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CHAPTER 1

THE ECONOMIC ROLE OF AGRICULTURAL MACHINERY: GLOBAL DYNAMICS AND THE PERSPECTIVE OF TÜRKİYE

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1. Introduction and Literature Review

1.1 Definition and Scope of Agricultural Machinery

Agricultural machinery refers to tools and equipment that reduce labor requirements, increase productivity, and lower production costs within agricultural production processes. These include tractors, planting machinery, harvesting equipment, irrigation devices, and other mechanical systems used for soil cultivation. Agricultural mechanization not only enables labor savings but also enhances product quality and expands production volume by optimizing the timing of agricultural operations throughout the production cycle.

The studies conducted by Hans Binswanger on the impact of mechanization on development emphasize the effects of technological change in agriculture on economic growth and production performance. These studies demonstrate that mechanization plays a critical role in countries' agricultural growth processes and provides analytical evidence regarding the economic outcomes of this transformation (Binswanger & Joachim, 1991).

1.2 The Academic Perspective on Mechanization

Academic studies examine the economic impacts of agricultural machinery from a multidimensional perspective. For instance, research conducted worldwide on the positive effects of agricultural mechanization on productivity has demonstrated that machinery also enhances the efficiency of other production inputs. Moreover, findings from different countries, ranging from Australia to China, indicate significant outcomes such as labor savings and increased productivity (Özoğul, 2018).

Research further reports that modern agricultural machinery not only contributes to increased production but also reduces input costs, improves product quality, and optimizes marketing and harvest timing. This impact is considered particularly critical in developing countries, where mechanization plays a key role in increasing agricultural income and employment opportunities (Peng et al., 2022).

2. The Economic Role of Agricultural Machinery Worldwide

2.1 Introduction

Agricultural machinery has assumed a critical function in the global economy by transferring industrialized production processes into agricultural production systems. Modern agricultural machinery includes tractors, combine harvesters, soil tillage equipment, planting and seeding machines, irrigation systems, and harvesting equipment. Beyond increasing agricultural productivity, these machines serve as fundamental tools for reducing production costs, maximizing input efficiency, and supporting global food security. As the level of mechanization in the agricultural sector increases worldwide, production scales expand and the economic value chain broadens. This section examines the global economic impacts of agricultural machinery in detail.

2.2 Productivity and Growth in Global Agricultural Production

The most fundamental aspect of understanding the economic impact of agricultural machinery is its contribution to agricultural productivity. Research indicates that mechanization increases agricultural output by enhancing production per unit area. A study conducted in China found that increases in the level of agricultural mechanization positively affected farm income, output value, and production efficiency. For each unit increase in mechanization intensity, significant improvements in crop income and productivity were identified. These effects were observed in both cereal crops and cash crops, clearly demonstrating the economic benefits of agricultural machinery (Peng, 2022).

Similarly, a broader body of literature reports that the use of agricultural machinery reduces production costs, increases labor productivity, and contributes to the growth of agricultural output, particularly in developing economies. Mechanization enables production capacities that are substantially higher than those achievable through traditional human and animal labor. This dynamic represents a crucial economic factor in meeting the growing global demand for food driven by population growth (Renius, 2022).

2.3 The Impact of Agricultural Machinery on the Industrial Economy

Agricultural machinery not only supports agricultural production but also plays a significant role in global manufacturing and trade systems. The global agricultural machinery industry is characterized by high levels of integration and globalization. Major multinational corporations—such as John Deere, CNH Global, and AGCO—are integrated into world trade through extensive production and distribution networks. These companies and manufacturing facilities generate economic activities related to investment, employment, and technology transfer through the production of agricultural machinery (Machinery Federation, 2021).

According to data from 2013, Europe accounted for approximately 31% of global agricultural machinery production, while North America and China together contributed around 26.5%. The total production volume represents economic value amounting to tens of billions of euros. This production capacity highlights the significance of the agricultural equipment market within the global economy in terms of both investment and international trade (Machinery Federation, 2021).

2.4 Employment and Structural Transformation

The widespread adoption of agricultural machinery leads to labor savings in agricultural production, thereby directly affecting labor demand. While traditional agriculture requires high levels of labor input, modern agricultural machinery enables the reallocation of labor from agricultural production to other economic sectors. However, the impact of automation on employment is complex. Although mechanization may eliminate certain agricultural jobs, it simultaneously creates new employment opportunities in areas such as machinery maintenance, operation, logistics, and manufacturing. In this context, mechanization plays a significant role in processes of social transformation and contributes to the transfer of labor resources toward the industrial and service sectors (Renius, 2022; Binswanger-Mkhize, 2017).

Studies examining the effects of mechanization on agricultural employment indicate that while mechanization reduces labor demand in agriculture, it increases overall production levels. Some academic models reveal that each incremental increase in machinery use leads to a long-term decline in agricultural employment rates, while simultaneously enhancing labor productivity and production capacity in the short term. This phenomenon is particularly associated with rural-to-urban migration and the transformation of employment structures in developing economies (Yücel & Çalışkan, 2021).

2.5 Economic Benefits of Agricultural Machinery

Reduction in Input Costs:

The use of machinery increases cost efficiency in agricultural production by reducing labor costs.

Productivity Gains:

Modern machinery provides higher efficiency across all production stages—including harvesting and soil cultivation—particularly in large-scale farming operations.

Environmental Impact and Sustainability:

Appropriate mechanization promotes more efficient use of inputs and contributes to sustainable production practices. This is especially evident in digital and precision agriculture technologies, which enable savings in water, fertilizer, and pesticide use (Pingali, 2007; Binswanger & Ruttan, 1978).

Global Food Security:

By increasing agricultural output and ensuring continuity and stability in production, agricultural machinery contributes to global food supply security.

2.6 Limitations and Policy Considerations

Although mechanization has made substantial contributions to agricultural production, challenges such as unequal distribution and limited access to capital remain significant. Small-scale farms, in particular, may face difficulties in adapting to mechanization due to high machinery costs. Consequently, governments have developed incentive mechanisms within agricultural policies, including machinery purchase subsidies, credit support programs, and technical training initiatives.

Furthermore, when mechanization is implemented incorrectly or without adequate planning, it may generate environmental burdens, such as soil compaction and increased energy consumption. Therefore, the development and implementation of sustainable mechanization strategies are of critical importance (Klerkx et al., 2019; Wolfert et al., 2017).

2.7 Summary

From a global economic perspective, agricultural machinery not only enhances productivity and production capacity but also serves as a key economic factor influencing the integration of agricultural industries into global supply chains, structural transformations, and employment dynamics. Mechanization exerts a decisive influence on productivity, production scale, and global trade structures.

3. The Economic Role of Agricultural Machinery in Türkiye

3.1 Introduction

Turkish agriculture has historically undergone a transition from a labor-intensive production structure to a modern system based on mechanization. Agricultural machinery constitutes one of the fundamental driving forces of this transformation, exerting both direct and indirect effects on production efficiency, agricultural income, rural development, and the national economy. In Türkiye, the agricultural sector holds strategic importance due to its role in food security, employment, exports, and its backward and forward linkages with industry. In this context, the economic role of agricultural machinery extends beyond increases in agricultural output and encompasses dimensions related to the machinery manufacturing industry, foreign trade balance, and technological development.

3.2 Development of Agricultural Mechanization in Türkiye

The process of agricultural mechanization in Türkiye accelerated particularly after the 1950s. With the widespread adoption of tractors, traditional production methods were gradually replaced by higher-capacity and more time-efficient mechanical systems. Data from the Ministry of Agriculture and Forestry and the Turkish Statistical Institute (TURKSTAT) indicate a steady increase in the number of tractors over time, with mechanization levels concentrated particularly in cereal-producing regions.

However, the level of mechanization in Türkiye exhibits significant regional disparities. While the use of agricultural machinery is more widespread in the Aegean, Marmara, and Central Anatolia regions, mechanization rates are relatively lower in Eastern and Southeastern Anatolia.

These differences are closely related to farm size, capital accumulation, topographical conditions, and cropping patterns (Akdemir, 2013).

3.3 Effects of Agricultural Machinery on Agricultural Productivity and Income

One of the most significant economic impacts of agricultural machinery in Türkiye is the increase in agricultural productivity. Mechanization enables soil cultivation, planting, fertilization, irrigation, and harvesting operations to be carried out more rapidly and in a more uniform manner. This reduces crop losses and increases output per unit area.

Academic studies reveal a positive and statistically significant relationship between the level of agricultural mechanization and agricultural production value in Türkiye. In particular, the widespread use of tractors and harvesting machinery has led to yield increases in cereal crops and industrial crops (Ministry of Agriculture and Forestry, 2021). Moreover, the timely execution of production processes facilitated by mechanization mitigates the adverse effects of climatic risks and contributes to greater income stability for farmers.

3.4 The Agricultural Machinery Industry and the National Economy

Agricultural machinery represents a subsector in Türkiye that directly affects not only the agricultural sector but also the manufacturing industry. Türkiye holds a significant regional position in the production of tractors and certain agricultural equipment. In tractor manufacturing in particular, Türkiye ranks among the leading countries in Europe, with domestic production supplying both the internal market and export demand.

Reports by the Machinery and Equipment Exporters' Association (MAİB) and the Machinery Federation (MAKFED) indicate that the agricultural machinery sector accounts for a substantial share of Türkiye's total machinery exports. The agricultural machinery industry generates a multiplier effect by supporting numerous subsectors, including casting, metal processing, hydraulics, electronics, and software. In this regard, agricultural machinery constitutes a concrete example of industry–agriculture integration within the Turkish economy (Machinery Federation, 2021).

3.5 Employment and Rural Development Dimension

The widespread adoption of agricultural machinery has transformed employment structures in rural areas. While mechanization reduces the direct demand for labor in agricultural production, it simultaneously creates new employment opportunities in areas such as machinery operation, maintenance and repair, spare parts supply, sales, and technical services. This demonstrates that the impact of agricultural machinery on employment is not unidirectional but instead leads to a qualitative transformation in employment structures.

Moreover, mechanization contributes to increased income levels and improved living standards in rural regions by making agricultural production more profitable. This effect is of particular importance in the context of rural development policies. Supporting mechanization is also regarded as a factor that may encourage younger populations to remain engaged in agriculture (FAO, 2016).

3.6 Government Support and Agricultural Policies

Government support plays a significant role in the dissemination of agricultural machinery in Türkiye. Rural development support programs implemented by the Ministry of Agriculture and Forestry—such as machinery and equipment purchase grants and low-interest credit schemes—facilitate farmers' access to modern agricultural machinery. These support mechanisms accelerate the transition to mechanization, particularly for small- and medium-scale farms.

However, the literature also highlights criticisms suggesting that such support measures have not fully addressed regional disparities and that the sustainability dimension of mechanization

has not been sufficiently considered. Unplanned and excessive use of machinery may lead to issues such as soil compaction, increased energy consumption, and environmental degradation. Therefore, it is emphasized that agricultural machinery policies in Türkiye should prioritize environmental sustainability alongside productivity objectives (Aybek, 2021).

3.7 Strategic Assessment from the Perspective of Türkiye

For Türkiye, agricultural machinery constitutes a strategic sector. Population growth, climate change, and global food crises necessitate the continuity of agricultural production. Under these conditions, agricultural machinery contributes to national food security by enabling timely, efficient, and cost-effective production processes.

Furthermore, the expansion of digital agriculture, precision farming, and smart machinery technologies presents new opportunities for the agricultural machinery sector in Türkiye. Sensor-based systems, data-driven decision support mechanisms, and autonomous agricultural machinery possess significant potential to enhance agricultural productivity while supporting high value-added production.

3.8 Summary

In Türkiye, agricultural machinery generates multidimensional economic impacts on agricultural productivity, farm income, industrial output, employment, and foreign trade. While mechanization represents an indispensable tool in the modernization of the agricultural sector, it must be planned with due consideration of regional disparities and environmental effects. Through appropriate policies and technology-oriented investments, agricultural machinery will continue to make substantial contributions to the sustainable growth of the Turkish economy.

4. The Importance of Agricultural Machinery in Terms of Employment, Foreign Trade, and Value Chains

4.1 The Relationship Between Agricultural Machinery and Employment

The economic impacts of agricultural machinery are not limited solely to increases in production; they also constitute a significant factor transforming employment structures. While mechanization reduces the demand for physical labor in agricultural production, it simultaneously alters the qualitative composition of employment. In traditional agricultural systems, tasks requiring intensive human labor can be performed with fewer workers through modern machinery, leading to a structural transformation of employment within the agricultural sector.

However, this transformation is often incorrectly perceived as “job loss.” The literature emphasizes that the net employment effect of mechanization may be neutral or even positive. The widespread adoption of agricultural machinery creates new employment opportunities in areas such as machinery operation, maintenance and repair, technical services, spare parts manufacturing, logistics, and sales (World Bank, 2019). Consequently, while mechanization reduces demand for low-skilled labor in agriculture, it promotes the emergence of new occupational groups requiring technical expertise.

4.2 Transition of the Rural Labor Force to Industry and Services

Agricultural machinery has played a significant role in redirecting the rural labor force toward the industrial and service sectors. Through mechanization, agricultural production has become sustainable with fewer workers, allowing surplus labor to shift to non-agricultural sectors. This process is regarded as one of the core components of structural transformation in economic development theories.

Reports by the FAO and the World Bank indicate that agricultural mechanization indirectly contributes to poverty reduction in rural areas, particularly in developing countries. Alongside productivity gains in agriculture, rising rural incomes also stimulate increased investment in areas such as education and healthcare (FAO, 2019).

4.3 Agricultural Machinery and the Global Value Chain

The agricultural machinery sector represents a high value-added production field at the global level. Tractors, harvesting machines, and smart agricultural equipment are embedded within complex value chains encompassing casting, metal processing, electronics, software, and hydraulic systems. This value chain activates a wide range of supporting industries and service sectors, thereby generating extensive economic spillover effects.

Although the global agricultural machinery market is dominated by multinational corporations, the share of domestic manufacturers in developing countries has been increasing. Given the high technological intensity of agricultural machinery products, the sector also reflects countries' industrial competitiveness (OECD, 2020).

4.4 Foreign Trade and Export Dimension

Agricultural machinery constitutes a major export category for many countries. Nations such as the United States, Germany, Italy, and Japan are global leaders in agricultural machinery exports. In recent years, Türkiye has also exhibited a notable increase in exports of tractors and certain agricultural equipment.

Exports of agricultural machinery contribute to the reduction of foreign trade deficits and support technology-driven growth within the manufacturing sector. Moreover, export-oriented production encourages firms to increase their investments in research and development, thereby accelerating technological advancement (MAİB, 2024).

4.5 Agricultural Machinery and Value Creation

Agricultural machinery serves as a key instrument for increasing value added within the agricultural sector. Through mechanization, higher quantities and improved quality of output can be obtained from the same production area, thereby enhancing the market value of agricultural products. Harvesting and post-harvest machinery, in particular, increase economic efficiency by reducing product losses.

5. Agricultural Machinery Policies, Incentives, and the Institutional Framework (Türkiye and the World)

5.1 The Importance of Public Policies for Agricultural Machinery

The dissemination of agricultural machinery does not always yield the desired outcomes when left solely to market conditions. High investment costs may limit access to modern machinery, particularly for small- and medium-scale farms. Therefore, public policies and incentive mechanisms play a decisive role in promoting agricultural mechanization.

Globally, agricultural policies support mechanization in line with objectives related to productivity growth and food security. In developing countries in particular, machinery purchase subsidies and low-interest credit programs are widely implemented to facilitate access to modern agricultural equipment (World Bank, 2019).

5.2 Global Support Models for Agricultural Machinery

The United States and the European Union implement policies that indirectly support agricultural machinery investments. Within the framework of the European Union's Common Agricultural Policy (CAP), investment support schemes provided to farmers encourage the

adoption of modern machinery. In the United States, agricultural equipment investments are supported through tax incentives and preferential credit arrangements.

In Asian countries—particularly China and India—mechanization policies rely more heavily on direct subsidy mechanisms. In China, state-supported machinery purchase programs have played a significant role in the rapid increase in mechanization levels (Yang et al., 2022).

5.3 Agricultural Machinery Support Policies in Türkiye

In Türkiye, support for agricultural machinery is primarily administered by the Ministry of Agriculture and Forestry. Machinery and equipment purchase grants provided under rural development investment programs constitute a key instrument for expanding mechanization. In addition, low-interest credit facilities offered through Ziraat Bank and Agricultural Credit Cooperatives facilitate farmers' machinery investments.

These support mechanisms are particularly critical for small- and medium-scale farms. However, the literature emphasizes that such measures have had limited success in reducing regional disparities and highlights the need for more targeted and region-specific policy instruments (Barutçu & Tepeli, 2015).

5.4 Sustainability and Environmental Policies

In recent years, environmental sustainability has become a central focus of agricultural machinery policies. Excessive or poorly planned mechanization may lead to environmental problems such as soil compaction, increased fuel consumption, and greenhouse gas emissions. Consequently, modern agricultural policies increasingly promote the use of energy-efficient and environmentally friendly machinery.

Precision agriculture technologies and smart machinery systems have significant potential to reduce environmental impacts by optimizing input use. This approach is critical for achieving both economic efficiency and environmental sustainability (OECD, 2019).

5.5 Policy Assessment

Policies targeting agricultural machinery should aim not only at short-term increases in production but also at long-term structural transformation. Mechanization strategies implemented alongside education, technical advisory services, and research and development support are likely to enhance economic efficiency. From the perspective of Türkiye, supporting domestic agricultural machinery production and shifting toward high-technology products are of strategic importance.

6. Conclusion and General Evaluation

Agricultural machinery plays a central role in the economic, social, and structural transformation of the agricultural sector, both at the global level and in the specific context of Türkiye. This study has examined the significance of agricultural machinery for the world and Turkish economies through multiple dimensions, including productivity, employment, industry, foreign trade, value chains, and public policies. The findings clearly indicate that agricultural machinery should not be regarded merely as technical tools that increase production, but rather as one of the fundamental components of economic growth, rural development, and sustainable food systems.

At the global scale, agricultural machinery performs a critical function in ensuring food supply security in the face of pressures arising from population growth and climate change. Through mechanization, agricultural production can be carried out in shorter timeframes, at lower costs, and with higher efficiency. The literature unequivocally demonstrates that increases in the level of mechanization generate significant and positive effects on agricultural productivity, farm income, and production stability. Moreover, the agricultural machinery industry, owing to its

technology-intensive structure, enhances countries' industrial competitiveness and occupies a strategic position within global value chains.

From the perspective of Türkiye, the agricultural machinery sector holds strategic importance for both the modernization of agricultural production and the development of industry and foreign trade. Türkiye has become a significant regional producer of tractors and certain agricultural equipment, thereby strengthening the industry-based contributions of agricultural machinery to the national economy. Agricultural mechanization has increased productivity, rendered production processes more predictable, and contributed to relative income stability for farmers in Türkiye.

Nevertheless, the economic benefits of mechanization are not distributed evenly due to regional disparities and differences in farm size. Capital constraints faced by small-scale farms may limit access to modern machinery, underscoring the need for targeted support mechanisms within agricultural policies. Furthermore, unplanned and excessive use of machinery may lead to adverse outcomes such as soil compaction, increased energy consumption, and environmental degradation. Consequently, it is essential to assess the economic contributions of agricultural machinery in conjunction with sustainability principles.

One of the key conclusions of this study is that the employment effects of agricultural machinery are not unidirectional. While mechanization reduces the direct demand for labor in agriculture, it simultaneously creates new employment opportunities that require technical knowledge and skills. This highlights the role of agricultural machinery as a transformative instrument that promotes skilled labor in rural areas. Mechanization policies supported by education, technical advisory services, and extension activities can further strengthen the positive outcomes of this transformation.

In conclusion, agricultural machinery constitutes an indispensable element for the continuity of agricultural production, economic efficiency, industrial development, and food security. With the increasing adoption of digital agriculture, precision farming, autonomous systems, and artificial intelligence-based machinery, the economic impacts of agricultural machinery are expected to intensify further in the future. Strengthening domestic production capacity, research and development investments, and sustainable mechanization policies will enable Türkiye to maximize the contributions of agricultural machinery to the national economy.

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CHAPTER 2

AUTOMATIC MILKING ROBOTS

Arda BEKCAN, Ahmet ÇOLAK

Introduction

Milking robots are automated systems used on modern dairy farms to increase efficiency, reduce labor, and improve animal welfare. These robots work through the integration of mechanical, electronic, and software components (Demir and Öztürk, 2011).

Milking robots typically consist of two main components;

- **Mechanical System:** Includes elements such as the recognition and entry system, robot arm, teat cups, brushes, pumps, and milk transfer lines. For example, a robotic arm automatically attaches to detected teats and performs the milking process.
- **Electronic Structure:** Includes components such as sensors, motors, motor drivers, embedded computers, lasers, and cameras. These systems control the robot's precise movements and milking operations by synchronizing over different protocols such as Profinet, CANopen, and Modbus.

The equipment for a robotic milking system consists of a computer, sensors, a robotic arm, a milking stall, automatic doors, a feeding area, and a cleaning system (Alıç and Yener, 2006).

1. Entry System and Cow Recognition

The entry system in milking robots encompasses the area where the cow enters the robot, as well as the mechanisms and technologies used for animal recognition, guidance, and preparation during this process. This system is critically important for ensuring that the milking process is automated, efficient, safe, and stress-free. Components of entry system and cow recognition are as follows:

- **Animal Recognition Unit:**
RFID tags, collars, leg tags, and other similar methods are used for identification.
- **Entrance Gate / Turnstile:**
Animals are only admitted when it is their turn. Prevents unauthorized entry or two animals entering at the same time.
- **RFID Antenna / Reader:**
Performs identity verification and sends information to robot.
- **Guidance System:**
Includes physical obstacles, barriers, and sometimes electromechanical systems that guide the animal.
- **Control Unit:**
Determines the entry order, milking time according to animal behavior data.
- **Feed Distribution Unit:**
Provides feed after the animal enters, encouraging it to stay there (positive reinforcement).
- **Camera / Laser Systems:**
Monitors the position of the entering animal and provides positional alignment for subsequent operations.

- **Weight / Height Sensors:**

The animal's condition can be monitored.

1.1. Operating Principle of the Entry System

In voluntary milking systems, the animal approaches the robot based on its natural movement behavior. Upon entry, an RFID reader identifies the animal and retrieves relevant information such as whether the cow has been milked previously, its milking order, milk yield data, and health status. If the system determines that the animal is eligible for milking, the entry gate is opened and the animal is guided into the milking unit. The system then detects whether the cow is correctly positioned within the milking area. Once proper positioning is confirmed, feed is dispensed to encourage the animal to remain stationary, and the milking process is initiated (Prasad, 2023).

2. Robotic Arm

Milking robot arms have fewer degrees of freedom, two or three instead of six like industrial robots, or they move in a Cartesian (linear) manner. Determining the motor positions that will cause the robot arm to move to a specific point in 3-dimensional space is achieved using the robot's inverse kinematic model. To solve the inverse kinematics DH parameters can be used (Denavit and Hartenberg, 1955).

Table 1. DH Parameters

Parameter	Name	Definition
θ	Joint Angle	Revolute joint variable
d	Joint Distance	Prismatic joint variable
a	Link Length	Distance between two Z axis (along x axis)
α	Link Twist Angle	Angle between two Z axis (rotation around x axis)

With these parameters, a coordinate transformation between previous and current frames can be calculated using rotation, translation, translation, and rotation operations respectively. When all matrices representing these operations are multiplied all together, following homogenous transformation matrix can be derived.

$$T_i = \begin{bmatrix} \cos\theta & -\sin\theta\cos\alpha & \sin\theta\sin\alpha & a\cos\theta \\ \sin\theta & \cos\theta\cos\alpha & -\cos\theta\sin\alpha & a\sin\theta \\ 0 & \sin\alpha & \cos\alpha & d \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

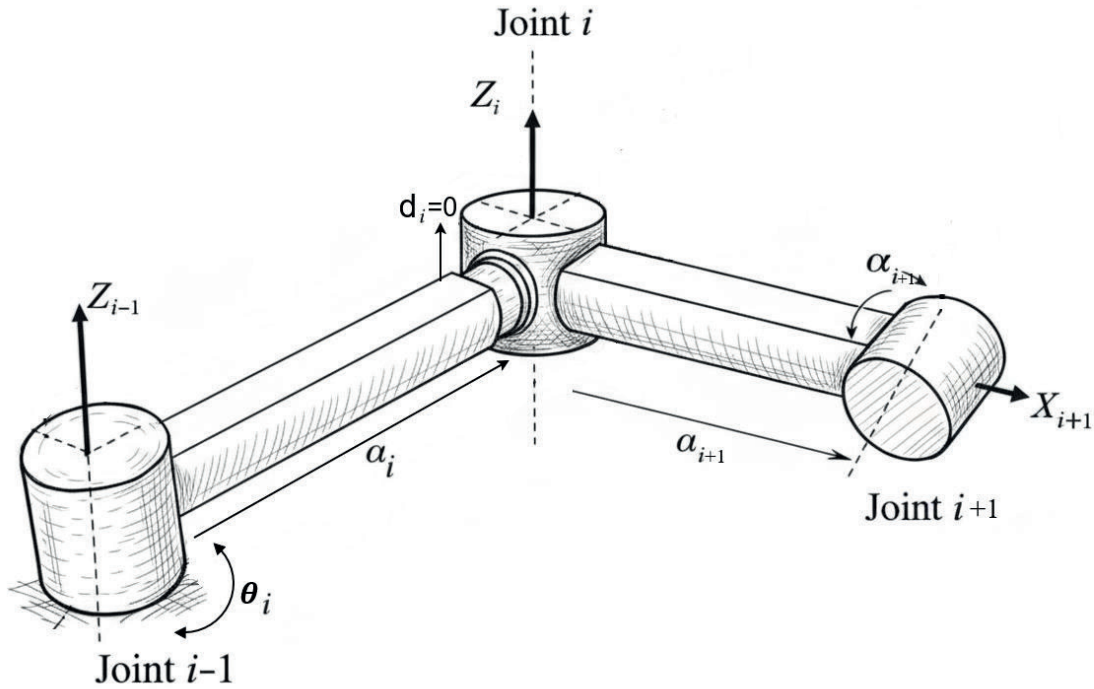


Figure 1. DH Parameters of 2 Link Mechanism

3. Teat Detection in Milking Robots

3.1. Using Laser detection technology

Laser detection in milking robots is an advanced technology that allows the system to detect the cow's udder with high accuracy and without contact. This method is often used with cameras and is particularly important for fast and automatic milking (International Organization for Standardization [ISO], 2016).

Table 2. Laser Types Used in Milking Robots

Technology	Description
LIDAR	2D or 3D surface mapping
Laser Distance Sensor	Measures distance of a point (Time-of-Flight – ToF)
Laser and Camera Combination	Together with image processing provides high accuracy position measurement
Infrared Laser	Uses invisible, non-irritant light source

Laser breast detection works with one or more laser scanners or laser range finders on the robot's arm. When this system is placed under the cow's udder, the laser beam strikes the teats, and sensors calculate the position (x, y, z) of the teats based on the reflection time or angle of this light. If there are previously recorded breast positions, this recorded data is used in error reduction. Strengths and weaknesses of laser systems are as follows (ISO, 2016):

Advantages

- Contactless and hygienic
- High precision (positioning at the millimeter level)
- Fast scanning and short milking time
- Animal-specific adaptation (Each cow's udder position is different; the laser instantly detects this.)
- Ability to detect breast location even in the dark.

Difficulties

- Light scattering due to contamination or milk/steam can affect the accuracy of the system.
- Physical obstacles (sagging breasts, moving animal) can cause errors.
- The laser's accuracy can be reduced by mechanical vibrations or alignment problems.
- Cleaning yourself with the help of brushes can increase accuracy.

3.2. Camera Usage In milking robots

Cameras are the fundamental sensors that allow the system to "see" its surroundings. They are generally used for tasks such as detecting cows' teats, determining position, and supporting cleaning and health checks. Thanks to the cameras, the robot can operate more precisely, automatically, and without harming the animal. While cameras may not be as precise as lasers, they offer significantly more information about the environment, such as color, size, object detection, and comparison. Functions of Cameras in Milking Robots are as follows (ISO, 2016; Akhloufi, 2014):

- **Teat Recognition:** The camera detects the teats using image processing or artificial intelligence algorithms.
- **Milking Cluster Placement:** The camera is used to align the milking cluster with the teat.
- **Cleanliness Check:** The images can be analyzed to determine if the breasts are dirty or clean.
- **Animal Recognition/Tracking:** Animal identification and tracking are possible with face recognition and color/pattern recognition.
- **Data Monitoring:** Data such as breast shape, wounds, and color changes can be collected with the camera (Michael, 2009; Lu et al., 2021).

Cameras used in milking robots need to be able to run in a harsh environment. The required properties are as follows:

- Water and dust proof (IP67)
- Corrosion resistant lids/caps (polycarbonate)
- Protection against evaporation and condensation (lens heater)
- Able to run in low light intensity (auxiliary light source can be used) (ISO, 2007; Akhloufi, 2014)

Different types of cameras are used in milking robots for various purposes. Examples and characteristics of camera types used in milking robots are provided in Table 3.

Table 3. Camera Types Used in Milking Robots

Camera Type	Features	Application Area
RGB Camera	Captures color images	General breast recognition and alignment
IR (Infrared)	Can operate in night/shadow environments	Temperature changes, observation of breast health
Depth Camera	3D positioning and distance measurement	Nipple positioning (x, y, z)
Thermal Camera	Generates a temperature map	Early diagnosis of disease, mastitis

For the cameras to function properly, they need to be used with appropriate software. Therefore, they often work in conjunction with image processing algorithms. These algorithms use Machine Learning (ML) and Deep Learning (DL) methods. In addition, object recognition and segmentation libraries such as OpenCV, TensorFlow, YOLO, and U-NET can be used. In some systems, there is an "udder map" learned for each cow. These maps reduce the margin of error in positioning (Borla et al.,2021; Siddique et al.,2020).

4. Teat Cups in Milking Robots

In milking robots, teat cups (also known as "milking clusters" or "teat cup assemblies") are one of the most critical parts of the milking process. The design of udder headings has a direct impact on animal welfare, milk yield, udder health, and milking efficiency.

The characteristics a nipple should have can be outlined as follows:

- Breast shields should operate at an appropriate vacuum level and have an adequate rest-period cycle (pulse rate).
- Inappropriate vacuum or pulsation rates can lead to nipple damage and mastitis (Ruegg, 2003; Rasmussen, 2004).
- The robotic arms must be able to attach the teat cup without harming the animal.
- Very heavy nipple shields can cause retraction of breast tissue (Rasmussen, 2004).
- Breast shields should be easy to clean and sterilize.
- Automatic washing systems must be available after milking.
- There should be one title for each breast, and they should be independent of each other.

The European Food Safety Authority (EFSA) recommends the following basic conditions for the teat cup in automatic milking systems (EFSA, 2009):

- The teat cup should be attached in no more than 15 seconds,
- Milking should start within 90 seconds,
- The vacuum should be immediately cut off when milking is finished.

Characteristics of typical teat cups used in current milking robots are as follows (Rasmussen, 2004; Mein et al., 2001):

- Vacuum level: 38-42 kPa
- Pulsation ratio: 60/40
- Pulsation speed: 60-70 cycle/min
- Weight: 1.5-2.5 kg
- Food compatible materials: silicon/rubber (SiO₂)
- Cup renewal: 2500-3000 milking cycle
- Proper geometry for milk flow

5. Brushes in Milking Robots

The brushes used in milking robots are also critically important for cleaning and stimulating the teats before milking, as well as for cleaning the robot components. The functions of the brushes can be listed as follows:

- **Cleaning:** Removes particles such as dirt, manure, and bedding residue from the teats and surrounding area. This directly affects milk quality (ISO, 2016).
- **Disinfection:** Brushes typically work by spraying an antiseptic solution along with water. Thus, the risk of diseases like mastitis is reduced (ISO, 2016; Rasmussen, 2004).
- **Stimulation:** Mechanical stimulation promotes the release of the hormone oxytocin, which initiates milk secretion and increases milking yield (Neijenhuis et al., 2000; Rasmussen, 2004).

Brush design features can be listed as follows:

- **Material:** Usually made of food-grade, flexible, soft plastic bristles. It is chosen in a way that will not damage the nipple (ISO, 2016; Neijenhuis et al., 2000).
- **Rotation Mechanism:** Double-sided rotating motorized brushes are used. There may be separate brushes for each breast, or both breasts can be cleaned together (Rasmussen, 2004).
- **Positioning:** Breasts are detected using laser/camera systems, and the brushes are automatically aligned (ISO, 2016; Rasmussen, 2004).
- **Working Time and Programming:** The cleaning time usually varies between 6–12 seconds. Milking robots can adjust this time based on the cow's history or udder cleanliness (e.g., longer for first-time milked cows) (Rasmussen, 2004; Neijenhuis et al., 2000).
- **Hygiene Management:** The brushes are self-washing and are cleaned after each cow. In some systems, disinfection with UV light is also performed (ISO, 2016; Neijenhuis et al., 2000).

6. Pumps and Milk Transfer Lines in Milking Robots

In milking robots, pumps and milk transport lines are critical systems for hygienically and quickly extracting milk from the udder without harming to animals and delivering it to tanks. They are also used in disinfection processes.

6.1. Vacuum Pumps

The breast pump creates a vacuum to draw milk out of the breast. It also initiates and maintains milk flow. The vacuum level is generally stabilized between 38–42 kPa. Quiet operation is preferred because it can affect animal behavior. It can be oily or dry (oil-free systems are preferred for hygiene). Vacuum regulators and balancing tanks are used against sudden pressure drops (Reinemann et al., 2005; Reinemann et al., 2021; ISO, 2007).

6.2. Breast Pumps (Milk Pump / Peristaltic or Centrifugal)

It transports the milk from the milking parlor to the cooling tank. It operates independently of the vacuum line, transferring milk with low turbulence and without oxygenation. Two types of pumps are used: peristaltic and centrifugal. Peristaltic pumps provide gentle delivery without direct contact with the milk. Centrifugal pumps provide faster milk transfer on large farms but can foam the milk if not carefully adjusted (Rasmussen, 2004; ISO 6690, 2007).

6.3. Drug pumps

After milking, the udder pores remain open for a while longer (15-25 minutes). The risk of bacterial infection is high during this process. To prevent this, the breasts are covered with disinfectants. Peristaltic pumps are generally used. The pressure value should be high enough to atomize the liquid (between 2-4 bar) but low enough not to irritate the skin. In the spraying process, a conical nozzle is preferred, and it lasts for 2-3 seconds. Failure to completely cover the surface leaves the breasts vulnerable to infection. Therefore, alignment and spray angle are important. Bactericidal materials such as iodine, chlorhexidine, and lactic acid are used in its composition. The milking robot arm can be connected or operated by a separate robot arm (Fitzpatrick et al., 2021).

6.4. Milk Transfer Lines

Stainless steel or food-grade clear silicone/plastic tubing is used; contact between the system and the external environment must be cut off. Smooth surfaces are preferred as they prevent bacteria from adhering. Sloped pipes are preferred; milk is conveyed directly without accumulating or foaming. Every part that contacts with milk must be automatically cleaned with a CIP (Cleaning In Place) system. The milk reaching the milk tank maintains its quality thru rapid cooling (below 4°C). Milk properties such as temperature, flow rate, foam formation, color, fat, protein, and conductivity (SSC) are monitored along the milk line with the help of sensors. If the milk quality is deemed unsuitable or is found to be diseased/contaminated, it is diverted to another tank outside the main tank or discarded and destroyed with the help of solenoid valves (ISO, 2007; Reinemann et al., 2005; Rasmussen, 2004; ISO 6690, 2007).

6.5. CIP (Cleaning In Place) Systems

CIP (Cleaning In Place) systems are a cleaning method that allows the cleaning process to be carried out automatically in closed systems used in the food, dairy, beverage, and pharmaceutical industries without disassembling the equipment. In milking robots, all pipes, pumps, sensors, and milking units that contact with milk are regularly cleaned with this system. It significantly reduces labor costs because cleaning is done without human intervention. Ensures food safety (prevents bacterial growth) (ISO, 2016). Basic Stages of the CIP System are as follows;

- Pre-rinse: Large dirt and milk residues inside the system are removed with warm water.
- Alkali Wash (NaOH): Cleans by dissolving grease, protein, and organic matter. It is usually applied hot (60–80°C).
- Intermediate Rinse: Chemical residues are rinsed away with water.
- Acid Washing (HNO₃, H₃PO₄): Removes mineral residues (lime, scale).
- Final Rinse: The system is completely rinsed with clean water. All surfaces that contact with food must be free of chemicals.

7. Other Critical Electronic System Components

7.1. RFID Reader

An RFID reader is a device that includes an antenna and a transceiver. This device communicates with an RFID tag to retrieve the information stored in the tag's memory. It enables wireless information transmission and is used for purposes such as automation, security, and monitoring in many sectors. The RFID system is basically composed of three components. It contains a chip and antenna that store data on the RFID tag. The RFID reader receives and processes signals from the tag. Antennas are used to transmit and receive signals. RFID readers are used to track data such as animal identification (ear tags or subcutaneous tags), health history monitoring, vaccination and treatment records, milk yield or weight tracking, and herd location tracking (especially in large pastures) (Prasad, 2023; Finkenzeller, 2010).

7.2. Encoder

In milking robots, encoders are used to precisely measure the position, speed, and direction information of the robotic arm and moving parts, and to provide feedback to the control system. It is a critical component for the robot to operate in the correct position, accurately locate the teat, and efficiently perform the milking process. There are two types: "incremental" and "absolute." Incremental encoders provide the direction and speed of movement, but do not directly give the absolute position. It is used in lower-cost, basic applications. An absolute encoder produces a unique digital output at every position. Even if the power goes out, location information is preserved. It is preferred in robotic arms and critical applications.

7.3. Motors

In milking robots, motors and motor drivers are fundamental building blocks in the system's automation. All mechanical activities of the robot, such as arm movements, placement of milking clusters, brushing systems, milk pumping, and cleaning operations, are performed by motors. They can be examined under three main groups: servo, stepper, and DC. Servo motors are used in controlling robot arms. It provides precise positioning by using encoder feedback. The advantages are high torque and precision, quiet operation, and fast response time. Stepper motors provide mechanical step-by-step rotation. It moves at specific angles; generally, 200 teeth correspond to a full rotation; resolution can be increased with micro-stepping. They are used in simpler axis of robots or in auxiliary parts because there is no feedback. DC brushed or brushless motors are preferred for brushing and pumping operations. Brushless motors are more durable, quieter, and more efficient because they have no friction; however, they require signal transmission at appropriate time intervals to operate. The signal is typically provided by microcontrollers (Roy et al., 2014; ISO, 2016).

7.4. Motor Drivers

Motor drivers take low-power control signals (e.g., from a microcontroller) and convert them into current and voltage to drive the motor. Its functions include rotating the motor forward and backward, providing speed and torque control, processing position feedback with encoder signals, and providing advanced functions such as braking and ramp control. Speed control is generally done with PWM (Pulse Width Modulation), while direction control is done with H-Bridge structures. Generally, a 6 MOSFET/IGBT model is used for 3-phase motors. In advanced systems, the energy efficiency of motors is increased by using algorithms such as vector space modulation.

7.5. Embedded Computers

Embedded computers are specialized systems based on microcontrollers or microprocessors, designed to perform a specific task. Unlike general-purpose computers, it is located within a specific robot and works integrated with it. It has input and output pins, thru which digital or analog signal measurement and signal generation can be performed. This allows them to exchange data with sensors and other electronic equipment. In milking robots, embedded computers serve as the "brain" of the

system. The robot's environmental perception, decision-making, motor control, data logging, communication, and safety operations are performed using embedded systems. These systems are vital in terms of both software and hardware. Typically, Linux or RTOS operating systems are used. RTOS is preferred in systems that involve sensitive timing and critical tasks. RTOS (Real-Time Operating System), or Real-Time Operating System, is an operating system designed to perform specific operations precisely within predefined time constraints. These types of systems are commonly used in time-sensitive applications such as embedded systems, robotics, automotive, industrial automation, and dairy milking robots (Kopetz and Steiner, 2022; Mall, 2009).

7.6. Communication Protocols

In complex machines like milking robots, communication protocols enable real-time and reliable communication between units such as motors, sensors, actuators, and embedded computers. It standardizes how devices exchange data, the format of data structures, and functionality. These are generally technologies developed by automation companies. The choice of communication protocol is made based on the following factors:

- Real-Time Requirements
- Number of Devices
- Data Volume
- Transmission Distance
- Security and Fault Tolerance
- Hardware Infrastructure and Cost

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CHAPTER 3

ERGONOMIC ASSESSMENT METHODS USED IN AGRICULTURAL ACTIVITIES

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Introduction

Agriculture provides the production of plant or animal products to meet the needs of nutrition, clothing, and shelter. The work done during the production process is called agricultural activity. With the advancement of technology, agricultural activities are changing and developing. In the first agricultural period, simple hand tools were used. After the Industrial Revolution, machines became widespread and production capacity increased. With advancing technology, more information has been gained in production processes. With precision agriculture practices, resources are better managed, leading to improvements in both the quantity and quality of production. A wide variety of tools and machines are used in agricultural activities. They range from simple machine designs used to perform a single task to more complex machine designs capable of performing three or four tasks simultaneously. Although access to machinery is more difficult for farmers in rural areas, mechanization has become widespread worldwide and indispensable for agriculture. However, in agricultural activities with diverse and complex structures where machine use is not possible, work is carried out manually. The risks faced by workers in the agricultural sector are being researched based on the tasks they perform, and efforts are being made to reduce these risks. Musculoskeletal disorders can arise as a result of the risks employees are exposed to. Among the topics studied for musculoskeletal disorders in manual labor, harvesting stands out with 51.9%. Its relationship with the musculoskeletal system is also being investigated for tasks such as load carrying, pruning, and planting. It has been shown that workers in manual jobs are exposed to ergonomic risks due to the repetition of body-straining postures such as bending and squatting, and the use of tools that are not suitable for the individual (Benos et al., 2020a). Vibration is a significant risk factor in agricultural activities, particularly in machines controlled by the driver, and is associated with lower back pain. Discomfort in the upper extremity can occur due to vibrations transmitted through the hand and arm, depending on the handheld machinery used. In addition to vibration, awkward body postures, mechanical impacts, and personal characteristics can pose risks to the musculoskeletal system. (Benos et al., 2020b) A literature review was conducted on the ergonomic risks faced by workers in the agricultural sector. This study aims to identify the ergonomic assessment methods used in research on ergonomics in the agricultural sector and to compile information on these methods.

The Importance of Ergonomics

Ergonomics is a discipline that evaluates the suitability of work for humans and humans for work. The employee's use of tools and machinery in the workplace, the working environment, and work studies play a role in making the workplace safe and comfortable. These parameters have a direct impact on work efficiency and, consequently, workplace profitability. Therefore, the discipline of ergonomics aims for the mutual benefit of both the worker and the employer. Ergonomic assessment studies are conducted by ergonomists to improve the ergonomic aspects of the work environment. Improvements will be determined based on the results of the ergonomic assessment and necessary measures will be taken. The first step in ergonomic assessment is to identify ergonomic risks. The scope of ergonomic risks encompasses all interactions the employee has in the workplace: the stress the employee experiences, the fear of losing their job, break times, body posture during work, the temperature of the work environment, and vibrations experienced while using machinery are among the ergonomic risks. In their literature review study, Aksüt et al. (2020) classified ergonomic risks into 6 main categories and 55 subcategories, including physical, cognitive, organizational, environmental, personal, and psychosocial factors. Employees are exposed to multiple risks in the workplace. In ergonomic studies, all risks can be superficially assessed with the help of checklists, and specific tasks performed by the employee can also be assessed in detail within the scope of risk factors. The assessment results determine the degree of risk and the need for precautions. Factors with a high degree of risk require immediate action. After the relevant measure is implemented, the risk level is reassessed to determine the effectiveness of the measure. It is important that the solution to be developed to eliminate the existing risk factor does not create new risks.

Ergonomics Studies Conducted in Agricultural Activities

Workers in the agricultural sector are exposed to different ergonomic risks. The ergonomic evaluation of agricultural activities is a subject of research, and the results of the studies conducted are shared. A literature review was conducted on ergonomics studies carried out in agricultural activities.

Akalp et al. (2021) conducted a study on the musculoskeletal risks faced by workers during olive harvesting. In a study conducted with 20 volunteers, the workers' body postures were recorded and analyzed using the Rapid Entire Body Assessment (REBA) method. It was concluded that workers in the olive industry are exposed to medium, high, and very high levels of risk. Researchers have highlighted the importance of using personal protective equipment, using appropriate machinery and tools for the job, and regulating working hours to improve the ergonomic conditions of workers.

In their study, Vitale et al. (2024) evaluated the musculoskeletal risks of screen position on tractor drivers within the framework of precision farming practices. In the semi-automatic tractor system, the driver's body posture was analyzed using surface electromyographic devices, and the driver's back surface temperature was measured to assess muscle activation. The high muscle activation at screen positions of 50° and 80° is noteworthy. Researchers have stated that the screen position's negative impact on the driver's body posture could pose a risk in terms of musculoskeletal disorders.

Kee (2022) conducted an ergonomic analysis at an organization involved in peach farming and proposed ergonomic interventions to reduce risk factors. Ergonomists, government, and organizational employees contributed to the conduct of the ergonomic analysis. Engineering and administrative controls have been recommended. To identify ergonomic interventions, a survey was administered to employees in the organization, and their body postures were evaluated using the Rapid Upper Limb Assessment (RULA) method. Tasks involving manual material handling, such as harvesting and pesticide spraying, and those that strain body posture, such as harvesting, pruning, and thinning flowers and fruit, are defined as the riskiest. Researchers expect the study to have positive effects on workers' health.

In their study, Baek et al. (2023) aimed to determine the agricultural ergonomic load and investigate its relationship with musculoskeletal pain. Data on agricultural workload, musculoskeletal pain, and subjective stress index, etc., were collected thru a survey conducted on 1001 farmers. Squatting with 51.2% and repetitive wrist movements with 53.5% are among the most common ergonomic loads. Researchers have stated that increasing agricultural ergonomic loads are associated with musculoskeletal pain and that the ergonomic load may vary depending on gender.

Fathimahayati et al. (2024) conducted a study examining the body posture of oyster mushroom growers from an ergonomic perspective. The Agricultural Whole-Body Assessment (AWBA), RULA, REBA, and Ovako Work Posture Analysis System (OWAS) methods were used to evaluate the 25 body postures of the workers throughout the day. The hit rate results achieved were 75% for AWBA, 62% for RULA, 54% for REBA, and 27% for OWAS. Researchers have emphasized the effectiveness of the AWBA method for assessing the musculoskeletal risks of oyster mushroom growers.

In their study, Hsu and Lin (2021) developed and evaluated a waist-assistive exoskeleton to reduce musculoskeletal risks for agricultural workers. A system has been developed where wearable sensors are used with the RULA, REBA, and AWBA methods for ergonomic assessment. It was concluded that the system they developed to support the bending movement has an output torque of 53.3 Nm. Researchers have stated that the design is intended to increase working comfort.

Das (2023) conducted an ergonomic risk assessment study on musculoskeletal disorders experienced

by different groups of Indian farmers. Employees were evaluated using the REBA, ART Tool, and Nordic surveys. It was concluded that the lower back and knee areas are the most affected parts of the body. It was concluded that 80.3% of musculoskeletal system disorders were most common among farmers involved in rice cultivation. Researchers have emphasized avoiding repetitive tasks and body-straining postures to reduce musculoskeletal risks.

Although agricultural activities vary, manual labor or machine-operated tasks show similarities. Employees are exposed to the same risk factors such as vibration, awkward postures, and repetitive movements. It is noteworthy that the studies primarily investigate musculoskeletal risk factors. In the material and methods sections of the studies conducted, methods were used to determine the exposure levels of musculoskeletal risk factors. It is observed that the REBA, RULA, and OWAS methods, frequently used by ergonomists in different workplaces, are also used by various researchers in the agricultural sector. The AWBA method is a method developed to address postural disorders in agricultural workers (Kong et al., 2015). In research, AWBA is compared with other methods. It is noteworthy that the prevalence of this method, developed for use in the agricultural sector, is low compared to other methods. The AWBA method, which is an easy-to-implement and effective method, is explained in the next section.

Ergonomic Assessment Methods

The AWBA method was developed for assessing postural disorders in agricultural activities. For method validation, work stances from pepper and bean farming were selected by experts. 80 body postures were evaluated for 4 risk levels. It was concluded that the AWBA method is suitable for agricultural activities. Analyses performed for the lower and upper extremities are used in the assessment of whole-body posture (Kong et al., 2015).

The Agricultural Lower Limb Assessment (ALLA) ergonomic assessment tool was developed to evaluate lower extremity postural disorders observed in tasks performed in agriculture (Yong-Ku et al., 2010). Similarly, the Agricultural Upper Limb Assessment (AULA) was developed to assess the risk of upper extremity disorders in farming tasks (Yong-Ku et al., 2011). It was concluded that the ALLA and AULA methods are suitable for assessing body postures for the lower and upper extremities (Kong et al., 2014). In Figure 1, the lower extremity posture is evaluated to determine the risk level. In Figure 2, the upper extremity posture is evaluated to determine the risk level (Kong et al., 2015).

Posture	Standing				Sitting			
	STD	KF 150	KF 120	KF90	SC 40	SC 20	SC 0	SF_CRS
Risk level	2	3	4	4	1	1	2	1

Posture	Squatting			Kneeling	
	KF60	KF30	KF30C	KNL_1	KNL_2
Risk level	4	3	3	3	3

Figure 1 Agricultural Lower-Limb Assessment (ALLA) (Kong et al., 2015)

Posture	B0-S0-E45	B0-S0-E90	B0-S45-E0	B0-S45-E45	B0-S45-E90	B0-S90-E45	B0-S90-E90	B0-S125-E0
Risk level	1	1	2	2	2	3	3	4

Posture	B45-S45-E0	B45-S45-E45	B45-S90-E0	B45-S90-E45	B90-S90-E0	B90-S90-E45
Risk level	2	3	3	3	2	2

Figure 2 Agricultural Upper Limb Assessment (AULA) (Kong et al., 2015)

In the REBA method, upper and lower extremity postures are evaluated separately to determine the REBA score and are used together to assess the whole-body posture (Hignett & McAtamney, 2000). Similarly, to obtain the AWBA score, the ALLA and AULA scores are determined. Figure 3 shows the AWBA score corresponding to the ALLA and AULA scores (Kong et al., 2015).

Agricultural Whole Body Assessment (AWBA)					
		AULA			
		4	3	2	1
ALLA	4	4	4	4	3
	3	4	3	3	3
	2	4	3	2	2
	1	3	3	2	1

Figure 3 Agricultural Whole-Body Assessment (AWBA) (Kong et al., 2015)

Yong-Ku et al. (2020) conducted a study to revise the AWBA method by evaluating disk compression for various workloads. In the AWBA method, the impact of workload and weights is not evaluated. AWBA risk levels are subdivided based on the employee using one or both hands during work and the weight contributing to the lumbar disk compression force. In the revised AWBA method, risk levels 1 and 2 are divided into three, and risk levels 3 and 4 are divided into four. Researchers emphasized that the AWBA method was revised based solely on lumbar compression force for its classification into subclasses, and stated that biomechanical data would be included in future studies for evaluation.

Figure 4 illustrates the work done for 4 kg using two hands. The evaluation of example body posture using the revised AWBA method is shown in Figure 5 (Yong-Ku et al., 2020).



Figure 4 Strenuous two-handed posture in agriculture (Yong-Ku et al., 2020)

4kg Two hand		Upper-limb posture														
		1			2				3				4			
		BO-50-E45	BO-50-E90	BO-545-E0	BO-545-E90	BO-545-E45	B45-545-E0	BO-590-E90	BO-590-E45	B45-545-E45	B45-590-E0	B45-590-E45	BO-5125-E0	B90-590-E0	B90-590-E45	
Lower-limb posture	1	STD	1-1	1-1	2-1	2-1	2-1	2-2	3-1	3-1	3-2	3-3	3-3	3-1	3-3	3-3
		SC40	1-1	1-2	2-1	2-1	2-1	2-3	3-1	3-2	3-3	3-3	3-4	3-1	3-3	3-3
		SC20	1-2	1-2	2-1	2-1	2-1	2-3	3-1	3-2	3-3	3-3	3-4	3-2		
		SF_CRS	1-2	1-2	2-1	2-1	2-2	2-3	3-1	3-2	3-3	3-4	3-4	3-2		
	2	SC0	2-1	2-1	2-1	2-1	2-1		3-1	3-2	3-3	3-3	3-4	4-2		
		KF150	3-1	3-1	3-1	3-1	3-1	3-2	3-1	3-1	3-2	3-3	3-3	4-1	4-3	4-3
		KNL_2	3-1	3-1	3-1	3-1	3-1	3-3	3-1	3-1	3-3	3-3	3-3	4-1	4-3	4-3
		KNL_1	3-1	3-1	3-1	3-1	3-1	3-3	3-1	3-1	3-3	3-3	3-3	4-1	4-3	4-3
	3	KF30	3-1	3-1	3-1	3-1	3-1	3-3	3-1	3-1	3-3	3-3	3-3	4-1		
		KF30C	3-1	3-1	3-1	3-1	3-1	3-3	3-1	3-1	3-3	3-3	3-3	4-1		
		KF120	3-1	3-1	4-1	4-1	4-1	4-3	4-1	4-1	4-3	4-3	4-3	4-1	4-3	4-3
		KF90	3-1	3-1	4-1	4-1	4-1	4-3	4-1	4-1	4-3	4-3	4-3	4-1	4-3	4-3
4	KF60	3-1	3-1	4-1	4-1	4-1	4-3	4-1	4-1	4-3	4-4	4-4	4-1			

Figure 5 Revised AWBA method (Yong-Ku et al., 2020)



Figure 6 Agricultural works with hand tools (Yong-Ku et al., 2020)



Figure 7 Various agricultural works (Yong-Ku et al., 2020)

Agricultural activities such as material handling, harvesting, tillage, planting, spraying, irrigation, and so on are carried out by workers throughout the season. Working conditions for workers may vary. Agricultural activities can be carried out outdoors in fields, in enclosed greenhouses, or on farms. Figures 6 and 7 illustrate the different tasks performed (Yong-Ku et al., 2020). To protect employee health and increase work efficiency, all tasks should be evaluated from an ergonomic perspective.

During a task, employees' heart rate and breathing rate may increase depending on the difficulty of the task and the working conditions. Fatigue during a task may indicate that employees need to take a break. The body's reactions during the task should be considered. Unpleasant posture or exposure to force can cause pain during work, and workers may also feel pain afterward. The severity of the pain experienced varies depending on the task and the worker's personal characteristics. Work-related illnesses can reduce work efficiency and have temporary or permanent negative effects on the employee's health. The key is to identify ergonomic risk factors and take immediate action to eliminate them. These measures will not only ensure the safety of employees working within the scope of occupational health and safety but also improve their working comfort.



Figure 8 Working posture of oyster mushroom farmers (Fathimahhayati et al., 2024)



Figure 9 Working posture in peach farming (Kee, 2022)



Figure 10 Agricultural activities of rice farming (Das, 2023)

In Figure 8, 9 and 10 are examples of agricultural tasks in different types of crops. Worker shown in Figure 8 is in an oyster mushroom farm, worker in Figure 9 is in a peach farming and worker in Figure 10 in rice farming. It is observed that all workers work in uncomfortable postures (Das, 2023; Fathimahhayati et al., 2024; Kee, 2022).

Conclusion

In the agricultural sector, plant and animal production is carried out to meet people's basic needs. Agricultural activities encompass the entire production process. Workers in agricultural activities can have very different tasks. Tasks are performed using machines and tools. Agricultural workers are

exposed to different ergonomic risk factors. There are studies on musculoskeletal disorders resulting from particularly challenging body postures. Agricultural tasks are defined and their limits are determined to reduce musculoskeletal risks. In carrying out the task, administrative and engineering solutions are implemented, and measures are taken to protect the worker's health using personal protective equipment. Various ergonomic methods are used to analyze musculoskeletal system risks and determine risk levels. Methods developed for use in workplaces such as offices or factories are also used in the agricultural sector for similar risk factors. However, these methods may be insufficient for evaluating the worker's body posture in agricultural activities. The AWBA method, developed for the ergonomic evaluation of agricultural activities, is introduced in this study. In the study, research papers using the AWBA method were included by compiling the literature. The revised AWBA method was mentioned and compared to its form before revision. In conclusion, the AWBA method is suitable for agricultural activities, and research studies are ongoing to further develop the method. The AWBA method is an effective and easy-to-implement method. It is expected that the method will become widespread through its use by researchers working on ergonomics in agricultural activities.

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CHAPTER 4

APPROACHES FOR EVALUATING BODY POSTURE RISKS DURING AGRICULTURAL WORK

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Introduction

Agricultural activities have been carried out by humans since the beginning of history. With the advancement of technology, machines were introduced in agricultural production, followed by electronic systems, which led to the use of not only physical strength but also cognitive abilities. Today, although humans continue to work as operators who use machinery or control systems in agricultural activities, they still work as manual laborers in many agricultural tasks. The distribution of registered employees by sector for 2024, as reported by TÜİK, is shown in Table 1.

Table 1. Employed Persons by Economic Activity, March 2025*

Economic Activities	Number of Employes (thousands)	Percentage of Employes
Agriculture	4847	14.9
Industry	6746	20.6
Construction	2162	6.6
Service Sector	18886	57.9
Total	32641	100.0

*TÜİK, Labor Statistics, March 2025 (15+ year)

According to TÜİK (2025) data, there are approximately 4,847,000 employees working in agricultural activities. This number constitutes 14.9% of registered employment. More than half of these workers, who are engaged in agricultural activities in our country, work with physical labor. It is necessary to improve the working conditions of workers performing agricultural activities, reduce the energy and time spent on the job, and prevent workers from experiencing musculoskeletal disorders in the long run due to their work. Since agricultural activities are dependent on climate conditions, it is impossible to control external factors originating from nature, such as temperature, humidity, wind, and dust. Therefore, evaluating and improving the tools or machines they use, their working positions while using them, or when performing physical labor, will help prevent discomfort for the employees.

There are generally three approaches to assessing the risks arising from body positions during work (NIOSH, 2014). These are:

1. Methods by which the employe evaluates the work they do
2. Observation-based methods
3. Direct measurement method While these methods have both positive and negative aspects, the researcher's decision on which method to choose is important.

Methods For Evaluating The Employee's Work

This method is based on the employe scoring the work they have done at the end of the job. There are two commonly used assessments for this method. The first of these is the Overall Discomfort Rating, which determines the evaluation of the entire task. The overall level of discomfort is indicated by marking the level of discomfort reported for the entire body at the end of the work on a 0-10 or 0-8 point scale (Corlett and Bishop, 1976). In this method, if desired, a scale like the one shown in Figure 1 can be prepared, and at the end of the work, the employe can be asked to mark the work they did that day according to its difficulty. Instead, if paper surveys are distributed to employees, an equal ten or eight-section straight line can be drawn. They might be asked to mark this correct part. Here, "0" represents comfortable and painless work, while "8" indicates that the pain felt is so severe that work cannot continue. It is stated that the midpoint represents a reasonable degree of difficulty depending on the work done.



Figure 1. Discomfort scale

The discomfort scale method shown in Figure 1 was developed by Corlett and Bishop (1976). With the help of this scale, workers mark a point on the scale to indicate the level of discomfort they felt at the end of the activity. This point they marked becomes the discomfort score for the entire study. In the other method, different researchers used schemes that divided the body into varying numbers of sections to calculate Body Part Discomfort Score values. The body schema used by Sam and Kathirvel (2008), which consists of 12 regions. With the help of the diagram, operators were asked to score on the diagram at the end of each shift, starting with the area where they felt the most discomfort. Later, by summing these scores, the discomfort score for body regions for that work period can be obtained. If necessary, specific areas of discomfort can be added to this diagram, the number of areas can be increased, and it can be prepared in a front-to-back format depending on the nature of the work being done.

Tewari et al. (2004) examined the discomfort levels of operators during two different tasks by installing a seat on a drilling machine. They found that the discomfort felt during the task with the added seat decreased by 27% based on the values obtained from the discomfort scale. In their study, Sam and Kathirvel (2008) measured the discomfort levels felt by workers during soil tillage at different speeds using two different power anchor machines. They emphasized that the discomfort score values for the entire task and for body parts increased with the increase in the machine's feed rate.

Meyer and Radwin (2007) examined the physiological responses between working in two different positions at the workstations they prepared for the simulation of manual harvesting. In the trials, 15 male students were tested in two 15-minute work periods; heart rate, EMG values, and body discomfort values were measured. When the data was evaluated, it was noted that heart rate values measured in the forward-leaning harvesting position were lower than those measured in the prone harvesting position.

Observation-Based Methods

In the observation-based method, the researcher observes how employees perform their work, their body positions during work, and classifies the work performed using different evaluation methods based on scales used to distinguish between risk-free and risky work. Takala et al. (2014) determined in their study that there are about 30 methods by which the work performed by workers can be observationally evaluated based on their body positions. In this section, an attempt will be made to explain the RULA and OWAS methods, which are frequently used and have a practical approach. While using these methods, it is not possible for the researcher to make an assessment during the study. The researcher should take video recordings from different planes according to the method they choose while observing the worker at work. Then, these video recordings should be separated into images. For this purpose, there are various software programs for computers and mobile devices. With these software packages, images (in jpg, png, etc. formats) can be captured from video recording at desired intervals. It is recommended that the researcher take notes while observing the worker, and evaluate the angular classifications and frequencies of body limbs in the images along with these notes.

In addition to this, there are computer programs developed based on these three methods. For example, the ErgoFellow software package includes ergonomic assessment methods such as NOISH, RULA, REBA, OWAS, Strain Index, and Discomfort Questionnaire. In addition to these, there are useful tools in these methods that will provide convenience, such as image and video analysis and load calculations. When reference lines are placed in the image analysis module, the limb angle is displayed in the program's toolbar (Figure 2).

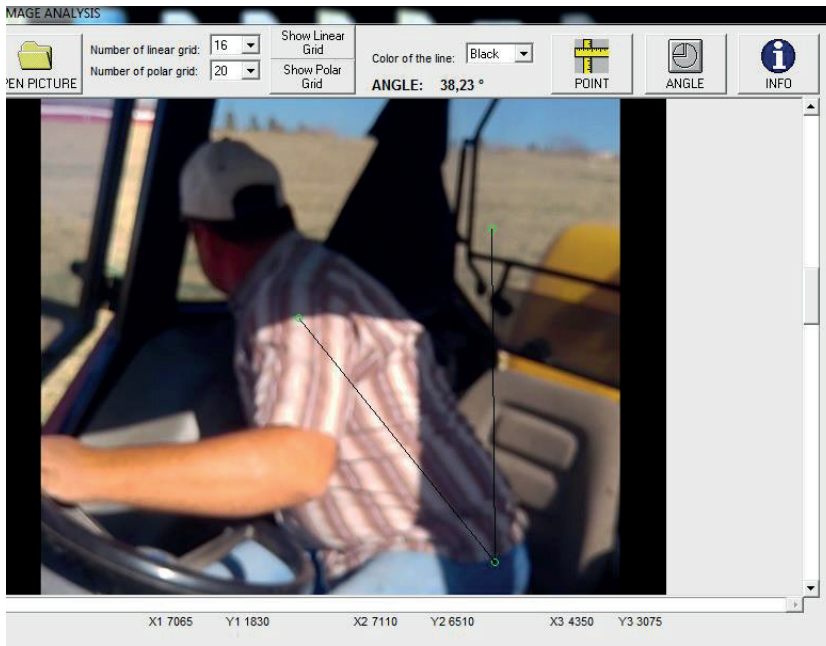


Figure 2. Determination of trunk bending angle using the image analysis module of the ErgoFellow software package (Eminoğlu and Koç, 2018)

Figure 2 examines the change in body positions of an operator using a conventional field sprayer and a smart field sprayer during work (Eminoğlu and Koç, 2018). When analyzing body positions, the video recording's images were evaluated using the image analysis module of the ErgoFellow3.0 software package.

Beside this program, after the video images are converted to picture format, they can be assigned as a background to the Autocad software package, and limb angles can be determined by drawing reference lines between the limbs. Beside this, angular classifications of the limbs can also be made on the screen using the protractors shown in Figure 3.



Figure 3. Protractor (Anonymous, 2020a)

When using the protractor in Figure 3, it would be beneficial to note the angles and frequencies in a table showing body positions.

The static power requirements for tasks such as pushing and pulling can be estimated using the 3DSSPP software package developed by the University of Michigan. The program includes posture data, force parameters, and male/female anthropometry. The output, including the percentage of men and women capable of performing the declared work, spinal compression forces, and data comparisons according to NIOSH guidelines, allows for the analysis of trunk bending and twisting, and the performance of complex hand force inputs. The analysis is supported by the automatic posture generation feature and three-dimensional human graphic drawings (Anonymous, 2020b). In her 2018 study, Widyanti used the RULA and REBA methods, as well as the 3DSSPP software package, to

evaluate the body positions of Indonesian agricultural workers during land clearing, rice planting, manual plowing, fertilization, harvesting, threshing, cleaning rice from straw, and drying rice in the sun. Compared to similar software used in body posture analysis, the 3D SSPP package program is reported to be easier to use and analyze.

Rapid Upper Limb Assessment (RULA) The RULA method is a method developed by Lynn McAtamney and E. Nigel Corlett (1993), two researchers at the University of Nottingham in England, to assess the effects of body positions during work on the musculoskeletal system due to loading. This method is based on observing and scoring the levels of strain experienced by the upper limbs (hand, wrist, elbow, forearm, upper arm, shoulder, neck).

In the RULA method, scoring is first done based on the angular classification of the upper arm (Figure 4).



Figure 4. RULA upper arm angular classification (Anonymous, 2020c)

After scoring in Figure 4, located in the upper left; if the shoulders are raised or deviated from their normal axis, one point is added, and if the upper arm is supported or the worker is reaching, one point is deducted. Subsequently, the angular classification and scoring of the forearm are performed (Figure 5).



Figure 5. Scoring and Angular Classification of the Forearm (Anonymous, 2020c)

After the scoring in Figure 5 is completed, if one of the arms is working in the midline or on the outside of the body, an additional point is added. The wrist score is determined according to Figure 6.

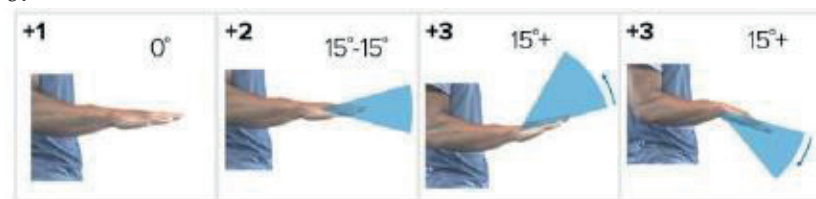


Figure 6. Angular classification and scoring of wrist joints (Anonymous, 2020c)

After the wrist score is determined according to Figure 6, one point is added to the wrist score if the wrist is tilted from the mid-axis. The wrist flexion score is determined as one point if the wrist is bent from its mid-axis, and two points if it is bent to its end point or near it. The Table A score is determined with the help of the upper arm, lower arm, wrist, and wrist flexion scores. If the working position continues statically for more than one minute or is repeated at least four times within one minute, one point is added to the Table A score. To this value, one point is added if the load is irregularly repeated between 2kg and 10kg, two points if there is a static or repeated load between 2kg and 10kg, and three points if the work involves a load greater than 10 kilograms. Thus, a Wrist & Arm score is obtained.

Scoring is done according to the image in Figure 6 to determine neck position.



Figure 6. Angular classification and scoring of the neck (Anonymous, 2020c)

If the neck is bent or twisted at the end of the scoring in Figure 6, one more point is added. To score body position, scoring is done according to the image in Figure 7.

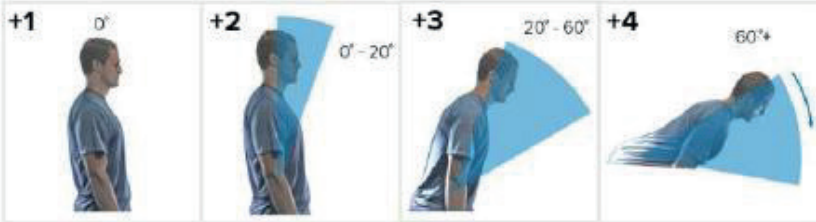


Figure 7. Angular classification and scoring of the body (Anonymous, 2020c)

At the end of the scoring in Figure 7, if the body is tilted or bent during operation, one more point is added. In leg scoring, if the legs and feet are supported, one point is marked in Table B; if they are not supported, two points are marked. Table B score is determined with the help of neck, trunk, and leg scores. If the working position lasts statically for more than one minute or is repeated at least four times within one minute, one point is added to the Table B score. To this value, one point is added if the load is irregularly repeated between 2kg and 10kg, two points if there is a static or repeated load between 2kg and 10kg, and three points if the work involves a load greater than 10 kilograms. Thus, neck, trunk, and leg scores are obtained. The RULA score is determined by selecting the Wrist & Arm score from the rows in Table C in Figure 8 and the Neck, Trunk, and Leg score from the columns.

Table C		Neck, Trunk, Leg Score						
		1	2	3	4	5	6	7+
Wrist / Arm Score	1	1	2	3	3	4	5	5
	2	2	2	3	4	4	5	5
	3	3	3	3	4	4	5	6
	4	3	3	3	4	5	6	6
	5	4	4	4	5	6	7	7
	6	4	4	5	6	6	7	7
	7	5	5	6	6	7	7	7
	8+	5	5	6	7	7	7	7

Figure 8. Determination of RULA score (Anonymous, 2020c)

Based on the obtained RULA score, the evaluations in Table 2 can be made for the work performed.

Table 2. Explanations of RULA scores

RULA score	Activity Level	Explanation
1 - 2	1	It is an acceptable position when the working posture is maintained and work is done over a long period. Further research should be conducted.
3-4	2	A change in work position may be necessary.
5-6	3	A change in work position should be made in a short period of time.
7	4	The working position needs to be changed urgently.

In their 2016 study, Yusuf et al. evaluated the working postures during the opening of mulch pits using two different methods, with the participation of 12 farmers working in strawberry cultivation in Bali. The study results showed that the RULA score for the old method was 7, indicating that the working position needed to be changed urgently; however, with the new method, the RULA score in the study decreased to 3 points.

OWAS

Method Ovako (1974) photographed the body positions of workers in Finland's heavy industry during their work and schematized them with visuals under different working postures. The OWAS (Ovako Working Postures Analyzing System) method allows for the determination of musculoskeletal loads on workers and inappropriate body positions during work (Akay et al. 2003). This method is based on the principle of defining and recording the position of the back, arms, and legs, as well as the load, thru four digital codes observed and recorded. Thus, the risks that each work position can pose to the musculoskeletal system can be determined. The risk groups defined to identify the positions that will be prioritized in correcting risky positions can be listed as follows:

Category 1: Working positions have no harmful effect on the musculoskeletal system, and no ergonomic adjustments are required.

Category 2: Working positions have some harmful effects on the musculoskeletal system, and necessary ergonomic adjustments need to be included in future plans.

Category 3: Working positions have harmful effects on the musculoskeletal system; necessary ergonomic adjustments to working postures should be made as soon as possible.

Category 4: Working positions have quite harmful effects on the musculoskeletal system, and necessary ergonomic adjustments need to be made immediately (Sönmez, 2011).

The coding done according to the OWAS method is shown in Figure 9.















Sirt Duruşu					1) Düz 2) Eğik 3) Çevrilmiş 4) Bükülmüş ve eğilmiş
Kol Duruşu					1) Her iki kol omuz hizasının altında. 2) Bir kol omuz hizasının üstünde. 3) Her iki kol omuz hizasının üstünde.
Bacak Duruşu					1) Oturma 2) Dik olarak iki bacak üzerinde ayakta durma 3) Dik olarak tek bacak üzerinde ayakta durma 4) Dik durumda, her iki bacak bükülmüş dur. 5) Dik durumda, bir bacak bükülmüş durumda 6) Diz çökerek durma 7) Yürüme
Kaldırılan Ağırlık					1) 10 kg'ın altında 2) 10 ile 20 kg arasında 3) 20 kg'dan fazla

Figure 9. OWAS codes (Lundqvist and Gustafsson, 1987)

In their study, Kurt and Erdem (2003) used the OWAS method to evaluate body positions for manual tasks performed while working on a lathe. Body positions during work were evaluated. They have made suggestions regarding the factors that cause inappropriate body positions for employees and how these can be prevented.

Öz and Çakmak (2017) used the RULA, REBA, and OWAS methods to evaluate the body postures of workers in a workshop that manufactures agricultural machinery. For this purpose, 15-minute video recordings were made, the images were watched, and the posture of the back, arms, and legs, as well as the lifted mass, were evaluated sequentially using the WinOWAS software. The assessment conducted using the OWAS method indicated that inappropriate body positions during cutting and sanding were maintained throughout the work and that corrective measures needed to be taken for these positions.

Direct Measurement Method

The most common device used in the direct measurement method is known as an electrogoniometer, which is an electronic measurement and recording system whose design is modified by increasing the number of components for different purposes. The structure of these devices includes electronic components such as strain gages, accelerometers, and potentiometers. The signal received from these units is interpreted by the electrogoniometer as voltage values representing the angle, acceleration, and other parameters of the joint or joints to which the device is connected; information related to these voltage values can be monitored and/or recorded instantly, depending on the system design. This system can be used in research related to biomechanical engineering, rehabilitation, ergonomics, and sports science. It can determine the angular value of the joint it is placed on with high accuracy.

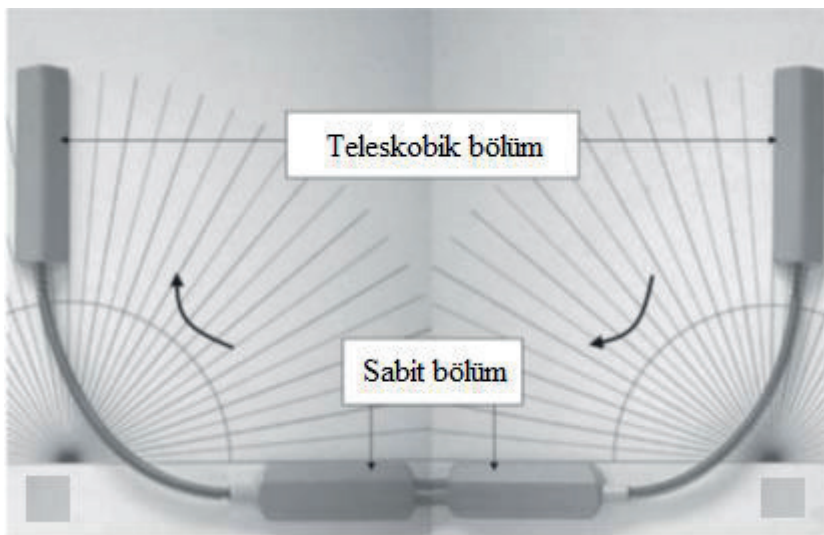


Figure 10. An elastic electrogoniometer (Anonymous, 2020d)

The electrogoniometer shown in Figure 10 consists of units connected elastically. The angular changes between the fixed and moving units are perceived as voltage values and stored in the data logger unit where they are transmitted.

In their study, Ruiz-Olaya et al. (2017) designed a portable electrogoniometer and compared its measurement values for the elbow joint in static, slow-motion, and fast-motion states with those of a commercially available electrogoniometer. As a result of their evaluations, they obtained a correlation above 0.95 in all three conditions. Rahimi et al. (2015) used the system shown in Figure 11 to evaluate tremor related to Parkinson's disease in a study on Parkinson's patients.

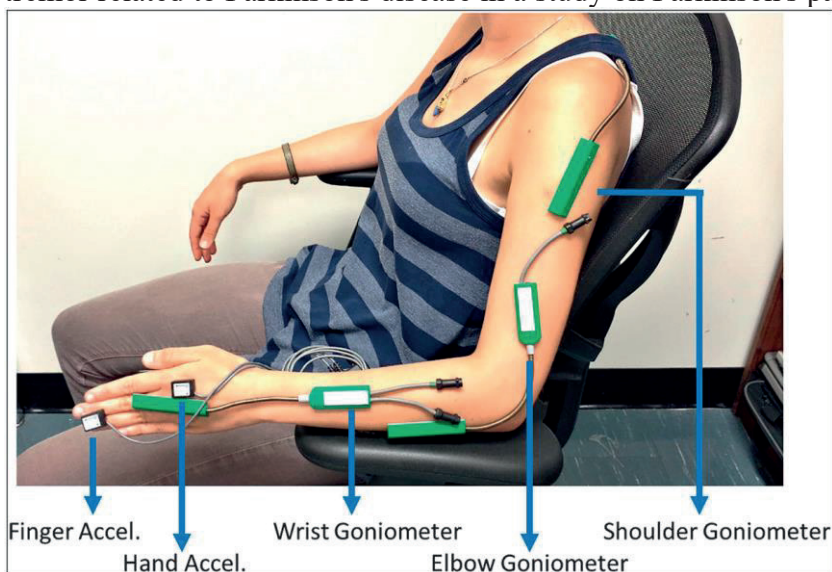


Figure 11. Sensors placed for tremor determination (Rahimi et al., 2015)

As a result of the study, they stated that the electronic system used would be helpful in muscle selection for the treatment of tremor in Parkinson's patients.

Portable designs of electronic angle meters, which entered our language with the term "electrogoniometer," have the potential to be an alternative for agricultural workers, especially in determining the angular values of small joints, for use under clothing, and for making angular assessments from images in crowded working environments. When combined with cloud storage systems, real-time data from the field obtained thru wireless technologies will be accessible from anywhere in the world via the internet.

When these three methods are examined, it has been stated by different researchers up to the present day that they have advantages and disadvantages compared to each other (NOISH, 2014). Here, the researcher should make a decision by evaluating the positive and negative aspects of the methods when deciding to examine body postures. Generally, it is recommended to use at least two methods together. For the method where employees evaluate themselves to be applied correctly, employees need to be clearly informed about the research, not be emotional, and not be influenced by each other. Additionally, it is important that employees who self-evaluate here are competent and experienced in performing the job in question. In methods based on observation, each method has its advantages and disadvantages compared to the others. While RULA only assesses the upper limbs, the REBA method provides a more detailed analysis of leg angles. In the OWAS method, although the scoring classifications are more general, the WinOWAS software can be used to determine how many times the body position is repeated during work and its percentage of the total work. Direct measurement methods, although expensive and difficult to transport and apply in the field, can measure and store limb angles in body positions without observer error. Considering these evaluations, the researcher should decide on the method suitable for their needs; if time and economic constraints are not an issue, the findings should be verified using a second and/or third method.

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