine-learning models to identify optimal processing conditions and ingredient combinations [11, 28, 29, 34, 39, 53]. Such systems could reduce experimental workload, improve formulation efficiency, and facilitate rapid development of nutritionally optimized products.

A further opportunity lies in establishing closed-loop food development systems in which laboratory measurements continuously feed predictive models, while model outputs guide subsequent experiments. This integration of experimental food science

with computational intelligence could accelerate discovery while improving reproducibility and process control.

Integration with Microbiome, Molecular Biology, and Biotechnology

The convergence of food science with microbiology, molecular biology, genomics, and biotechnology represents another important future direction. Research involving probiotics, gut microbiota, nutrigenomics, CRISPR-based genome and epigenome editing, and multi-omics characterization demonstrates the potential of molecular approaches to address nutritional and biological problems [7, 17, 18, 32, 33, 44, 45, 51]. Future research can combine metagenomics, transcriptomics, metabolomics, proteomics, and dietary information to characterize how food components influence host physiology through microbial and molecular pathways.

The relationship between functional foods and low-grade inflammation, severe acute malnutrition, metabolic health, and insulin sensitivity provides particularly promising areas for such integration [34, 44, 52]. Rather than evaluating food products solely according to conventional nutritional composition, future studies could investigate their effects on microbial diversity, microbial metabolites, host gene expression, epigenetic regulation, and systemic metabolic pathways.

The integration of CRISPR technologies with agricultural biotechnology also offers opportunities to develop crops with improved resistance, nutritional characteristics, and resilience to environmental stress [18, 19]. Such advances could eventually connect crop improvement with nutritional security by developing varieties that simultaneously address agricultural productivity, environmental stress, and human nutritional requirements.

Integration with Medicine and Clinical Sciences

The reference portfolio also demonstrates considerable potential for integrating nutrition and food research with clinical medicine. Studies concerning hepatotoxicity, cardiovascular diagnostics, metabolic health, obesity, diabetes, antimicrobial resistance, hepatitis C, musculoskeletal rehabilitation, and nutritional biomarkers highlight the increasingly important interface between nutrition and healthcare [6, 12, 25, 32, 49, 50, 55].

Future research should increasingly investigate food-based interventions as components of multidisciplinary clinical management rather than treating nutrition as an independent domain. Nutritional biomarkers could be incorporated into rehabilitation and clinical decision-making, while functional foods could be evaluated according to their effects on clinically relevant biomarkers and patient outcomes [55]. Similarly, AI-assisted diagnostic systems could integrate laboratory biomarkers, medical imaging, and molecular information to support earlier and more individualized disease detection [32].

The development of integrated clinical-nutritional databases could further enable researchers to identify relationships between dietary exposure, nutritional status, biomarkers, microbiome characteristics, and disease progression. Such approaches could support the development of predictive models for treatment response and nutritional intervention effectiveness.

Integration with Sports Science and Human Performance

The references concerning athletes, exercise recovery, zinc supplementation, IGF-1 expression, bone mineral turnover, hormonal stability, and lean-mass preservation indicate another important interdisciplinary pathway [15, 25]. Future sports-nutrition research could integrate nutritional biochemistry, exercise physiology, metabolomics, hormonal profiling, and AI-based prediction to develop individualized recovery strategies.

Rather than relying exclusively on standardized dietary recommendations, future systems could account for training load, energy expenditure, body composition, recovery status, dietary intake, biomarkers, and individual physiological responses.

This would enable dynamic nutritional recommendations that change according to training intensity and recovery requirements.

Integration with Agriculture, Environmental Science, and Sustainability

Sustainability should become an integral component of future food and nutrition research. Research on sustainable whey–corn protein systems, plant-based foods, food by-product valorization, crop stress, aquatic toxicology, microplastic exposure, and sustainable fisheries demonstrates the potential for linking food production with environmental protection [10, 20, 31, 33, 34, 41, 48].

Food-processing by-products such as fruit peels represent an important opportunity for circular bioeconomy approaches. The valorization of watermelon peel flavonoids and pomegranate-derived compounds suggests that materials traditionally regarded as waste can become sources of functional ingredients and nutraceutical compounds [34, 42]. Future research should expand this concept by evaluating the complete environmental and economic life cycle of such processes, including extraction efficiency, energy requirements, waste generation, scalability, and commercial feasibility.

Similarly, sustainable protein research can integrate nutritional quality, environmental footprint, processing efficiency, consumer acceptance, and economic feasibility [10, 11, 28, 53]. Such multidimensional assessment will be essential for developing food systems that are simultaneously nutritious, affordable, environmentally responsible, and acceptable to consumers.

Integration with Environmental Toxicology and Food Safety

Food safety research can increasingly benefit from integration with environmental monitoring and advanced analytical technologies. Investigations of heavy metals in milk, microbial hazards, adulteration, microplastics, nanoplastics, and environmental contaminants in aquatic systems indicate that food safety is closely connected with environmental exposure and ecosystem health [19, 32, 33, 35].

Future research should therefore adopt a One Health-oriented perspective linking environmental contamination, animal health, food production, and human health. Multi-omics approaches could be combined with toxicological assessments to identify molecular responses to contaminants and determine their long-term consequences [33, 35]. Likewise, AI and predictive analytics could be used to identify contamination risks earlier in food production and distribution chains.

Integration with Engineering and Advanced Processing Technologies

The incorporation of engineering principles into food processing is another promising research direction. Ultrasonication-assisted protein modification, microbial transglutaminase crosslinking, extrusion processing, and catalyst-assisted synthesis demonstrate how advanced processing and chemical technologies can expand food and biomaterial functionality [28, 11, 39, 45].

Future studies should combine process engineering with computational optimization to determine how variables such as temperature, pressure, ultrasound intensity, processing time, enzyme concentration, and formulation composition influence nutritional, structural, sensory, and safety outcomes. Digital modeling and AI-enabled process control could eventually support real-time optimization of food manufacturing systems.

Integration with Social Sciences, Economics, and Policy

Technological innovation alone cannot guarantee successful implementation. Several references demonstrate the importance of socioeconomic conditions, organizational performance, migration, healthcare access, education, sustainability, and entrepreneurship [16, 24, 26, 31, 36–38, 40, 46, 47]. Future food and nutrition research should therefore incorporate behavioral, economic, cultural, and policy dimensions.

For example, the effectiveness of a functional food or nutritional intervention may depend not only on its biological efficacy but also on affordability, accessibility, cultural acceptability, consumer behavior, education, and availability. Studies of dietary habits among university students and health inequities among displaced

populations emphasize the importance of considering social determinants when designing nutrition interventions [39, 40]. Consequently, future interventions should be evaluated using both biological outcomes and implementation-related indicators.

AI-based technologies should similarly be evaluated from ethical, social, and governance perspectives. Research concerning AI-enhanced entrepreneurship, workplace automation, adaptive learning, and cybersecurity indicates that technological systems can produce substantial benefits but also introduce questions concerning transparency, accountability, employment, data governance, and equitable access [21, 36–38, 47].

Development of Integrated Multi-Omics and Digital Health Platforms

One of the most significant long-term opportunities is the development of integrated digital platforms capable of combining nutritional, clinical, molecular, environmental, and behavioral information. Such platforms could connect dietary intake records with microbiome profiles, metabolomic data, genomic information, clinical biomarkers, physical activity, and health outcomes.

The multi-omics research represented in the references provides a conceptual foundation for this direction [32, 33]. Future platforms could employ machine learning to identify complex interactions that cannot be adequately captured using conventional statistical approaches. Predictive models could then be used to identify individuals at higher risk of metabolic dysfunction, nutritional deficiencies, adverse environmental exposures, or poor rehabilitation outcomes.

However, such systems will require rigorous validation, standardized data collection, interoperability between datasets, privacy protection, and transparent model development. The future value of digital health and precision-nutrition platforms will depend not simply on computational complexity but on their clinical validity, reproducibility, usability, and equitable implementation.

Toward a Unified One Health and Sustainability Framework

Ultimately, the strongest future direction emerging from these references is the integration of human health, animal health, food systems, environmental sustainability, and technological innovation within a unified framework. Research on food safety, aquatic toxicology, agricultural biotechnology, functional foods, nutrition, clinical health, and sustainability already addresses different components of this interconnected system [18–20, 33–35, 41].

A future interdisciplinary framework could therefore connect soil and crop health → food production → food processing → nutritional composition → gut microbiome → human metabolism → clinical outcomes → environmental impact. AI and multi-omics technologies could serve as analytical bridges across these domains, while socioeconomic and policy research could determine how innovations are translated into real-world practice.

This integrated approach would move research beyond isolated investigations toward evidence systems capable of addressing complex global challenges such as metabolic disease, malnutrition, food insecurity, environmental contamination, climate-related agricultural stress, and sustainable food production. The breadth of the 50-reference research portfolio provides a foundation for such cross-disciplinary development, while future work should prioritize experimental validation, longitudinal human studies, standardized methodologies, reproducibility, scalability, and translation into practical interventions [6–55].

Conclusion

The future of this research area lies not in further separation of disciplines but in their strategic integration. Food science can be strengthened through biotechnology and molecular biology; nutrition through microbiome and nutrigenomic research; medicine through functional foods and nutritional biomarkers; agriculture through genome editing and environmental science; food processing through engineering and artificial intelligence; and public-health interventions through socioeconomic and behavioral

research. The convergence of these domains has the potential to produce more precise, sustainable, evidence-based, and personalized solutions to emerging health and food-system challenges. The next phase of research should therefore emphasize interdisciplinary collaboration, integrated datasets, advanced predictive modeling, clinical validation, sustainability assessment, and translation from laboratory findings into scalable real-world applications [6–55].

REFERENCES

- Kirker, K., O'Connell, M., Bradley, L., Torres-Panchame, R. E., & Masaracchio, M. (2023). Manual therapy and exercise for adhesive capsulitis: A systematic review with meta-analysis. *Journal of Manual & Manipulative Therapy*, 31(5), 311–327. doi:10.1080/10669817.2023.2180702.
- Jain, T. K., & Sharma, N. K. (2013). The effectiveness of physiotherapeutic interventions in patients with adhesive capsulitis: A systematic review. *Journal of Physical Therapy Science*, 25, 1517–1522.
- Page, M. J., Green, S., Kramer, S., Johnston, R. V., McBain, B., & Buchbinder, R. (2014). Manual therapy and exercise for adhesive capsulitis (frozen shoulder). *Cochrane Database of Systematic Reviews*. CD011275.
- Kubuk, B. S., Carrasco-Uribarren, A., Cabanillas-Barea, S., Ceballos-Laita, L., Jiménez-del-Barrio, S., & Pérez-Guillén, S. (2024). The effects of end-range interventions in the management of primary adhesive capsulitis of the shoulder: A systematic review and meta-analysis. *Disability and Rehabilitation*, 46(15), 3206–3220. doi:10.1080/09638288.2023.2243826.
- Kim, Y. S., Lee, H. J., & colleagues. (2023). Effects of exercise intervention with and without joint mobilization in patients with adhesive capsulitis: A systematic review and meta-analysis. *Healthcare*.
- Khan, Waqas Ahmad, Muhammad Inam-ur-Raheem, Hina Rasheed, Muhammad Abdullah Butt, Farhan Saeed, Muhammad Afzaal, Faiyaz Ahmed, Noor Akram, Aasma Asghar, and Gebremichael Gebremedhin Hailu. "Comparative effect of olive oil and flaxseed oil on drug induced hepatotoxicity in rats." *Food Science & Nutrition* 12, no. 11 (2024): 9673-9681.
- Ahmed, Naveed, Muhammad Saeed, Aasma Asghar, Muhammad Abdullah Butt, Muhammad Afzaal, Farhan Saeed, Rizwan Wahab et al. "Utilization of Lactobacillus rhamnosus as probiotic adjunct culture for the development of tempeh." *International Journal of Food Properties* 27, no. 1 (2024): 1279-1289.
- Butt, Muhammad Abdullah, Rizwan Shukat, Muhammad Afzaal, Farhan Saeed, Ali Imran, Aftab Ahmed, Fakhar Islam et al. "Comparative evaluation of the quality and safety attributes of local and branded beef seekh kabab." *Cogent Food & Agriculture* 10, no. 1 (2024): 2360769.
- BUTT, MUHAMMAD ABDULLAH, MUHAMMAD UMAIR ARSHAD, ALI IMRAN, and MUHAMMAD AFZAAL. "NUTRITIONAL AND BIOSAFETY ASSESSMENT OF A NOVEL SOY-WHEY HYBRID PROTEIN CROSSLINKED BY MICROBIAL TRANSGLUTAMINASE IN SPRAGUE DAWLEY RATS." *TPM–Testing, Psychometrics, Methodology in Applied Psychology* 32, no. S7 (2025): Posted 10 October (2025): 597-608.
- Butt, Muhammad Abdullah, Muhammad Hameez Shahzad, Samiyah Tasleem, Rabiya Riaz, Xianjiang Ye, Burhan Khalid, Muhammad Atiq Ashraf et al. "Design of a Sustainable Whey–Corn Hybrid Protein Powder for Enhanced Nutrition, Functionality, and Environmental Stewardship." *Innovative Research in Applied, Biological and Chemical Sciences* 3, no. 2 (2025): 32-51.
- BUTT, MUHAMMAD ABDULLAH, MUHAMMAD UMAIR ARSHAD, SAMIYAH TASLEEM, ALI IMRAN, and MUHAMMAD AFZAAL. "COMPARATIVE ANALYSIS OF CHICKEN AND MEAT ANALOGUE PATTIES: EVALUATING PHYSICOCHEMICAL, COOKING, TEXTURAL,

- MICROBIAL, AND SENSORY ATTRIBUTES." *TPM–Testing, Psychometrics, Methodology in Applied Psychology* 32, no. S6 (2025): Posted 15 September (2025): 1274-1285.
- Rashid, Mian Shahan, Zubaria Gull, Muhammad Abdullah Butt, Sawera Hayat, Shnshah E. Azam, Shazia Saeed, Muhammad Mudassar Bashir et al. "The Role of Functional Probiotic Yogurt Consumption in Medical Weight Loss: A GLP-1 Friendly Nutritional Approach to Metabolic Health in UK Adults: <https://doi.org/10.5281/zenodo.19121209>." *Pakistan Journal of Medical & Cardiological Review* 5, no. 1 (2026): 1623-1632.
- Kamal, Numra, Muhammad Abdullah Butt, and Umer Javeid. "An empirical study on the effectiveness of artificial intelligence tools in English language acquisition and teaching strategies within an ESG framework." *Social Science Review Archives* 4, no. 1 (2026): 3562-3568.
- Mahmood, Basit, Minahil Arif, Hafiz Muhammad Moiz Basit, Beenesh Nadeem, Ammarah Abdullah, and Muhammad Abdullah Butt. "Long-term knee joint loading alterations in athletes 5 years post-ACL reconstruction: A comparative gait analysis." *Pakistan Journal of Medical & Cardiological Review* 5, no. 2 (2026): 310-321.
- Butt, Muhammad Abdullah, Muhammad Asif Ali, Anam Ishaq, Ambreen Saleem, Sawera Hayat, and Nida Khalil. "The Influence Of Dietary Zinc Supplementation On The Expression Of Insulin-Like Growth Factor 1 (Igf-1) In Adolescent Athletes: <https://doi.org/10.5281/zenodo.19438363>." *Pakistan Journal of Medical & Cardiological Review* 5, no. 2 (2026): 12-19.
- Butt, Muhammad Abdullah, Muhammad Asif Ali, Anam Ishaq, Ambreen Saleem, Shazia Saeed, and Mujahid Ul Islam. "Phytochemical-Rich Functional Diet Regulates Epigenetic Markers (DNA Methylation) Associated with Obesity and Insulin Resistance: <https://doi.org/10.5281/zenodo.19438403>." *Pakistan Journal of Medical & Cardiological Review* 5, no. 1 (2026): 2707-2715.
- Fatima, Ambreen, Nadia Jabeen, Muhammad Abdullah Butt, Muhammad Noman, Talha Riaz, Shazia Saeed, Ambreen Saleem, and Qaisar Sohail. "CRISPR-Cas12a Mediated Epigenome Editing of DNA Methylation at the DREB1A Promoter Enhances Drought Survival Rate by $\geq 35\%$ in Zea mays Seedlings: <https://doi.org/10.5281/zenodo.20031798>." *Research Consortium Archive* 4, no. 2 (2026): 1093-1102.
- Jabeen, Nadia, Musaffa Shahzadi, Muhammad Taha, Nida Shahzadi, and Muhammad Abdullah Butt. "CRISPR-Cas mediated genome editing for disease resistance in crops: advances and challenges." *Pakistan Journal of Medical & Cardiological Review* 4, no. 3 (2025): 2677-2689.
- Riaz, Talha, Syed Tahaa Munawar, Ahmad Din, Muhammad Abdullah Butt, Sawera Hayat, Areej Azhar, Rabiya Riaz et al. "Microbiological safety, adulteration, and heavy metal-associated health risks in raw cow and buffalo milk from Punjab, Pakistan." *Food Science & Applied Microbiology Reports* 5, no. 1 (2026): 18-28.
- Riaz, Talha, Areej Azhar, Zhijun Xia, Aliza Batool, Xianjiang Ye, Burhan Khalid, Muhammad Moeid Khan et al. "Advances in plant-based functional foods: Emerging trends, nutritional potential, and health implications." *Food Science & Applied Microbiology Reports* 5, no. 1 (2026): 1-17.
- Naeem, Waleed, Muhammad Abdullah Butt, and Umer Javeid. "From entrepreneurship theory to startup execution: A simulation-based benchmark analysis of AI-enhanced venture decision systems in early-stage business performance." *Social Science Review Archives* 4, no. 1 (2026): 4065-4075.
- khan Swati, Menahil, Musaffa Shahzadi, Muhammad Taha, Nida Shahzadi, and Muhammad Abdullah Butt. "The impact of orthodontic treatment on

- periodontal health: gingival recession, bone loss and patient-specific risk factors." *Research Consortium Archive* 4, no. 2 (2026): 1198-1213.
- khan Swati, Menahil, Musaffa Shahzadi, Muhammad Taha, Nida Shahzadi, and Muhammad Abdullah Butt. "Silver diamine fluoride for caries arrest in pediatric and special needs populations: a decade of clinical evidence." *Pakistan Journal of Medical & Cardiological Review* 5, no. 2 (2026): 693-704.
- Khurshid, Jamila, Zarlakhta Babar, Sajjad Ahmed, Muhammad Abdullah Butt, Umer Javeid, and Nida Khalil. "Beyond carbon footprints: unpacking the social dimensions of sustainability performance in emerging market firms." *Social Science Review Archives* 4, no. 1 (2026): 3386-3402.
- Butt, Muhammad Abdullah, Anam Ishaq, Rizwan Shukat, Qaisar Sohail, Muhammad Hamid Javed, Ambreen Saleem, Shazia Saeed, and Muhammad Mudassar Bashir. "Clinical Effects of Post-Exercise Low-Carbohydrate Recovery Diets on Bone Mineral Turnover, Hormonal Stability, and Lean Mass Preservation in Endurance-Trained Adults." *Research Consortium Archive* 4, no. 2 (2026): 1586-1599.
- Butt, Muhammad Abdullah, Feng Yiwen, and Umer Javeid. "Risk Governance Frameworks and Strategic Control Mechanisms for Managing Complexity in Global Business Operations." *Social Science Review Archives* 4, no. 2 (2026): 292-302.
- Butt, Muhammad Abdullah, Muhammad Umair Arshad, Ali Imran, and Muhammad Afzaal. "Ultrasonication-Enhanced Microbial Transglutaminase Crosslinking of Botanical and Foreign Protein for Sustainable High-Moisture Extruded Meat Analogue: A Comprehensive Multidimensional Characterization." *Genetics and Molecular Research* (2026).
- Shah, Muhammad Saleem, and Muhammad Abdullah Butt. "Multi-Scale Computational Investigation of Plasma Instabilities in Next-Generation Fusion Reactors." *Spectrum of Engineering Sciences* 4, no. 3 (2026): 2257-2266.
- Arif, Neha, Hafsa Shafiq, Moiza Noor, Taha Shahbaz, Aswad Khan, Hafsa Noor, Khalil Ahmed, Eman Farrukh, and Muhammad Abdullah Butt. "Artificial Intelligence in Cardiovascular Diagnostics: Integration of Laboratory Biomarkers, Medical Imaging, and Molecular Data." *Pakistan Journal of Medical & Cardiological Review* 5, no. 2 (2026): 5665-5695.
- Butt, Muhammad Abdullah, Wajid Hussain, Muhammad Junaid Anwar, Anam Ishaq, Luqman Khan, Muhammad Hammad Anwar, Talha Riaz et al. "AI-Guided Precision Fermentation for the Development of Personalized Functional Foods: A Food Technology Framework for Nutritional Optimization." *Research Consortium Archive* 4, no. 2 (2026): 2778-2795.
- Awais, Muhammad, and Muhammad Abdullah Butt. "AI-DRIVEN ADAPTIVE PROTECTION SCHEMES FOR RESILIENT POWER SYSTEMS WITH HIGH PENETRATION OF DISTRIBUTED ENERGY RESOURCES." *Spectrum of Engineering Sciences* 4, no. 6 (2026): 1424-1434.
- Butt, Muhammad Abdullah, Talha Riaz, Muhammad Abdullah Sadiq, Anam Ishaq, Ambreen Saleem, and Iza Almas. "AI-Assisted Nutrigenomic Modeling of Blueberry Anthocyanin–Gut Microbiome Interactions to Predict Butyrate Production and Insulin Sensitivity Improvement in Type II Diabetes." *Social Science Review Archives* 4, no. 2 (2026): 2159-2177.
- Ullah, Saif, Muhammad Abdullah Butt, Qaisar Sohail, and Talha Riaz. "Multi-Omics Characterization of Fish Responses to Emerging Environmental Contaminants: Implications for Aquatic Toxicology and Sustainable Fisheries Management." *Pakistan Journal of Medical & Cardiological Review* 5, no. 2 (2026): 5666-5685.
- Butt, Muhammad Abdullah, Talha Riaz, Muhammad Abdullah Sadiq, Anam Ishaq, Ambreen Saleem, and Iza Almas. "Development of Polyphenol-Rich

- Pomegranate Peel Nutraceuticals for Glycemic Regulation, Insulin Sensitivity Improvement, and Oxidative Stress Reduction in Type II Diabetes Mellitus." *Journal for Current Sign* 4, no. 2 (2026): 2398-2413.
- Ullah, Saif, Muhammad Abdullah Butt, Qaisar Sohail, Talha Riaz, and Shazia Saeed. "Toxicological Evaluation of Microplastic and Nanoplastic Exposure on Growth Performance, Oxidative Stress Biomarkers, and Histopathological Alterations in Cultured Fish Species." *Social Science Review Archives* 4, no. 2 (2026): 2178-2198.
- Naeem, Waleed, Muhammad Abdullah Butt, and Umer Javeid. "The Influence of Artificial Intelligence Automation on Employee Productivity, Job Redesign, and Organizational Performance in Service Industries." *Social Science Review Archives* 4, no. 2 (2026): 2534-2552.
- Naeem, Waleed, Muhammad Abdullah Butt, and Umer Javeid. "Machine Learning-Based Fraud Detection Systems and Their Effectiveness in Reducing Cybersecurity Risks in Digital Banking." *Social Science Review Archives* 4, no. 2 (2026): 2553-2573.
- Riaz, Muhammad, Neelam Tariq, Madiha Iqbal, Muhammad Abdullah Butt, Qaisar Sohail, and Talha Riaz. "Migration, Displacement, and Health Inequities: A Comparative Study of Refugee Populations and Access to Healthcare Services." *Social Science Review Archives* 4, no. 2 (2026): 2704-2722.
- Riaz, Muhammad, Muhammad Abdullah Butt, Qaisar Sohail, Talha Riaz, and Ambreen Saleem. "Dietary Habits, Nutritional Status, and Socioeconomic Factors Among University Students in Punjab, Pakistan: A Multicity Nutritional and Social Survey." *Social Science Review Archives* 4, no. 2 (2026): 2723-2742.
- Rehman, Anees Ur, Muhammad Abdullah Butt, Talha Riaz, and Qaisar Sohail. "Wellbeing-Oriented Human Resource Management and Workforce Sustainability in Healthcare Organisations: Comparative Evidence from Pakistan and Australia." *Journal for Current Sign* 4, no. 2 (2026): 3422-3440.
- Faizi, Waqar Un Nisa, Saira Akhtar, and Muhammad Abdullah Butt. "The Impact of Artificial Intelligence-Assisted Learning on Academic Performance and Critical Thinking Skills Among Undergraduate Students." *Social Science Review Archives* 4, no. 2 (2026): 2925-2948.
- Butt, Muhammad Abdullah, Anas Mustafa, Rizwan Shukat, Talha Riaz, Ambreen Saleem, Shazia Saeed, Muhammad Mudassir, and Qaisar Sohail. "Valorization of Watermelon Peel Flavonoids: Kaempferol, Quercetin, and Rutin as Natural Antioxidants for Functional Food and Nutraceutical Applications: <https://doi.org/10.5281/zenodo.21234696>." *Journal for Current Sign* 4, no. 2 (2026): 2761-2776.
- Butt, Muhammad Abdullah, Anas Mustafa, Ahmad Din, Rizwan Shukat, Talha Riaz, Ambreen Saleem, Shazia Saeed, Muhammad Mudassir, Qaisar Sohail, and Muhammad Hamid Javaid. "Effects of Ultrasound-Assisted Protein Modification on the Functional and Nutritional Properties of Soy Protein Isolate." *Pakistan Journal of Medical & Cardiological Review* 5, no. 2 (2026): 5678-5704.
- Nawaz, Hira, Nimra Shaukat, Ali Ahmad Bhatti, Moiza Noor, Savera Sayam, Tahira Yasmeen, Saira Fatima, Saira Sattar, and Muhammad Abdullah Butt. "Modulation of Gut Microbiota Through Functional Foods to Reduce Low-Grade Chronic Inflammation." *Pakistan Journal of Medical & Cardiological Review* 5, no. 1 (2026): 2231-2246.
- Shafeeq, A., Shokat, T., Rizvi, R., Gohar, F., Riaz, R., Ansar, S., Khalid, B., Butt, M.A., Raza, A., Ahamed, M.S. and Khan, M.M., 2026. *Alleviation of adverse effects of salinity stress on cauliflower by foliar application of trehalose. Scientific Records* 3 (2): 84-100 [online]

- Raza, Hamad, Muhammad Abdullah Butt, Iza Almas, Hafiza Ariba Javaid, Talha Riaz, Ambreen Saleem, and Shazia Saeed. "Catalyst-Assisted Synthesis of Functionalized Organic Molecules for Sustainable Pharmaceutical and Industrial Applications." *Social Science Review Archives* 4, no. 1 (2026): 6589-6608.
- Farrukh, Eman, Laiba Amjad Malik, Moiza Noor, Aneesa Ajmal, Hina Ali Ahmed, Afroz Rais, and Muhammad Abdullah Butt. "Prevalence, Antimicrobial Resistance Profiles, and Virulence Determinants of Staphylococcus aureus Isolated from Hospitalized Patients." *Pakistan Journal of Medical & Cardiological Review* 5, no. 1 (2026): 5875-5903.
- Gulzar, Muhammad, Areeba Fatima, Mahpara Ch, Muhammad Issa Khan, and Muhammad Abdullah Butt. "Association Between Diet Quality and Premature Gray Hair Among Young Adults: A Cross-Sectional Study in Faisalabad, Pakistan." *Pakistan Journal of Medical & Cardiological Review* 5, no. 1 (2026): 5572-5588.
- Nadeem, Muhammad Aqib, Sadia Sarwar, Chand Ali, Adeem Masih, Saleha Sohail, Kainat Saleem, Zarf E. Haider et al. "Comparative Analysis of Hepatitis C Virus (HCV) Screening Tests and Confirmatory PCR: Evaluation of Diagnostic Accuracy, Weak Positive Results, and Clinical Impact." *Pakistan Journal of Medical & Cardiological Review* 5, no. 1 (2026): 5561-5572.
- Shazif, Nawal, Aneesa Ajmal, Hafsa Noor, Nimra Anees, Malahat Choudhary, Shafi Ullah, Moiza Noor, and Muhammad Abdullah Butt. "Association Between Gut Microbiome Diversity and Severe Acute Malnutrition in Children Under Five Years." *Social Science Review Archives* 4, no. 1 (2026): 6130-6146.
- Fatima, Anees, Muhammad Awais, Shazeen Khalid Raja, and Muhammad Abdullah Butt. "Decolonizing Gendered Subjectivities in Mohammed Hanif's Rebel English Academy A Postcolonial Feminist Analysis of Language, Power, and Identity." *Social Science Review Archives* 4, no. 1 (2026): 6246-6269.
- Amanat, Asma, and Muhammad Abdullah Butt. "Evaluating the Impact of Adaptive Learning Platforms on Personalized Learning Outcomes and Cognitive Achievement in Higher Education." *Social Science Review Archives* 4, no. 2 (2026): 2991-3012.
- Adnan, Muhammad, Kaifa Saddique, Misbah Khalid, Muhammad Abdullah Butt, Shazia Saeed, and Hafiza Ariba Javaid. "Comparative Evaluation of Oat Flour and Soy Protein Incorporation on the Nutritional, Textural, Antioxidant, and Sensory Properties of Plant-Based Patties." *Research Consortium Archive* 4, no. 2 (2026): 4147-4164.
- Zaidi, Zarish Fatima, and Muhammad Atif Randhawa. "Calcium and Vitamin D3-Fortified Chocolate Spread: Development, Properties, and Stability." *RADS Journal of Food Biosciences* 4, no. 2 (2025): 91-98.
- Zaidi, Zarish Fatima, Shiza Fatima Zaidi, Sameen Ahsan, Dua Afzal Butt, and Sundus Ghayas Munir. "Nutritional Biomarkers as Predictors of Rehabilitation Success in Musculoskeletal Disorders: Bridging Nutrition Science and Physiotherapy." *Pakistan Journal of Medical & Cardiological Review* 5, no. 1 (2026): 5705-5722.