

Nutritional Immunomodulation for Mitigating Occupational Inflammation and Supporting Immune Function: A Randomized Controlled Trial of a Novel Antioxidant Beverage among Sanitation Workers

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ABSTRACT

Background: Biological risks and oxidative stresses that impair immune function are long-term occupational exposures for sanitation workers. In this population, nutritional treatments that target systemic inflammation are yet mostly studied. **Methods:** 100 sanitation workers (Intervention n = 50; Control n = 50) participated in a 12-week parallel-group randomized controlled study. The intervention group was given 100ml of an antioxidant drink made from fermented rice water daily, while the control group was given health information about PPE and WHO hand cleanliness on a weekly basis. Haematological parameters (CBC), Total IgE and CRP were measured at baseline and after 12 weeks. Chi-square analysis, Pearson correlations, paired t-tests and independent samples t-tests were used. Cohen's d was used to calculate effect sizes. **Results:** The antioxidant group's CRP significantly decreased after the intervention (9.87 to 4.51mg/L, $p < 0.001$) and IgE (451.88 to 278.99 IU/mL, $p < 0.001$), as well as increases in haemoglobin, RBC count, PCV, WBC, and monocyte counts. The control group's neutrophil-lymphocyte balance deteriorated and showed no discernible improvement. CRP, IgE, neutrophils, lymphocytes, monocytes, RBC, haemoglobin and PCV all showed significant between-group changes (all $p < 0.05$) with substantial effect sizes. **Conclusion:** Over 12 weeks, daily consumption of an antioxidant beverage based on fermented rice water considerably reduced systemic inflammation and enhanced haematological and immunological markers in sanitation workers. This low-cost, culturally relevant strategy has great potential for occupational health targeting immune suppression.

Keywords: antioxidant drink, immunomodulation, C-reactive protein, IgE, CBC, sanitation workers

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INTRODUCTION

According to a WHO/ILO analysis, sanitation workers are among the most understudied occupational cohorts when it comes to targeted nutritional interventions, while suffering disproportionately from musculoskeletal, respiratory, and communicable diseases.¹

Sanitation workers, including solid waste collectors, municipal sweepers, and sewage handlers, are among the most exposed groups in the world. Long-term exposure to microbial pathogens, chemical pollutants, and biological effluents is part of their regular tasks, which can lead to chronic

oxidative stress and immunological dysregulation.² According to international systematic studies, gastrointestinal illnesses, Hepatitis A and respiratory symptoms are more common among sanitation workers.^{3, 4} Chinese sanitation workers had lower serum albumin and lymphocyte counts than comparable controls, according to Song et al. (2024), with telomere length and lymphocyte count inversely associated, indicating accelerated biological aging linked to inflammatory load.⁵ Research from Puducherry and Telangana in India confirms high prevalence of hypertension and occupational morbidities, which are exacerbated by limited access to nutrition education and preventative treatment.^{6, 7} While abnormal IgE responses indicate increased allergy and immunological responsiveness, elevated CRP indicates systemic inflammation.⁸ Neutrophil-to-lymphocyte ratio (NLR) and other CBC-derived metrics have become sensitive indicators of inflammatory immunological dysregulation.⁹ Adwas et al. showed that natural antioxidants, such as polyphenols, vitamins C and E, and bioactive substances present in plants, reduce ROS-mediated cellular damage by scavenging free radicals, blocking enzymatic pathways that promote inflammation, and restoring endogenous antioxidant enzyme activity. Oxidative stress, an imbalance between reactive oxygen species (ROS) and endogenous antioxidant defences, plays a role in mediating the immunological effects of long-term occupational exposure.¹⁰

There are no human clinical trials of antioxidant nutritional treatments, particularly for sanitation workers, despite strong preclinical results. There is a lack of evidence for high-risk occupational groups because the available RCTs on antioxidant beverages have concentrated on either healthy volunteers or metabolically impaired people.^{11, 12}

By giving a culturally native beverage, fermented rice water enhanced with amla, ginger, mint, coriander, and curry leaves and evaluating its immunomodulatory effect on CBC parameters, CRP, and IgE over a 12-week period, this trial closes that gap.

NEED FOR THE STUDY

Sanitation workers are chronically exposed to microbial pathogens, chemical pollutants, and sewage effluents, leading to sustained oxidative stress, low-grade systemic inflammation, and immune dysregulation that manifest as high burdens of musculoskeletal, respiratory, and communicable diseases. Despite this well-documented vulnerability, occupational health programmes for this cohort rarely incorporate structured nutritional strategies that specifically target inflammatory and immunological markers such as C-reactive protein (CRP), immunoglobulin E (IgE), and complete blood count (CBC)-derived indices. Existing randomized trials on antioxidant

beverages have focused predominantly on healthy adults or metabolically impaired patients, leaving a critical evidence gap regarding high-risk occupational groups like sanitation workers who face compounded biological and socioeconomic stressors.¹³

The baseline data from the present cohort reveal markedly elevated CRP and IgE levels in the majority of participants, alongside suboptimal haematological profiles indicative of immune compromise, which are further exacerbated by monotonous cereal-dominant diets, poor intake of fruits, nuts, seeds, and milk products, and a complete absence of prior nutrition education. This combination of occupational exposure, inflammatory load, and nutritional vulnerability underscores the need for simple, low-cost, culturally acceptable interventions that can be integrated into routine work environments without disrupting schedules or requiring complex resources. Fermented rice water, traditionally consumed in several Indian communities, is an accessible matrix that can be enhanced with locally available antioxidant-rich ingredients such as amla, ginger, mint, coriander, and curry leaves to deliver polyphenols, vitamins, and bioactive compounds known to modulate oxidative stress and immune function. Evaluating such a beverage in a rigorously designed randomized controlled trial among sanitation workers is essential to generate context-specific evidence for nutritional immunomodulation, inform occupational health guidelines, and support policy-level integration of nutrition into worker welfare schemes. By directly measuring changes in CRP, IgE, and CBC parameters over 12 weeks, the study addresses a major gap in translational nutrition research for an understudied, high-risk workforce.

Aim of the Study

The aim of the study is to evaluate the immunomodulatory and anti-inflammatory effects of a culturally acceptable antioxidant beverage based on fermented rice water among municipal sanitation workers. Specifically, the study seeks to determine the impact of daily consumption of this beverage for 12 weeks on systemic inflammatory markers (CRP, IgE) and key haematological parameters derived from CBC, compared with an education-only control group. The ultimate objective is to generate evidence to support incorporation of low-cost nutritional antioxidant strategies into occupational health programmes for sanitation workers.

METHODOLOGY

Study design

This was a 12-week, open-label, parallel-group randomized controlled trial among sanitation workers.

Participants and sample size

One hundred sanitation workers were enrolled and randomly allocated to intervention (n = 50) or control (n = 50) groups.

Randomization and allocation

Eligible participants who gave consent were randomly assigned in a 1:1 ratio to the antioxidant beverage group or the control group. Blinding was not feasible because the intervention was a visible daily drink.

Intervention

The intervention group received 100 ml of a fermented rice water-based antioxidant beverage daily for 12 weeks. The drink was prepared with amla, ginger, mint, coriander and curry leaves.

Control condition

The control group did not receive any nutritional supplement. They were provided weekly education on PPE use and WHO-recommended hand hygiene.

Data collection and outcome measures

Fasting venous blood samples were collected at baseline and after 12 weeks. Complete blood count, serum CRP and total IgE were measured at both time points.

Operational definitions and derived indices

CRP, IgE and CBC parameters were classified using standard laboratory reference ranges to identify abnormalities. CBC-derived inflammatory indicators, including neutrophil-lymphocyte balance, were treated as markers of immunological dysregulation.

Statistical analysis

Descriptive statistics summarised socio-demographic, occupational, dietary and laboratory variables. Independent t-tests, paired t-tests, chi-square tests and Pearson correlations were applied, and Cohen's d was used to estimate effect sizes, with $p < 0.05$ considered significant.

Ethical considerations

The study protocol was approved by the Institutional Ethics Committee. Written informed consent was obtained from all participants, and confidentiality and the right to withdraw were ensured.

RESULTS

Demographic data

Disease Burden and Genetic History

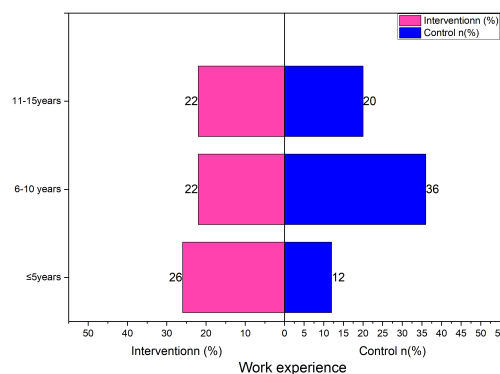


Fig. 1 Work experience of participants

Table 1: Occupational characteristics, working Hours and sleep pattern by study Group (N= 100)

Variable	Categor y	Interventio nn (%)	Contro ln (%)	Tota l (%)
Work experien ce	≤5years	13(26)	6(12)	19
	6-10 years	11(22)	18(36)	29
	11- 15years	11(22)	10(20)	21
	≥16yea rs	15(30)	16(32)	31
Work Hours/da y	9 hours	10(20)	3(6)	13
	12 hours	40(80)	47(94)	87
Work injuries	yes	50(100)	50(100)	100
Tirednes	yes	50(100)	50(100)	100

s			0)	
Sleep hours	≤4hours	8(16)	9(18)	17
	5-6hours	18(36)	26(52)	44
	7-8hours	24(48)	15(30)	39

A family history of non-communicable diseases was reported by nearly half of the cohort (48%). The most common congenital condition was hypertension (6%), which was followed by myocardial infarction (2%) and coronary artery disease (1%). 19% had endocrine problems, including hypothyroidism in 5% and diabetes mellitus in 14%. Notable were respiratory disorders (asthma 4%, COPD 2%) and a history of infectious diseases (typhoid 5%). COVID-19 was the most common vaccination; 99% of the participants were vaccinated, with Food frequency and dietary practices

Fig. 1 shows the work experience of participants. Dietary habits are summarized in Table 2. Every member of the cohort (100%) included cereals every day and was non-vegetarian. Despite this, the diet was of poor quality: 70% did not eat nuts or seeds, 62% did not eat any fruits, and 39% did not eat any green leafy vegetables. Fifty-seven% of individuals did not consume milk or milk products. At the time of recruitment, none of the participants were using any nutritional supplements, and all participants (100%) reported missing meals. The observed high CRP and IgE readings at baseline have a significant contextual backdrop provided by this nutritional vulnerability, which is typified by monotonous cereal-dominant diets with insufficient micronutrient diversification. Of those who drank beverages two to five times a day, 49% chose coffee and 39% preferred tea. PPE use was almost universal (95%), while only 39% of the sample as a whole practiced WHO-compliant hand washing and 61% did not adhere to conventional hand hygiene regimens at baseline. Before this study, none of the participants received nutrition education.

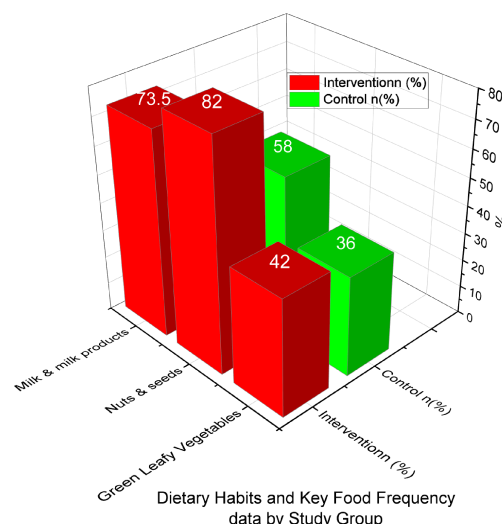


Fig. 2 Dietary habits and food frequency data by study group

Fig. 2 shows the dietary habits and food frequency data by study group. The intervention group demonstrated a higher frequency of consumption of selected nutrient-rich foods compared with the control group. Consumption of milk and milk products was higher in the intervention group (73.5%) than in the control group (58%). Similarly, consumption of nuts and seeds was markedly higher among participants in the intervention group (82%) compared with the control group (36%). The intervention group also demonstrated a 42% frequency of consumption of green leafy vegetables. Overall, the findings suggest more favorable dietary practices among participants who received the intervention.

Table 2: Dietary Habits and Key Food Frequency data by Study Group (N=100)

Variable	category	Intervention n(%)	Control n(%)	Total %
Food Habits	Non-Vegetarian	50(100%)	50(100%)	100
Cereals	7 times/week	50(100%)	50(100%)	100
Fruits	None	37(74)	25(5)	62
	1-2 times/week	11(22)	13(26)	24
Green Leafy	none	21(42)	18(36)	39

Vegetables				
Nuts & seeds	none	41(82)	29(58)	70
Milk & milk products	none	36(73.5)	20(40)	56
Meal skipping	Yes(all)	50 (100)	50(100)	100
Nutritional supplement	none	50(100)	50(100)	100
WHO Hand Hygiene	yes	14 (28)	25(50)	39
Nutrition Education	Never Receive	50(100)	50(100)	100

Group Comparisons of Baseline Blood Parameters

Baseline (pre-intervention) the intervention and control groups were comparable for most demographic and haematological markers indicating overall balance between groups however significant difference is observed in BMI ($p<0.001$), haemoglobin ($p=0.008$), MCH ($P=0.005$) and CRP ($P<0.001$) all showed statistically higher (24.12 vs. 9.87mg/L). This significant baseline imbalance was taken into consideration when interpreting post-intervention comparisons. IgE did not show a significant baseline difference ($p=0.564$). The immunocompromised character of this occupational cohort was confirmed by pre-test CRP being raised (>5 mg/L) in 78% of participants in the intervention group and 90% of individuals in the control group, and IgE being elevated in 80% and 94% of participants, respectively.

Post-Intervention Comparisons between Groups

Group Comparisons following Intervention

The main comparison for this RCT, post-intervention between-group comparisons after 12 weeks, is shown in Table 3. When compared to the control group, the antioxidant beverage group showed noticeably improved results across all important inflammatory and immunological markers.

After the intervention, the intervention group had significantly reduced CRP (4.51 VS. 28.36 mg/L;

$p<0.001$; Cohen's $d = 2.07$) and IgE levels (278.99 vs. 505 IU/mL; $p<0.001$; $d= 0.93$). A beneficial shift in the neutrophil-to-lymphocyte balance was shown by the intervention group's significantly greater lymphocyte percentage (33.72 vs. 25.07%; $p<0.001$; $d=0.97$) and significantly lower neutrophil percentage (57.93 vs. 69.40%; $p<0.001$; $d=1.10$) in the haematological parameters. Haemoglobin ($p<0.001$) and total RBC ($p<0.001$; $d= 2.02$) were all significantly higher in the intervention group. Monocyte percentage was significantly higher in the intervention group (2.95 vs. 1.89%; $p<0.001$), consistent with enhanced innate immune surveillance.

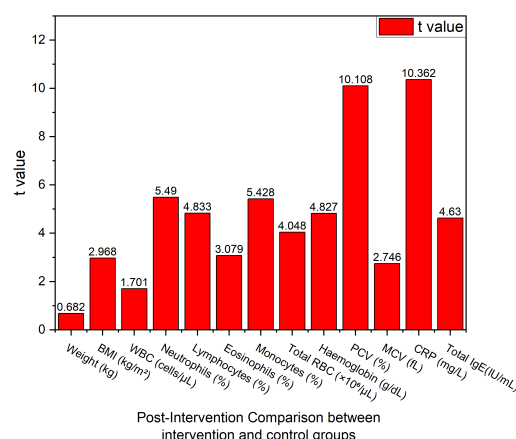


Fig. 3 Post intervention comparison between intervention and control groups

Table 3: Post-Intervention Comparison of key parameters between intervention and control groups (12 weeks)

Parameter	Intervention Mean (SD)	Control Mean (SD)	t value	p value	Cohen's d
Weight (kg)	61.93 (11)	63.60 (13.38)	0.682	0.497	-0.14
BMI (kg/m²)	23.29(3.40)	25.73 (4.71)	2.968	0.004*	-0.59
WBC (cells/μL)	8118 (1409)	8962 (3212)	1.701	0.092	-0.34
Neutrophils (%)	57.93(8.04)	69.40 (12.40)	5.49	<0.001*	-1.10
Lymphocytes (%)	33.72(6.30)	25.07 (10.98)	4.833	<0.001*	0.97
Eosinophils (%)	3.54	2.57(1.0)	3.079	0.003	0.62

Nutritional Immunomodulation for Mitigating Occupational Inflammation and Supporting Immune Function: A Randomized Controlled Trial of a Novel Antioxidant Beverage among Sanitation Workers

WBC (cells/ μ L)	13.58(1.65)	11.75(2.11)	4.827	<0.001*	0.97
Monocytes (%)	2.95(0.92)	1.89(1.03)	5.428	<0.001*	1.09
Total RBC ($\times 10^6/\mu$ L)	4.60(0.57)	4.09(0.68)	4.048	<0.001*	0.81
Haemoglobin (g/dL)	13.58(1.65)	11.75(2.11)	4.827	<0.001*	0.97
PCV (%)	38.32(4.93)	28.96(4.31)	10.108	<0.001*	2.02
MCV (fL)	84.61(4.90)	78.86(3.95)	2.746	<0.001*	-
CRP (mg/L)	4.51(3.56)	28.36(5.88)	10.362	<0.001*	-2.07
Total IgE (IU/mL)	278.99(48.07)	505(9.01)	4.639	<0.001*	-0.93

Within-Group Modifications: Intervention Group

Paired t-tests within the intervention group verified statistically significant gains over 12 weeks (Table 4). Total IgE dropped from 451.88 to 278.99 IU/mL ($p<0.001$) and CRP from 9.87 to 4.51mg/L ($p<0.001$). WBC dramatically dropped from 8718 to 8118 cells/ μ L; $p=0.002$), indicating leucocytosis resolution. Erythropoiesis was enhanced, as seen by the considerable improvements in haemoglobin ($p<0.001$), total RBC ($p<0.001$), and PCV ($P=0.004$). The number of monocytes rose ($p<0.001$), and there were also statistically significant alterations in the numbers of platelets and basophils.

Table 4: Within-Group Pre-Post comparison: Intervention Group (N=50)

parameter	Pre Mean (SD)	Post Mean (SD)	t value	p value
WBC (cells/ μ L)	8718 (1871)	8118 (1409)	3.253	0.002*
Monocytes (%)	2.03 (1.09)	2.95 (0.92)	4.951	<0.001*
Total RBC ($\times 10^6/\mu$ L)	4.35 (0.60)	4.60 (0.57)	4.545	<0.001*

Haemoglobin (g/dL)	13.07 (1.65)	13.58 (1.65)	8.381	<0.001*
PCV (%)	36.81 (5.50)	38.32 (4.93)	3.010	0.004*
MCHC (g/dL)	35.74 (1.81)	34.87 (1.46)	2.892	0.006*
Platelet ($\times 10^5/\mu$ L)	2.63 (0.69)	2.77 (0.58)	2.544	0.014*
CRP (mg/L)	9.87 (7.86)	4.51 (3.56)	5.103	<0.001*
Total IgE (IU/mL)	451.88 (306.71)	278.99 (248.07)	7.628	<0.001*

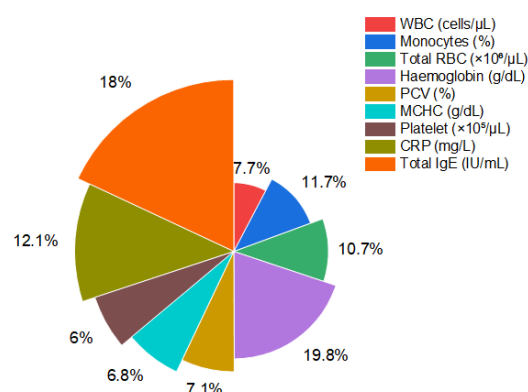


Fig. 4 Within-group Pre-Post comparison: Intervention Group (N=50)

Chi-Square Analysis: Clinical Variables' Relationship to Demographics

The association between baseline immunological biomarker abnormalities and demographic characteristics (age, gender, marital status, education) were investigated using chi-square analysis. MCV status and age ($\chi^2=8.883$, $df=2$, $p=0.012$), RBC status and gender ($\chi^2=4.026$, $df=1$, $p=0.045$), and RBC and education ($\chi^2=7.837$, $df=2$, $p=0.020$) were all significantly correlated in the intervention group at pre-test. Age was strongly correlated with lymphocyte abnormalities in the control group at pre-test ($\chi^2=8.133$, $df=2$, $p=0.017$). Eosinophil status was strongly correlated with education level ($\chi^2=13.768$, $df=2$, $p=0.001$) and post-CRP status with education ($\chi^2=11.49$, $df=2$, $p=0.003$) at the post-test in the intervention group.

Analysis of Correlation

Pearson correlation analysis in the intervention group at baseline revealed a strong relationship between pre-neutrophils and pre-lymphocytes ($r = -0.837$, $p<0.001$), consistent with the immunological seesaw of innate versus adaptive immunity. CRP showed an unfavourable correlation with lymphocytes ($r = -0.353$, $p=0.012$) and a positive correlation with neutrophils ($r=0.280$, $p=0.049$),

indicating that changes toward innate immune activation at the expense of adaptive immunity co-occur with high CRP. Haemoglobin showed an inverse correlation with CRP ($r=0.297$, $p=0.036$), and PCV with CRP ($r=-0.280$, $p=0.049$) at the intervention group's post-test, indicating a mechanistic relationship between improvements in erythropoietic parameters and the resolution of inflammation.

Neutrophils and lymphocytes in the control group showed a strong inverse association that continued and became stronger after the intervention ($r=-0.983$, $p<0.001$), indicating a growing immunological imbalance in the absence of intervention. In the control group, pre-IgE and eosinophils showed a correlation ($r=0.472$, $p=0.001$), which is consistent with atopic inflammatory pathways.

For the first time, the immunomodulatory effectiveness of an antioxidant beverage based on fermented rice water has been documented in a 12-week randomized controlled study among sanitation workers, a population with chronic occupational exposure and very low dietary antioxidant intake. The degree and range of improvement seen across haematological and inflammatory indicators are convincing.

DISCUSSION

This study's occupational and demographic characteristics show a convergence of immunological risk variables that are rarely examined jointly: 87% worked 12-hour shifts every day, all claimed chronic fatigue and work-related ailments, 57% slept for less than 6 hours every night, 62% ate no fruits and 100% frequently skipped meals. These results are consistent with international systematic reviews showing that occupational morbidity disproportionately affects sanitation workers^{3,4} Khatri et al. (2026) found that poor eating habits and occupational stress were associated with a significant prevalence of hypertension among Nepali sanitation workers.²⁰ The main inflammatory biomarkers in our investigation, increased CRP, is independently linked to lifestyle factors, particularly poor dietary habits, as shown by Islam et al. (2026).²¹

The degree of immunological impairment in this group at enrolment is shown by the baseline prevalence of increased CRP (78% in intervention, 90% in control) and IgE (80% and 94% respectively). The occupational immune suppression theory is supported by these baseline rates, which are significantly higher than those reported for general south Indian adult populations. The genetic predisposition data (48% with a family history of NCDs, including diabetes in 14% and hypertension in 6%) emphasizes this workforce's increased vulnerability.

Following the intervention, the antioxidant beverage resulted in statistically significant and

clinically significant decreases in IgE (38% reduction; $d=0.93$) and CRP (54% reduction; Cohen's $d=2.07$). Large and clinically meaningful, these effect sizes outweigh the decreases shown in RCTs of standalone antioxidant supplementation in populations with impaired metabolism.²²

Ginger's gingerol-mediated NF- κ B inhibition, coriander's polyphenols, fermented rice water contains probiotic and amla, with tannins, ascorbic acid and emblicanin A have been demonstrated to lower CRP in meta-analyses of RCTs and likely worked in concert to reduce systemic inflammatory signalling.¹⁴⁻¹⁷ The advancement in haematology is as significant. At the post-test, haemoglobin was still higher than the control group ($p<0.001$) and had grown significantly within the intervention group (13.07 to 13.58 g/dL; $p<0.001$). Total RBC greatly improved and PCV had the biggest effect size of all the measures ($d=2.02$). These results imply that the beverage enhanced erythropoietin capacity. Potentially via increased iron bioavailability made possible by amla's high ascorbic acid content, which is known to boost absorption of non-heme iron.²³

Given that the intervention group maintained acceptable haemoglobin throughout, but 56% of the control group who had haemoglobin at post-test, this is actually significant. Mechanistically, the neutrophil-lymphocyte dynamics between groups are significant. Following the intervention, the control group showed significantly higher neutrophil percentages (69.40%) and lower lymphocyte percentages (25.07%), which chronic immune activation, a pattern linked to the risk of infection and chronic inflammation. On the other hand, the intervention group showed significant between group effect sizes ($d>1.0$) and maintained a balanced neutrophil-lymphocyte profile (57.93% and 33.72%, respectively). The control group's growing immunological imbalance is indicated by the inverse correlation between neutrophils and lymphocytes ($r=-0.983$ in the control vs. $R=-0.837$ in the pre-test), while the intervention group stabilized this connection.⁹

Particular attention should be paid to the IgE results. 80-94% of participants had elevated total IgE (>100 mL) at baseline, which is probably due to long-term sensitization to chemical happens, microbial antigens, and occupational allergens, a pattern seen in workers with occupational exposure. The intervention group's 38% decrease in IgE ($p<0.001$) indicates that the antioxidant beverage may have regulated indications that polyphenols suppress IgE associated signalling pathways, which is compatible with Th2-dominated immune responses toward improved immunological balance.^{8, 15-19}

With the notable exception of the age-MCV association in the intervention group and the age lymphocyte association in the control group, the

chi-square analysis showed that demographic characteristics (age, gender and education) had little independent association with the majority of immunological biomarker abnormalities.

This finding supports the biological plausibility of a food intervention as a remedial method by indicating that the immunological deficiencies seen in this cohort are predominantly driven by occupation and nutrition rather than demographics.

LIMITATIONS

There are a few limitations on this experiment. Although suitable for the nature of the intervention, the open label design makes blinding impossible. Total antioxidant capacity was not quantitatively examined using dietary recall data. Larger sample sizes, oxidative stress indicators (such as MDA and GPx activity), and longer follow-up to evaluate the benefits' durability should also be included in the future research.

CONCLUSION

A daily 100 ml of fermented rice water-based antioxidant taken over a period of 12 weeks dramatically lowers systemic inflammation (CRP) and allergic immune activation (IgE) and enhances haematological immune parameters in sanitation workers, according to this randomized controlled trial. A convergence of lifestyle, nutritional and occupational risk factors such as 12-hour workdays, universal meal skipping, fruit and vegetable deficiency, sleep deprivation and genetic predisposition to NCDs that together sustain chronic immune suppression is revealed by the comprehensive demographic profiling of this cohort. For occupational health programs aimed at frontline sanitation workers, this beverage made from inexpensive, locally accessible ingredients represents a scalable, culturally appropriate and evidence-based nutritional immune-modulatory approach.

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