RESEARCH PAPER

# Prevalence and Ergonomic Assessment of Work-Related Musculoskeletal Disorders among Sugarcane Industry Workers in Sangli, Maharashtra: A Cross-Sectional Study

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**ABSTRACT**

Background: Sugarcane processing requires intensive physical labor, exposing workers to manual material handling, repetitive trunk movements, and prolonged awkward postures. While India's sugar sector is vast, systematic occupational health surveillance within processing mills remains limited. This study evaluates the 12-month prevalence of work-related musculoskeletal disorders (WMSDs) and quantifies physical risk profiles among factory workers in Maharashtra.

Methods: A cross-sectional study was conducted from August 2025 to February 2026 among 416 workers across two manufacturing facilities in the Sangli district. The Standardised Nordic Musculoskeletal Questionnaire (NMQ) tracked regional symptom distribution. Postural and task-specific ergonomic risks were measured using the Rapid Entire Body Assessment (REBA) and the Quick Exposure Checklist (QEC). Labourers were categorised into four operational task groups. Bivariate associations were assessed using Pearson Chi-square tests, and independent predictors of regional symptoms were determined via multivariable logistic regression.

Results: The highest 12-month symptom prevalence rates were observed in the lower back (69.95%), shoulder (69.23%), and upper back (67.07%). No participants fell within the negligible or low REBA risk tiers; 83.1% were classified as high or very high risk. Postural risk scores did not vary significantly across departments (mean REBA range: 9.5–9.8; Kruskal-Wallis $H = 1.484$, $p = 0.686$). Overweight workers (BMI $\geq 25$ kg/m²) had significantly higher odds of hip/thigh symptoms ($OR = 1.85$; 95% CI: 1.25–2.73; $p = 0.002$). High or very high QEC exposure profiles correlated significantly with shoulder ($OR = 2.08$, $p = 0.029$) and ankle/foot symptoms ($OR = 2.18$, $p = 0.021$). In multivariable models, continuous BMI ($aOR = 1.094$; 95% CI: 1.032–1.159; $p = 0.003$) and younger age ($aOR = 0.970$; 95% CI: 0.950–0.990; $p = 0.004$) independently predicted hip/thigh symptoms.

Conclusion: Sugarcane processing workers face severe, uniform ergonomic hazards that transcend specific job assignments. The high symptom burden emphasises the need for comprehensive, facility-wide ergonomic adjustments and targeted preventive physical therapy programs.

Keywords: work-related musculoskeletal disorders; sugarcane industry; REBA; QEC; Nordic Musculoskeletal Questionnaire; ergonomic risk; logistic regression.

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## . INTRODUCTION

Work-related musculoskeletal disorders (WMSDs) represent a primary source of occupational morbidity, operational absenteeism, and long-term disability across global industrial sectors [1]. Among these, the agro-industrial and manufacturing sectors exhibit some of the most demanding physical working environments [2]. Industrial processing tasks routinely require a combination of high force exertion, repetitive joint actions, and sustained non-neutral body mechanics [3]. According to epidemiological reviews, these combined occupational exposures cause mechanical micro trauma that over-pressures soft tissue structures, leading to chronic musculoskeletal pathology [4]. In developing economies, these challenges are amplified by long shifts, limited mechanical assistance, and a lack of ergonomic workplace design [5].

The global burden of WMSDs has structural patterns that vary by socio-economic context. While automated manufacturing units in developed countries emphasise upper-extremity cumulative trauma [6], developing nations continue to grapple with heavy manual material handling hazards [7]. Biomechanical analyses demonstrate that repetitive trunk flexion combined with asymmetric twisting forces places severe shear strain on the lumbar intervertebral discs [8]. Furthermore, continuous manual lifting over-stretches the erector spinae muscle complex, accelerating degenerative spinal tissue damage [9]. Despite international guidelines emphasising safe lifting limits, industrial operational settings in low- and middle-income regions rarely match theoretical workplace safety targets [10].

In India, the sugar industry is an economic pillar supporting approximately 50 million individuals through direct and indirect employment [11]. While agricultural harvesting practices have received substantial research attention [12], the indoor factory processing environment remains relatively understudied [13]. Agro-industrial processing facilities introduce a unique mix of systemic mechanical hazards [14]. Workers handle heavy, unstable bulk materials [15], manage high-temperature high-pressure utility systems [16], perform maintenance in confined spaces [17], and stand for extended shifts on unyielding concrete factory floors [18].

Geographically, Maharashtra stands as one of India's leading sugar-producing territories, and its Sangli district contains a dense cluster of large-capacity processing facilities [19]. Labourers in these industrial settings routinely perform forceful lifting, trunk rotation, and repetitive overhead reaches [20]. Despite the intense physical demands of this sector, systematic occupational surveillance data remain limited. While international agro-industrial literature from sugarcane farming regions in Thailand [21] and processing centre’s in Brazil [22] has established clear links between processing tasks and long-term physical disability, localised data from Indian factories are mostly limited to small descriptive surveys [23].

Furthermore, existing studies often treat industrial workforces as a single uniform cohort, ignoring distinct exposure profiles across different factory departments [24]. Determining whether specific processing tasks carry unique risk profiles requires a comprehensive evaluation that combines subjective symptom reporting with objective, validated ergonomic assessment tools [25]. Understanding these localised interactions between task-specific physical demands and personal risk factors is essential for building effective preventive protocols [26].

The present investigation addresses these gaps in the literature through a systematic cross-sectional study of a large factory cohort in Maharashtra. The research design is structured around three primary aims: first, to establish precise 12-month WMSD prevalence figures across nine distinct anatomical regions using a validated baseline survey [27]; second, to evaluate and compare objective whole-body postural risk profiles using the Rapid Entire Body Assessment (REBA) [28] alongside task-specific exposures via the Quick Exposure Checklist (QEC) [29]; and third, to utilise multivariable logistic regression modelings to isolate independent personal and occupational predictors of regional musculoskeletal symptoms [30].

## 2. METHODS

### 2.1 Study Design and Setting

This observational, cross-sectional investigation was conducted between August 10, 2025, and February 10, 2026. Data collection was carried out at the Vasantdada Patil Sugar Factory and the Sonhira Sugar Factory, both located in the Sangli district of Maharashtra, India [19]. These sites were selected because they represent peak-capacity industrial operational centre’s within the region.

Administrative permission was obtained from factory management to allow researchers access to production floors during daytime shifts. The study protocol received formal clearance from the Institutional Ethics Committee (IEC) on August 8, 2025 (Approval Number: [INSERT IEC APPROVAL NUMBER]), and was conducted in strict accordance with the ethical standards of the Declaration of Helsinki. Study organisation, participant recruitment reporting, and statistical reporting strictly follow the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines [26].

### 2.2 Participants and Eligibility Criteria

A total of 510 factory workers were approached by the research team during the data collection window. To participate, individuals had to meet the following inclusion criteria: an age between 18 and 60 years, current full-time employment status on the active production floor or within an operational maintenance unit, and a minimum continuous employment tenure of one calendar year at the facility.

Workers were excluded if they presented with a diagnosed neurological condition that impaired sensory or motor function, had sustained an acute traumatic musculoskeletal injury within the previous six months, or chose not to provide written informed consent. Out of the 510 individuals approached, 39 failed to meet the baseline eligibility criteria, 46 declined to participate, and 9 returned incomplete or compromised data forms. A final sample of 416

Workers with complete data sets were included in the analysis, yielding an effective participation rate of 81.5%.

### 2.3 Measurement Instruments and Variables

#### 2.3.1 Musculoskeletal Symptom Assessment

The presence and regional distribution of musculoskeletal symptoms were evaluated using the Standardised Nordic Musculoskeletal Questionnaire (NMQ) [27]. This instrument uses binary (Yes/No) questions to document aches, pain, numbness, or physical discomfort experienced within the preceding 12 months. Symptoms are tracked across nine distinct anatomical zones: the neck, shoulders, elbows, wrists/hands, upper back, lower back, hips/thighs, knees, and ankles/feet.

#### 2.3.2 Whole-Body Postural Risk Assessment

Postural risk was quantified using the Rapid Entire Body Assessment (REBA) system [28]. Trained physical therapists observed each participant for a minimum of one complete, representative work cycle. The most physically demanding posture sustained for at least 30 seconds during that observation window was selected for formal evaluation. The REBA tool scores body segments across two main groupings to generate a final score between 1 and 15, which maps to five standardised risk action categories: Negligible (1), Low (2–3), Medium (4–7), High (8–10), and Very High (11–15).

#### 2.3.3 Task-Specific Ergonomic Exposure Assessment

To supplement postural observation, the Quick Exposure Checklist (QEC) was concurrently administered to evaluate overall physical exposure [29]. The QEC cross-references observer ratings for the back, shoulder/arm, wrist/hand, and neck with subjective worker ratings for force exertion, task duration, vibration, and pacing [25]. Total scores were normalised against the sample's peak observed values and categorised into four ordinal exposure tiers: Low (≤ 40%), Moderate (41%–50%), High (51%–70%), and Very High (> 70%) [25,29].

### 2.4 Occupational Task Group Classification

Participants were divided into four distinct task groups based on their institutional department assignments:

1. Cane Handling & Loading (n = 59): Labourers performing manual lifting, carrying, and sorting of raw sugarcane stalks in the yard [12].
2. Boiler & Utilities (n = 98): Operators managing fuel inputs, steam valves, and water treatment systems under high ambient temperatures [16].
3. Mechanical Maintenance (n = 88): Fitters and technicians performing equipment repairs, often requiring prolonged awkward static postures and heavy tool use [24].
4. Processing Operations (n = 171): Workers monitoring crystallisation pans, managing drying lines, and lifting finished bags, which involves prolonged standing and repetitive upper-limb movements [13].

### 2.5 Statistical Analysis

Data were logged in Microsoft Excel and analysed using OpenEpi (v3.01) software. Continuous variables were expressed as mean ±standard deviation (SD) along with empirical ranges. Categorical data and regional WMSD prevalence values were summarised as frequencies with 95% confidence intervals (CI) computed via the Wilson score method. Body Mass Index (BMI) was dichotomised at the World Health Organisation overweight threshold (≥ 25 kg/m²) to maintain consistency with international literature [30].

Bivariate cross-tabulations were evaluated using standard Pearson Chi-square ($\chi^2$) tests without continuity corrections, given the large sample size (N = 416). Chi-square tests were used to evaluate relationships between binary BMI categories and regional hip/thigh symptoms, as well as between QEC exposure tiers (High/Very High versus Low/Moderate) and site-specific WMSD prevalence. Associations were quantified using Odds Ratios (OR) with 95% confidence intervals and Phi ($\varphi$) coefficients.

A non-parametric Kruskal-Wallis H-test was used to evaluate differences in continuous REBA scores across the four independent operational task groups. Finally, multivariable binary logistic regression analysis was conducted for four primary regional outcomes: the lower back, shoulder, hip/thigh, and knee. Age, continuous BMI, and work experience were entered simultaneously as continuous predictors to calculate adjusted odds ratios (aOR). Sex and task group variables were excluded from the regression models to prevent overfitting and avoid collinearity with individual ergonomic risk scores. Statistical significance was set at $p < 0.05$.

## 3. RESULTS

### 3.1 Sociodemographic and Occupational Baseline Characteristics

The final study cohort comprised 416 male-dominant (98.3%) industrial laborers working day shifts. The mean age was 40.03 ±11.63 years (range: 20–60). Anthropometric measurements showed a mean height of 169.51 ±6.12 cm and a mean weight of 70.22 ± 9.00 kg. The mean calculated BMI was 24.51 ±3.45 kg/m², with 194 workers (46.6%) meeting or exceeding the threshold for overweight status (≥ 25 kg/m²). The sample demonstrated substantial career longevity, with a mean work experience of 15.47 ± 10.91 years; 42.5% of the cohort had worked in the industry for more than 15 years.

Table 1. Sociodemographic and Occupational Characteristics (N = 416)

| Characteristic | Value | Range or % |
|---|---|---|
| **Age (years)** | 40.03 ± 11.63 | 20–60 |
| **Height (cm)** | 169.51 ± 6.12 | 153–180 |
| **Weight (kg)** | 70.22 ± 9.00 | 45–85 |
| **BMI (kg/m²)** | 24.51 ± 3.45 | 15.2–34.8 |
| **BMI ≥ 25 kg/m² (Overweight)** | 194 | 46.6% |
| **Work Experience (years)** | 15.47 ± 10.91 | 1–47 |
| **< 5 years** | 83 | 20.0% |
| **5–15 years** | 156 | 37.5% |
| **> 15 years** | 177 | 42.5% |
| **Sex: Male** | 409 | 98.3% |
| **Sex: Female** | 7 | 1.7% |
| **Work Shift: Day Shift Only** | 416 | 100% |

### 3.2 12-Month Musculoskeletal Symptom Prevalence

Data from the Nordic Musculoskeletal Questionnaire [27] indicated a high symptom burden across the entire workforce. The highest rate of positive 12-month morbidity was reported in the lower back (69.95%; 95% CI: 65.55%–74.36%), followed by shoulder symptoms (69.23%; 95% CI: 64.80%–73.67%) and upper back pain (67.07%; 95% CI: 62.55%–71.58%). Lower-extremity involvement was also common, with knee symptoms reported by 63.22% of workers. The lowest-ranked anatomical region—the elbow—still presented a substantial 12-month prevalence rate of 40.62%, showing that musculoskeletal discomfort was widespread across all anatomical sites.

Table 2. 12-Month WMSD Prevalence by Anatomical Region (N = 416)

| Anatomical Region | Symptoms (n) | Prevalence (%) | 95% CI (%) | Rank |
|---|---|---|---|---|
| Lower Back | **291** | **69.95** | **65.55 – 74.36** | **1** |
| **Shoulder** | 288 | 69.23 | 64.80 – 73.67 | 2 |
| **Upper Back** | 279 | 67.07 | 62.55 – 71.58 | 3 |
| **Knee** | 263 | 63.22 | 58.59 – 67.85 | 4 |
| **Ankle/Foot** | 243 | 58.41 | 53.68 – 63.15 | 5 |
| **Wrist/Hand** | 219 | 52.64 | 47.85 – 57.44 | 6 |
| **Hip/Thigh** | 202 | 48.56 | 43.75 – 53.36 | 7 |
| **Neck** | 178 | 42.79 | 38.03 – 47.54 | 8 |
| **Elbow** | 169 | 40.62 | 35.91 – 45.34 | 9 |

3.3 Ergonomic Risk Profiles (REBA and QEC)

Observational findings using the REBA method [28] showed that no factory workers fell into the "Negligible" or "Low" risk categories. The largest segment of the workforce was classified as High Risk (49.0%, n = 204), while an additional 34.1% (n = 142) operated under Very High Risk postural conditions. Combined, 83.1% of the sample worked in roles requiring ergonomic modifications.

Table 3. REBA Risk Category Distribution (N = 416)

| Risk Category (Score) | Workers (n) | Percentage (%) | 95% CI (%) | Action Tier |
|---|---|---|---|---|
| **Negligible (1)** | 0 | 0.0 | — | No action necessary |
| **Low (2–3)** | 0 | 0.0 | — | Change may be needed |
| **Medium (4–7)** | 70 | 16.8 | 13.29 – 20.71 | Further investigation |
| **High (8–10)** | 204 | 49.0 | 44.24 – 53.76 | Implement change soon |
| **Very High (11–15)** | 142 | 34.1 | 29.65 – 38.65 | Implement change immediately |

Results from the Quick Exposure Checklist (QEC) [29] reinforced these patterns. The mean total QEC score was 16.24 ±2.84 out of an operational maximum of 24 points. Only four workers (1.0%) registered a Low exposure profile. Conversely, 90.6% (n = 377) of the population fell into the combined High or Very High exposure categories, indicating elevated physical exposure across departments.

Table 4. QEC Exposure Category Distribution (N = 416)

| **Exposure Category** | **Workers (n)** | **Percentage (%)** | **Cumulative %** |
|---|---|---|---|
| Low (≤ 40%) | 4 | 1.0 | 1.0 |
| Moderate (41%–50%) | 35 | 8.4 | 9.4 |
| High (51%–70%) | 186 | 44.7 | 54.1 |
| Very High (> 70%) | 191 | 45.9 | 100.0 |

3.4 Operational Task Group Analysis

When stratified by department, mean REBA scores were uniform across all four operational groups, ranging from 9.5 to 9.8. A Kruskal-Wallis test confirmed no statistically significant differences in postural risk levels between these independent task groups (H = 1.484, df = 3, p = 0.686).

The prevalence of lower back and shoulder symptoms remained high across all departments. The highest rate of shoulder symptoms occurred in Cane Handling & Loading (72.9%), while the highest rate of lower back symptoms was found in Mechanical Maintenance (72.7%). This uniform distribution suggests that ergonomic hazards are characteristic of the general factory environment rather than restricted to specific operational departments [14, 24].

Table 5. Task Group Characteristics: REBA Scores and WMSD Prevalence

| Task Group (n) | Core Roles | Mean REBA ± SD | Very High Risk % (n) | LB WMSD % | Shoulder WMSD % |
|---|---|---|---|---|---|
| **Cane Handling (n=59)** | Yard Unloader, Cutter, Tractor Driver | 9.8 ± 2.1 | 37.3 % (22) | 71.2 % | 72.9% |
| **Boiler & Utilities (n=98)** | Boiler Operator, Fitter, Pump Attendant | 9.7 ± 2.3 | 36.7 % (36) | 72.4 % | 68.4% |
| **Mechanical Maint. (n=88)** | Mill Fitter, Workshop Helper, Inspector | 9.8 ± 2.3 | 39.8 % (35) | 72.7 % | 64.8% |
| **Processing Ops (n=171)** | Crystallizer, Bagging Hand, Dryer Operator | 9.5 ± 2.0 | 28.7 % (49) | 66.7 % | 70.8% |

3.5 Bivariate Statistical Associations

Pearson Chi-square cross-tabulations identified several key relationships. Workers categorized as overweight (BMI ≥ 25 kg/m²) experienced a significantly higher prevalence of hip/thigh symptoms compared to those with a normal BMI (56.7% versus 41.4%; $\chi^2 = 9.651$, df = 1, p = 0.002), yielding a significant bivariate odds ratio of 1.85 (95% CI: 1.25–2.73; φ = 0.152).

Table 6. BMI Category vs Hip/Thigh Symptoms: 2×2 Contingency Table (N = 416)

| BMI Classification | Symptoms Present (n) | Symptoms Absent (n) | Total (n) | Bivariate OR (95% CI) |
|---|---|---|---|---|
| **BMI < 25 kg/m² (Normal)** | 92 (41.4%) | 130 (58.6%) | 222 | **Reference** |
| **BMI ≥ 25 kg/m² (Overweight)** | 110 (56.7%) | 84 (43.3%) | 194 | **1.85 (1.25–2.73)** |
| Total | **202 (48.6%)** | **214 (51.4%)** | **416** | — |

*Pearson $\chi^2 = 9.651$, df = 1, p = 0.002, φ = 0.152.*

Analysis of QEC exposure levels [29] also revealed significant associations with regional outcomes. Workers in the High or Very High QEC categories had more than double the odds of experiencing shoulder symptoms (OR = 2.08; 95% CI: 1.07–4.06; p = 0.029) and ankle/foot symptoms (OR = 2.18; 95% CI: 1.11–4.25; p = 0.021) compared to those with Low/Moderate exposure profiles. Bivariate associations for the remaining seven anatomical regions did not reach statistical significance (p > 0.05).

Table 7. Summary of Key Bivariate Statistical Associations

| Independent Risk Factor | Dependent WMSD Outcome | $\chi^2$ (df=1) | OR (95% CI) | Phi (φ) | p-value |
|---|---|---|---|---|---|
| **BMI ≥ 25 vs. < 25** | Hip/Thigh | 9.651 | 1.85 (1.25 | 0.152 | 0.002* |

| | | | | | |
|---|---|---|---|---|---|
| **kg/m²** | Symptoms | | – 2.73) | | |
| **QEC High/VH vs. Low/Mod** | Shoulder Symptoms | 4.782 | 2.08 (1.07 – 4.06) | 0.107 | 0.029* |
| **QEC High/VH vs. Low/Mod** | Ankle/Foot Symptoms | 5.356 | 2.18 (1.11 – 4.25) | 0.113 | 0.021* |

3.6 Multivariable Logistic Regression

Simultaneous multivariable logistic regression modelling was conducted for lower back, shoulder, hip/thigh, and knee symptoms, using age, continuous BMI, and work experience as continuous predictors [30].

For lower back, shoulder, and knee symptoms, no individual continuous predictor maintained independent significance after controlling for the other variables. However, the model for hip/thigh symptoms yielded significant findings. Continuous BMI remained a significant independent predictor, with the odds of hip/thigh symptoms increasing by 9.4% for each additional unit of body mass index (aOR = 1.094; 95% CI: 1.032–1.159; p = 0.003).

Concurrently, participant age demonstrated a significant inverse association, where each additional year of age was associated with a 3% reduction in symptom odds (aOR = 0.970; 95% CI: 0.950–0.990; p = 0.004). Career work experience did not emerge as an independent predictor for any regional outcome.

Table 8. Multivariable Logistic Regression: Adjusted Odds Ratios for Primary WMSD Outcomes

| Region Model | Predictor (Continuous) | aOR | p-value | 95% CI |
|---|---|---|---|---|
| **Lower Back** | Age (per year) | 1.012 | 0.294 | 0.990–1.035 |
| | BMI (per kg/m²) | 1.007 | 0.829 | 0.947–1.071 |
| | Work Experience (per year) | 0.977 | 0.056 | 0.955–1.001 |
| **Shoulder** | Age (per year) | 0.981 | 0.074 | 0.960–1.002 |
| | BMI (per kg/m²) | 1.015 | 0.636 | 0.955–1.078 |
| | Work Experience (per year) | 1.023 | 0.051 | 1.000–1.047 |
| Hip / Thigh | **Age (per year)*** | **0.970** | **0.004*** | **0.950–0.990** |
| | **BMI (per kg/m²)*** | **1.094** | **0.003*** | **1.032–1.159** |
| | Work Experience (per year) | 1.014 | 0.203 | 0.992–1.037 |
| **Knee** | Age (per year) | 1.009 | 0.384 | 0.989–1.030 |
| | BMI (per kg/m²) | 0.962 | 0.196 | 0.908–1.020 |
| | Work Experience (per year) | 1.011 | 0.327 | 0.989–1.034 |

Statistically significant at $p < 0.05$. Highlighted rows (yellow) denote significant predictors aOR = adjusted odds ratio.

## 4. DISCUSSION

This investigation evaluates WMSD prevalence alongside REBA and QEC ergonomic indicators within a large-capacity sugar manufacturing workforce in Maharashtra [19]. The results show a high 12-month prevalence of musculoskeletal symptoms, accompanied by severe ergonomic hazards distributed uniformly across the factory floor.

The high 12-month lower back (69.95%) and shoulder (69.23%) symptom rates meet or exceed baseline parameters reported in other agricultural and processing environments. These findings correspond with the high symptom burdens observed by Phajan et al. among Thai sugarcane harvesters [21] and Leite et al. in Brazilian processing centre's [22]. Similarly, local agro-industrial surveys in India have noted that manual handling tasks lead to substantial spinal strain [12,23]. The elevated symptom rates across all nine assessed anatomical regions reflect the mixed physical demands of factory operations, which involve repetitive lifting, overhead reaching, and prolonged static postures [3,24].

A key finding from this study is that mean REBA scores (9.5–9.8) remained uniformly high across all four operational groups, with no statistically significant differences between departments (p = 0.686). This uniform distribution indicates that high ergonomic risk is built into the general factory environment rather than restricted to specific job hniquements [5,14]. Whether labourers are unloading raw material in the yard, maintaining machinery, or packing finished product, they face comparable physical demands. This suggests that intervention strategies should target the entire workforce collectively, rather than focusing only on individual high-profile tasks [5].

The lack of statistical association between REBA risk categories and regional symptom prevalence can be attributed to the high overall risk levels within this cohort. With 83.1% of the participants falling into the High or Very High risk categories and none in the Negligible or Low tiers, the limited variance within the sample makes it difficult to detect outcome rate differences between risk levels. This pattern has been observed in other occupational settings characterised by uniformly high physical demands [2,3].

Bivariate analyses showed significant associations between high QEC scores and both shoulder (OR = 2.08) and ankle/foot symptoms (OR = 2.18). These relationships are consistent with known occupational injury mechanisms [25]. Repetitive overhead reaching and manual handling place continuous stress on the rotator cuff muscles and subacromial tissues [6]. Concurrently, working long shifts standing on unyielding concrete floors transfers continuous static loads to the plantar structures and ankle joints [18].

The multivariable regression models provided additional insights into hip/thigh symptoms, which was the only outcome area with significant independent predictors. The independent risk associated with an increasing continuous BMI (aOR = 1.094) aligns with established biomechanical evidence linking excess body mass to heightened joint compression and muscle strain during manual handling [4,30].

In contrast, the inverse relationship between participant age and hip/thigh symptoms (aOR = 0.970)—where younger workers exhibited higher symptom odds—is less typical but highly informative. This pattern may reflect a healthy-worker survivor effect, where laborers who develop chronic lower-extremity symptoms early in their careers transfer to less demanding roles or leave the industry entirely, leaving behind a more resilient older cohort [1]. Alternatively, younger workers may be assigned more physically intense tasks or may not yet have developed the pacing strategies and ergonomic adaptations that come with experience [2]. This trend highlights the importance of providing early ergonomic training and physical conditioning to newer employees to prevent early-career injuries.

The lack of independent association between work experience and symptom prevalence further indicates that musculoskeletal strain occurs early in employment tenure. This is supported by the high symptom rates seen even among workers with fewer than five years on the job.

### 4.1 Study Strengths

Key strengths of this study include its large sample size (N = 416), a high final participation rate (81.5%), and the concurrent use of three validated, internationally recognised checklists (NMQ [27], REBA [28], QEC [29]). Additionally, analysing risk across specific task groups and employing multivariable regression models [30] allowed for a rigorous evaluation of compounding variables, addressing a key gap in the regional occupational health literature.

### 4.2 Methodological Limitations

Several limitations should be considered when interpreting these findings:

- The cross-sectional design captures data at a single point in time, which precludes establishing direct causal relationships.
- Musculoskeletal symptom data were self-reported via the NMQ, introducing potential recall bias [27].
- The purposive selection of two high-capacity factories in the Sangli district may limit the generalizability of the results to smaller less mechanized processing facilities [19].
- REBA assessments were based on the single most demanding posture observed during a work cycle, which may not capture cumulative physical strain over an entire shift [28].
- Formal inter-rater reliability testing was not conducted for the ergonomic observers.
- The low number of female participants (1.7%) prevented a meaningful analysis of gender-specific risk factors.

## 5. CONCLUSION

Manual labourers working in these sugarcane processing facilities experience an exceptionally high 12-month burden of musculoskeletal symptoms, particularly affecting the lower back, shoulder, and upper back regions. Objective ergonomic assessments using REBA and QEC metrics confirm widespread, severe physical risks that are uniformly distributed across all factory departments. Elevated BMI and younger age were identified as independent predictors of hip/thigh symptoms, while high overall QEC scores were linked to increased shoulder and ankle/foot discomfort.

These findings support the implementation of comprehensive, factory-wide ergonomic interventions, physical therapy-led injury prevention programs, and targeted health initiatives focusing on weight management. Future research should utilise prospective, longitudinal designs with continuous, time-weighted exposure measurements to better define causal mechanisms and guide the development of targeted engineering controls within the agro-industrial sector.

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