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Review

A Review on Ergonomics in Agriculture. Part I: Manual Operations

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Abstract: Background: Agriculture involves several harmful diseases. Among the non-fatal ones, musculoskeletal disorders (MSDs) are the most prevalent, as they have reached epidemic proportions. The main aim of this investigation is to systematically review the major risk factors regarding MSDs as well as evaluate the existing ergonomic interventions. Methods: The search engines of Google Scholar, PubMed, Scopus, and ScienceDirect were used to identify relevant articles during the last decade. The imposed exclusive criteria assured the accuracy and current progress in this field. Results: It was concluded that MSDs affect both developed and developing countries, thus justifying the existing global concern. Overall, the most commonly studied task was harvesting, followed by load carrying, pruning, planting, and other ordinary manual operations. Repetitive movements in awkward postures, such as stooping and kneeling; individual characteristics; as well as improper tool design were observed to contribute to the pathogenesis of MSDs. Furthermore, low back disorders were reported as the main disorder. Conclusions: The present ergonomic interventions seem to attenuate the MSDs to a great extent. However, international reprioritization of the safety and health measures is required in agriculture along with increase of the awareness of the risk factors related to MSDs.

Keywords: biomechanics; musculoskeletal disorders; risk factors; field operations

1. Introduction

Agriculture is considered to be the primary source of the supply of food worldwide as well as raw materials for industry and medicine. Moreover, taking into consideration the increasing global population and the consequent demand for food, certainly, agriculture constitutes the backbone of global economy. To that end, agriculture production has experienced a relatively high diffusion of advanced technologies including information systems [1], automated machinery systems [2], and even robotic systems that complement or substitute labor tasks [3]. However, as an occupational environment, regardless of these major technological advances, agriculture is regarded as one of the most demanding and hazardous sectors. As a matter of fact, it is ranked second among occupational injuries, fatalities, and illnesses [4]. The host of health problems involve hearing loss, cancers, musculoskeletal disorders (MSDs), and pesticide-caused and respiratory illnesses [5]. Among the non-fatal occupational illnesses appearing in farm workers, MSDs seem to be the most widespread [6,7]. In particular, repetitive lifting and moving of heavy loads, prolonged trunk flexion (also called stooping), intensive hand work, and working in awkward postures of wrist and trunk are tasks associated with the main risk factors regarding the reported MSDs [6,8,9]. Remarkably, low back pain is recognized as the most prevalent musculoskeletal disorder that the agricultural workforce suffers from, in both developed and developing countries [8,10–14]. In fact, repetitive and sustained stooping is the primary risk factor for low back pain [8].

The risk factors associated with the MSDs during different agricultural tasks have been extensively investigated in the literature; for example, in the harvesting of fruit and tree nut crops, climbing ladders meet the burden of bearing heavy loads, repetitive cutting, and excessive reaching. These arduous tasks turn out to cause pain in the whole body, but mostly in the hands, wrists, shoulders, and low back [9]. Concerning the harvesting of fresh market vegetables, such as tomato and lettuce, prolonged and iterative stooping, lifting loads of great weight, as well as intensive and repetitive cutting, contribute to discomfort also in the hands, wrist, and low back [9]. The same risk exposures with the similar pain complaints have been observed in nurseries and greenhouses [6,9]. Finally, in vineyard work, the high risk of back injury is mainly due to the iterative forces imposed to the upper extremities and trunk in combination with awkward stooping, twisting movements, and repetitive lifting of excessive loads [15].

Weeding, namely, the examination of each plant to check the weed growth and decide if a removal of it is necessary by tools (hoe or shovel) or hand, is also a common hazardous operation. Prolonged stooping, stresses on the one hand from the tool, and on the other hand from the plant and repetitive gripping are the principal risk factors [6]. Overall, pains have been reported due to weeding in the neck, arm, shoulder, and trunk [15]. In addition to weeding, pruning constitutes an ordinary agricultural operation. In this task, the worker utilizes different shears for the purpose of cutting some parts of the plant. The dominant hand is exposed to iterative gripping, while the non-dominant one usually holds the cuttings with moderate ulnar deviation and wrist flexion. Again, the landmark risk factors comprise extended stooping; awkward postures of both dominant and non-dominant wrists, as previously mentioned; and stresses from the shears [6]. Wrist, shoulder, and elbow pains have been observed to be associated with pruning [15]. Finally, repetition of lifting, carrying, and moving of heavy loads by using awkward postures is a common risk factor in a plethora of industries, including of course agriculture. Complaints for low back, wrist, and shoulder pains have been widely mentioned by workers [6]. Even during agricultural activities that do not entail heavy lifting, repetitive or sustained actions involving stooping posture can increase the risk of low back pain [16].

Apart from low back pain, knee and hip osteoarthritis (OA) are very prevalent among rural workers [17]. OA takes place when the articular cartilage, which protects the ends of the bones, starts wearing down. Furthermore, OA constitutes the most common type of arthritis and its prevalence increases with age. The constantly increasing age of the agricultural workforce justifies the international concern about the rising incidence of OA in this field. Additional risk factors are obesity, female gender, and low educational level [18]. Repetitive bending of the knee, which is very common in rural activities, contributes to the aggravation and acceleration of knee OA [19].

Given the huge number of agricultural workers globally, ergonomic technologies have been developed, implemented, and evaluated as a means to attenuate the MSDs. These interventions intend to assist the agricultural workforce via optimizing the worker–workplace interface, improving the tools, as well as investigating ways to prevent workers from extravagant forces, repetitive motions, and awkward postures. Throughout systematic ergonomic efforts it has been observed that even small changes translate to large differences in reported pains [20]. A characteristic successful example was the use of tubs of smaller size regarding the harvesting of grapes. Another, also successful, simple ergonomic intervention was the reducing of the space between rungs in orchard ladders [20]. Moreover, Ramahi and Fathallah [21] showed that introducing a long-handled hoe for weeding substantially reduced the flexion of the trunk and, at the same time, this approach proved to be more productive when compared with other weeding techniques. The use of extended-handle carriers was also tested for potted plants, a method that substantially diminished the stoop and squat with the intention of moving or lifting them [22]. Additionally, the incorporation of pneumatically-powered cutters during manual cutting demonstrated that even workers with partial disability, owing to the overuse of shears, could return to their occupational tasks [21]. Finally, the list of small successful interventions includes also frequent breaks that enable temporary relief, for example, during persistent labor in a stooped posture [23].

In a nutshell, ergonomics in agriculture is a versatile and interdisciplinary topic that involves the identification of the risk factors pertaining to MSDs; the determination of the root causes; as well as the development, implementation, and evaluation of ergonomic interventions. The present review study aims at summarizing the recent scientific articles dealing with all the above-mentioned aspects. The 27 selected articles presented in this review were published in peer-reviewed journals during the last decade, namely, between 2010 and 2019, in an effort to guarantee the reliability and up-to-date progress in this field.

The methodology, exclusive criteria, along with the search engines that were used are presented in the “Methods” section. Subsequently, the “Results” section follows, which is divided into three main subsections. In the first subsection, a preliminary data visualization analysis is presented for the identification of the relevant research organizations and trends in this field, whereas the second one briefly describes the selected articles. As agricultural manual operations involve a variety of activities, each of them is investigated in a different subsection for the sake of better analysis of the results. The third subsection deals with the identification of the main risk factors for the development of MSDs based on our literature survey. Finally, the “Discussion” section follows, where concluding remarks are drawn, along with strengths and limitations of the present study, as well as future policy directions.

2. Methods

With the intention of finding recent journal articles associated with “ergonomics in agriculture”, the search engines of Google Scholar, PubMed, Scopus, and ScienceDirect were utilized. To this end, combinations of the keywords “agriculture”, “ergonomics”, “biomechanics”, “risk factors”, and “musculoskeletal disorders” were used. In particular, when a paper was being found, a systematic research was being performed within the website of this specific journal in order to seek for relevant studies. Subsequently, additional articles were being found from the reference list of the resultant journal papers. This process was iterated until no other relevant paper existed. The date for the last search was 15 December 2019.

Based on their title and abstract, the papers were filtered with the aim of selecting the adequate ones that meet the following four basic criteria: (a) the subject is related to agriculture, (b) MSDs caused by manual operations are investigated, (c) the paper was published within the last decade, namely, between 2010 and 2019, and (d) the journal has a relatively high impact factor, namely, larger than 1. In the next stage, the whole article was read as a means to decide whether the paper was acceptable or not. Furthermore, non-English and Conference Proceedings papers as well as master and doctoral theses were excluded from the aforementioned research.

Interestingly, several papers were found concerning the anthropometric characteristics of different nationalities, mainly of developing countries, such as in [24–26]. These articles, as they did not investigate any risk for MSDs or ergonomic interventions, were excluded from this review. Investigations dealing with milking, fishing, and livestock were also excluded. Moreover, review papers were found that either summarized papers that were performed before 2010 or studied safety, geographical, and psycholsociological factors [27–29]. As a consequence, they were also excluded from the present literature survey. Finally, older review papers, such as in [6,8,15,30–33], were found and served as a theoretical basis for the present study. In total, 27 papers were identified as meeting all the aforementioned criteria. A flowchart of the present methodology is depicted in Figure 1.

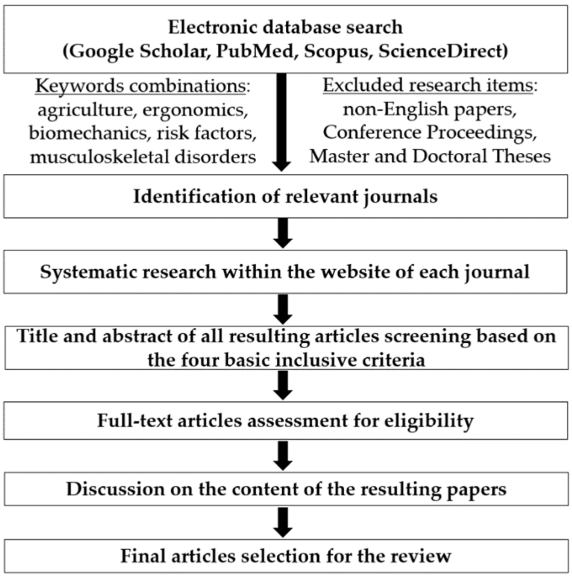

Figure 1. Flowchart of the present review methodology.

3. Results

3.1. Preliminary Data Visualization Analysis

Examining how data are visualized in the relative literature has recently received great attention. Data visualization analysis produces interesting results concerning the identification of (a) the relevant research organizations worldwide, (b) relevant journals, and (c) categories and emerging trends being the most popular of the field [34].

3.1.1. Geographical Distribution of All Contributing Research Organizations

After resulting in the relevant articles for the present survey, a bibliometric analysis was first carried out in an effort to identify the geographical distribution of the research organizations dealing with the present subject. To this end, the country of origin of the organization, which is mentioned in the affiliation of the author, was taken into account as a representative sample. For two or more authors, each country contributed only once. Figure 2 depicts the aforementioned geographical distribution of the contributing research organizations, whereas the official 2-letter codes were used.

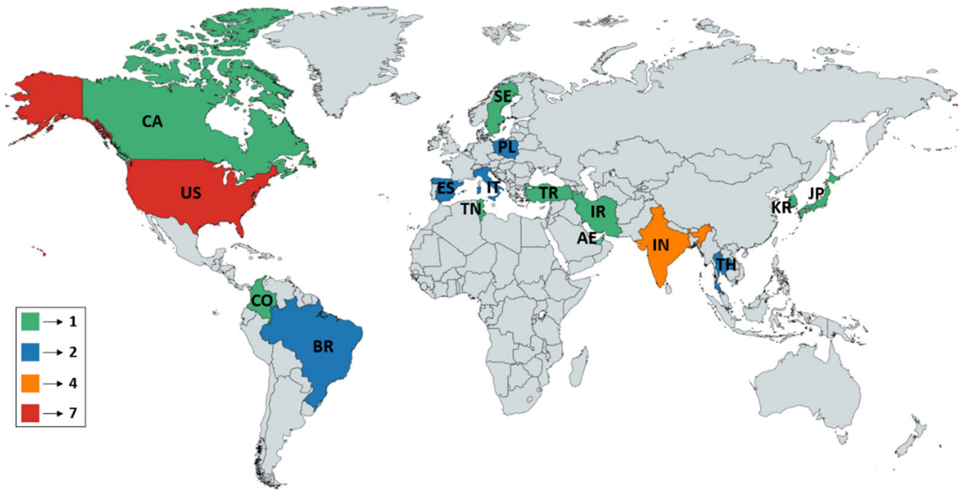

Figure 2. Geographical distribution of all contributing research organizations worldwide.

Remarkably, the issue of MSDs owing to rural activities and the determination of possible risk factors concern both developed and developing countries, as it has also been mentioned in the section of "Introduction". Significant contributions have been made from organizations located in Central Europe (particularly in Poland (PL)), Mediterranean Sea (mainly in Italy (IT), Spain (ES), and incidentally in Turkey (TR) and Tunisia (TN)), and South Asia (predominantly in India (IN) and secondarily in Thailand (TH)). In addition, research centers from USA (US) (especially from California) constituted a large part of the investigated sample. Research on agricultural ergonomics also spreads into South America (Brazil (BR) and Colombia (CO)); Canada (CA); Sweden (SE); and in parts of Asia, apart from India and Thailand, such as Iran (IR), United Arab Emirates (AE), Japan (JP), and South Korea (KR).

In all the above countries, agriculture occupies a considerable amount of workers. Thus, determining the principal risk factors for MSDs and testing interventions for their decrease are of major importance. The present results agree, to a great extent, with the findings of Trask et al. [28], who examined, among other factors, the geographical distribution of the research organizations engaging with low back disorders due to agricultural occupation.

3.1.2. Distribution of All Contributing International Journal Papers

The second analysis demonstrates the relevant international journals, which included the selected articles, required to identify the research areas engaging with ergonomics in agriculture. As can be gleaned from Figure 3, the "International Journal of Industrial Ergonomics" is the main source of the present bibliographic survey with eight papers. Apart from the above journal, which pertains to occupational ergonomics from various industries, "Journal of Agromedicine", which is obviously an agriculture-oriented journal, contributed three articles. Two journals, from which, one focusing on ergonomics and one dealing with other occupational issues, come next with two papers along with one regarding human movement coming from muscle contraction. Finally, ten journals follow with one article found on their website about occupational safety and health, ergonomics, manufacturing, sustainability, and interdisciplinary fields combing agriculture with medicine and safety. As can be easily inferred, the subject of the present literature review is a versatile issue concerning multiple scientific fields, not only the agricultural one. This is reasonable, as agriculture occupies the majority of workers worldwide. As a consequence, determining of the optimal body postures, risk factors, and interventions as a means to lessen the pathogenesis of MSDs is an urgent duty. In Figure 3, the abbreviation of each journal was used for the sake of brevity.

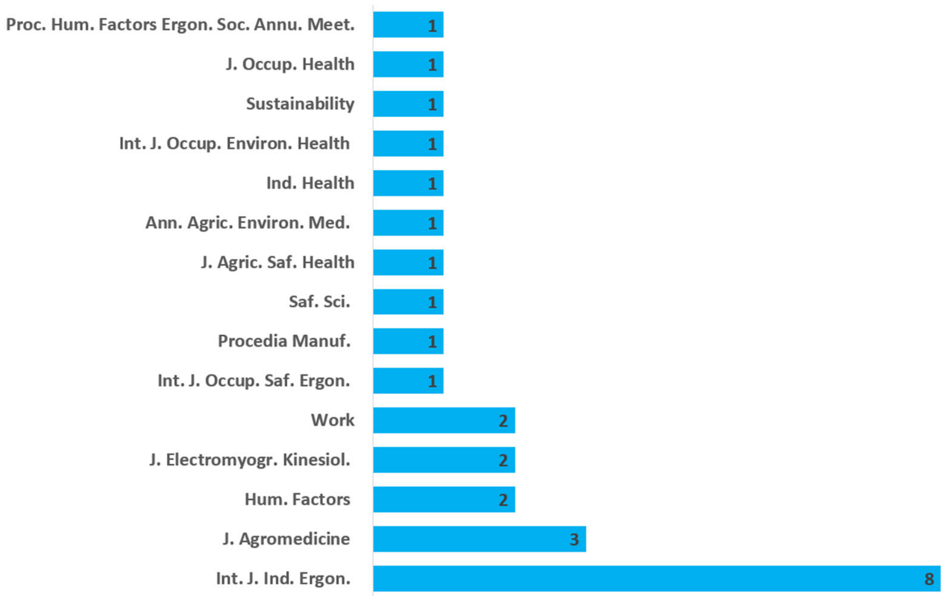

Figure 3. The distribution of all contributing international journals.

3.1.3. Keyword Information Clustering

An additional analysis that was performed in the present study was the keyword information clustering. To this end, approximately 135 keywords were found in the 27 selected papers, which were scanned for the purpose of selecting the 10 most common ones. The result of this analysis, presented in Figure 4, helped us to identify the dominant research topics and get a first taste of the prevalent reported disorder. In Figure 4, the font size of each keyword is proportional to its frequency, whereas the identical color denotes the same incidence.

Figure 4. Keyword information clustering of the relevant papers.

As it was expected, "ergonomics" was the most common keyword. The keyword "low back pain" followed, showing the body part that is most affected from agricultural activities, which is in line with the relative literature [8]. The keywords "musculoskeletal disorders" and "farm" came next, as they are strongly associated with the subject of the present investigation. The keywords "agriculture" (demonstrating the field of interest) along with "risk factors" (indicating that the studies focused on identifying the causes for MSDs) followed with the same frequency. Moreover, "biomechanics", which pertains to kinesiology and the mechanics of movement, came next. The keyword "load transfer device" that follows corresponds to a personal device, which has been introduced in agriculture, as an ergonomic intervention to lessen the load in the region of the lumbar spine [35]. Finally, the keywords "harvesting" and "health" presented with equal incidence. The former constituted the majority of the investigated manual operations of the selected papers, whereas the latter indicated the adverse consequences of rural occupation and the need for implementing ergonomic interventions for the safety of workers.

3.2. Literature Survey

In this fashion, it should be clarified that some manual tasks may also contain other tasks. However, each task was analyzed in a different subsection for the sake of better identifying the origin of the risk factors.

3.2.1. Harvesting

Harvesting is defined as the procedure of gathering crops from the fields and putting them to secure sites for storage, processing, and consumption. In small farms (especially in developing countries), greenhouses, and several horticultural crops, such as vegetables, minimal mechanization takes place [8]. On large farms, however, harvesting is carried out with expensive and sophisticated machinery, such as modern combine harvesters. In this subsection, the studies dealing with MSDs coming from manual harvesting are briefly analyzed. According to our survey, 13 journal papers were found to be associated with this subject.

Cecchini et al. [36] and Merino et al. [37] investigated the potential MSDs originated from tomato and banana harvesting, respectively. The former study revealed that workers showed an alarming risk exposure due to the repetitive activities of the upper limbs, while the replacing of manual with optoelectronic selection was thought to eliminate the risk for MSDs. In [37], pains at the regions of the spine and hips were reported. Furthermore, risks factors associated with lateral and forward trunk flexion, flexion and abduction of the shoulders, cervical protrusion, awkward postures of the wrists, and repetitive movements were found. In addition, Meucci et al. [38] and Udom et al. [39] examined the low back pain among tobacco farmers of Brazil and Thai rubber farmers, respectively. Both studies revealed that exposure to pesticides was associated with the low back discomfort. Indeed, the pesticides can cause impairment to nerves and, thus, intensify the pain [40]. Moreover, in [38], the increasing of age, the exposure to labor-intensive tasks, the awkward postures, and the green tobacco sickness were identified as possible risk factors, whereas in [39], primary school education, Body Mass Index, and kneeling were also found to be risk factors.

Młotek et al. [41] and Houshyar & Kim [42] focused on the MSDs of apple harvesting workers. In [41], the musculoskeletal strains and surface pressures were measured for investigating the favorable work conditions in terms of minimum risks for MSDs along with a high quality of apples. Houshyar & Kim [42] tried to identify solutions by applying break times and ergonomic techniques. In [41], it was concluded that inattentive workers can simply surpass the acceptable pressure limits, whereas in [42], the authors found that rest breaks coupled with ergonomic positions can benefit the workers. Introduce of more ergonomic tools and rest breaks was also suggested by Jain et al. [43]. In [43], the authors identified the main risk factors connected to MSDs during manual harvesting in Indian area. Seventy-seven percent of the participants reported pain at the low back, shoulders, neck, hands, wrists, and fingers with aging principally being related to all body pains apart from the neck and shoulders. Gender was also a significant risk factor with male workers exhibiting discomfort to a greater extent than female workers.

Ulrey & Fathallah through three studies [35,44,45], evaluated a weight transfer device for attenuating low back disorders during stooping in a laboratory environment to imitate harvesting of low-growing crops. Electrogoniometers, microelectromechanical accelerometers, and surface electromyographs were used to measure movements of the knee and ankle; thoracic and lumbar flexion; and the electrical activity produced by tibialis anterior muscles, rectus abdominis, biceps femoris, and erector spinae. Overall, it was concluded that the device can be advantageous for workers who routinely work on stooped posture and lessen the risk of experiencing low back disorders. Furthermore, based on their above encouraging results, they developed subject-specific whole-body musculoskeletal models in [46] to estimate loads on the passive tissues of the leg joints and back. It was deduced that the weight transfer device decreases the loads on the spine passive tissues during stooping, without bearing the joints of the hip and ankle. Furthermore, shear force and compression at the L5-S1 level were declined, whereas, remarkably, in some cases the levels of compression and shear forces exceeded the safety limits.

Ergonomic interventions were also evaluated in [47–49] for lessening the physical load during harvesting. Silverstein et al. [47] utilized an ergonomically designed bag in place of the tied basket around the waist during coffee harvesting. Basket users reported pain in a somewhat larger percentage comparing with the bag users. Pranav & Patel [48] developed an ergonomic tool for manual harvesting of oranges that is suitable for hilly regions and compared its performance in relation with two existing tools. The findings demonstrated considerable reduce of damage quantity and body discomfort that was combined with augmented work output. Finally, Pinzke & Lavesson [49] tested a conveyor belt in place of carrying a box, which was proved to lessen the harmful stooping. Interestingly, for the case of strawberries growing in pots, the position was characterized by a straight neck and back along with lowered arms, whereas when growing on raised beds, kneeling or bending forward with straight legs was noted, which can result in harmful lumbar compression.

3.2.2. Load Carrying

Manually load carrying constitutes one of the most common activities in all farms and needs substantial amount of energy, in spite of the mechanization that has been introduced. In fact, loads can be carried for a long distance on a daily basis. Often enough, children and women have to execute this arduous task. Different techniques of load carrying involving the back, head, or shoulders have been seen to be associated with spinal and other MSDs. Energy demands for this activity depend on several factors such as the gender, age, posture, burden, walking speed, and individual characteristics [50,51]. Manually load carrying is an essential duty that should be carried out in a lot of industries with plenty of studies related to this task such as [52–54]. In agriculture, only three studies were found during the last decade.

Fathallah et al. [55] investigated the effectiveness of two ergonomic interventions, namely, "ergo bucket carrier" and "easy lift", with the object of handling water with buckets, which is a very common task in farms. The dimensions of the equipment relied on the anthropometric data and environmental factors [56]. The two interventions reduced the risk for developing low back disorders to a great extent. A notable experimental study was also conducted by Raczkiewicz et al. [57], who evaluated the possible spinal pain risk factors of postmenopausal women performing load carrying. It was concluded that postmenopausal women are more likely to suffer from musculoskeletal pains, especially spinal pain, principally in the region of lumbar and more rarely in cervical spine and least in thoracic spine. In particular, the spinal pain appeared to be related to the early onset of the menopause and increased with age. In a different manner, Jena et al. [58] developed a biomechanical model to estimate the consumption of the metabolic energy for manual currying under various conditions. Experimental tests were also performed regarding three modes (head, shoulder, and back), three slopes (0, 5, and 10 degrees), and three loads (10, 15, and 20 kg load) in the laboratory. It was concluded that the energy consumption for a 20 kg load with back and head at 10% inclination demonstrated medium effort, whereas carrying on shoulders requires high effort. The excess energy consumed because of either frontal or sagittal torque has a polynomial trend, while the torque is generated owing to asymmetric load position.

3.2.3. Pruning

Pruning with pruners or knives involves repetitive and powerful movements. These demands constitute principal risk factors, as hand-intensive work seems to be associated with the occurrence of biomechanical stresses on the upper extremities [9,59,60]. Most of the time, pruning is carried out at awkward postures, thus contributing to musculoskeletal injuries [61]. For example, the opening span of the common pruners may not match with hand anthropometry of the workers. Thus, they have to apply additional force to prevent the handles from wide opening [24]. The studies that were found to fulfill the requirements of the present investigation pertain to the flower industry and winter pruning in vineyards with the aim of sustaining their quality.

Berrio & Barrero [62] examined the impact of the time passed from the last maintenance of the pruner on the muscular activity and kinematics of the upper extremities for the period of flower-cutting operations. The kinematics of the workers including posture; angular velocity; and acceleration of the forearm, elbow, wrist, and the muscular activity of the upper limbs were evaluated. As expected, the regular pruner maintenance was proved to lessen the biomechanical demands. Additionally, Çakmak & Ergül [63] evaluated the influence of various types of pruning shears, ambient temperatures, working hours, personal characteristics, and experience of the workers on grip strength. The grip strength values were proved to be affected by the type of the shear and have a negative correlation with the ambient temperature.

3.2.4. Planting

Planting, namely, the activity of putting plants in the ground, poses several risks for musculoskeletal pains, principally owing to the repetitive stooping and forceful exertions. An additional adversity in planting is the muddy work terrain [64]. It is not surprising that a high frequency of MSDs has been reported regarding the lower extremities and trunk of rice farmers in Southeast Asian countries [65,66]. Similar observations have been highlighted in sports sciences, as for example, among American footballers that play on muddy ground [67]. Given that rice planting is commonly carried out with bare feet, the extent of loads on the feet are intensified.

The study of Juntaracena et al. [65] was found to deal with the present analysis. More specifically, this investigation focused on the impact of muddy ground on the lower extremities of 30 healthy agricultural workers throughout simulated rice planting. Pain of lower extremities and muscle activity on rigid terrain were compared with the case of muddy surface. The findings showed considerably enhanced muscle activity and pain of ankle and knee in muddy terrain. The reported high risk for rice farmers of musculoskeletal injury should therefore be reduced by ergonomic protective equipment.

3.2.5. Digging

Digging is necessary in common agricultural operations, such as the plastic mulching process. Digging demands arduous repetitive forward flexion, whereas it is regarded as a major risk factor for pain on the low back. On-body worn personal assist suits have been tested for the purpose of reducing the muscular activity of the low back during digging.

Dewi & Komatsuzaki [68] recruited six female and eight male workers to carry out three-minute digging tasks. Electrocardiograph and electromyography of the lumbar erector spinae and the left and right upper trapezius were conducted simultaneously with motion data record via a telemetry system. During the final minute, the amount of the required load was declined by using the ergonomic suit in males, even though the average workload was the same. In addition, males attained more stable acceleration patterns with wearing the personal assist suit, whereas 86% of the female participants reported pain in the crotch area. The authors suggested that hip straps should be improved for the sake of increasing the user acceptance. Overall, for a common task in agriculture, such as digging, the proposed suit can reduce strain on muscles of low back to a great extent as gleaned from the standardized Nordic questionnaire.

3.2.6. Peeling

In pineapple processing, the task of peeling is considered to be the most demanding one because of its time-consuming and repetitive nature. Using awkward postures, not ergonomically designed tools, prolonged work, and a small number of rest breaks are some of the risk factors that are frequently related to pineapple peeling. Moreover, as pineapple is an acidic fruit, gloves should be worn during peeling. Nevertheless, if gloves are worn, the task becomes more demanding because the juicy pineapple itself is too slippery and, thus, the risk of musculoskeletal discomfort increases by influencing the effectiveness and productivity of workers. Due to the particularity of this subject, plausibly only one paper was found.

In particular, Kumar et al. [69] studied work-related MSDs originated from labor involved with the activity of pineapple peeling in small units in North East India. A questionnaire-based interview was implemented in conjunction with a pain-related questionnaire and direct observation. The rapid upper limb assessment was utilized so as to evaluate the involved ergonomic risks. Pain discomfort in various body parts was observed with the higher frequency reported in low back (45.7%), shoulders (41.1%), upper (37.1%) and lower arms (15.9%), neck (13.2%), wrists (12.6%), and palm (6%). By using logistic regression analysis, some risk factors were identified such as gender, age, working hours, rest breaks, and experience.

3.2.7. Sorting

Vegetable sorting, which take place from slow moving conveyors, is essential for ensuring specific sizes of vegetables that have the least possible imperfections. The width and speed of the conveyor seem to play a key role on the exposure of the workers to a host of biomechanical risks, because of the repetitive movements pertaining to the upper limbs. In spite of the introduction of electronic sorters, manual work is still necessary [70].

Boubaker et al. [70] was the only study dealing with the investigation of vegetable sorting. In particular, an analytical model was developed for evaluating the musculoskeletal fatigue that is originated from the sorting duty. Evaluation criteria of posture, fatigue and discomfort were studied by Borg scale as well as a polynomial expansion method. Their findings demonstrated that, for the given operation, fatigue state appears earlier than the minimum limit, i.e., that of 240 min.

3.2.8. Weeding

Manual weed removal refers to the inspection of the plants to check the growth of the weeds and determine if their removal is needed. It usually demands seasonal agricultural migrant workers to stoop and grip weeds throughout prolonged periods of walking on rough grounds [71]. Prolonged stoop work, stresses from the tools, and repetitive movements are recognized as primary risk factors for the pathogenesis of MSDs [6]. Discomfort of the workers has been stated at the regions of the low back, neck, and shoulders [15]. Warming-up has been extensively studied in sports research for the purpose of preparing soft tissues for the subsequent performance [72,73]. Potential use of this finding in weeding is presented below.

In particular, Hudson et al. [74] investigated the use of prolonged walking as a precursor task to alter the biomechanics of manual weeding in a laboratory setting. Two different conditions were examined, namely, a group of 23 participants who walked 1600 m before the required manual simulated task and a group of 11 participants without warming-up. Special markers and motion capture sensors were utilized to estimate toe–target proximity together with knee, ankle, and hip angles as well as toe–target proximity during weeding. The participants with the precursor walking showed a larger distance to the weed comparing to the second group, resulting in reduced trunk flexion during the simulated task. It was inferred that warming-up can positively affect the postures of the workers, thus preventing the onset of MSDs.

3.2.9. Various Agricultural Tasks

Apart from the studies presented above regarding specific agricultural operations that have been widely identified as being detrimental to human health, there are some investigations dealing with multiple manual tasks as a means to make an overall conclusion. Almeria, which is a region in Southeast Spain, has the majority of the greenhouses in Europe and occupies a considerable number of workers from different nations. In these greenhouses, almost no mechanization takes place, a fact that demonstrates that most of the tasks have to be carried out manually. Inevitably, investigation of concomitant MSDs that are developed in the workforce of Almería-type greenhouses are of utmost importance. Two studies have been published in the relative literature concerning Almeria's greenhouses [75,76], which are presented below along with one investigation examining the prevalence of MSDs in South Korea.

Regarding the greenhouses of Almeria, the studies of Gómez-Galán et al. [75] and López-Aragón et al. [76] were found. The former examined the working postures in melon cultivation for common tasks, such as transplanting, leaf removal, manual spraying, cleaning, and harvesting. The results revealed that workers acquired uncomfortable postures, which tend to be harmful. In brief, the workers did not report any discomfort in their arms, and the most dangerous posture for legs was kneeling. López-Aragón et al. [76] used the standard Nordic questionnaire to evaluate the MSDs. It was concluded that, overall, there was a musculoskeletal disorder symptom incidence of 92%, whereas approximately 55% had to find another job on occasion owing to pains on neck, shoulders, and lower back. The most alarming cases, however, were observed for participants being over 40 years old, women, and eggplant manual workers. It was noteworthy that even participants under 25 year olds reported musculoskeletal discomfort with the percentage reaching 81%. Finally, Kang et al. [77] interviewed 16,113 Korean farmers concerning their agricultural characteristics, demographic profiles, and self-reported musculoskeletal discomfort with the use of specific questionnaires. Participants reported pain on the back (26.9%), lower extremities (19.62%), and on the regions of neck or muscles of the upper limbs (5.89%). In conclusion, the years of working in farms, type of agriculture, and ergonomic considerations increased the health related risks among Korean farmers.

3.3. Identification of the Main Risk Factors for the Development of MSDs

Agricultural manual operations usually include a plethora of physically demanding tasks that, most of the time, entail a combination of material handling, high muscular force, and postural load [78]. The manual activities are carried out under adverse weather conditions, frequently on muddy grounds (usually with bare feet), and awkward postures. Even in developed nations, there are some cultivations, such as vegetable production, that remain highly dependent on manual labor [8]. The journal papers, which were selected according to the limitations presented in the section of "Methods", are summarized in Table 1 in chronological order. Moreover, they are classified according to the investigated manual operation, the type of crop, the followed method, and the main risk factors identified for MSDs. In this fashion, it should be stressed that review papers, such as in [79], contained studies conducted before 2010 and were, therefore, not considered eligible for their inclusion in the present bibliographic review.

Obviously, according to Table 1, out of the 27 accepted journal papers, the most highly examined manual operation during the last decade was the activity of harvesting (51.9%). The second considered tasks were the load carrying (11.1%) as well as the examination of multiple tasks taking place in agriculture (11.1%). Pruning followed (7.4%), with planting, digging, peeling (of pineapples), sorting, and weeding coming next (3.7%), with one study presented for each of them. The content as well as the dangers, in terms of exposure to MSDs, involved in each task was described in the corresponding subsections in 3.2. Concerning the crops that were involved in the accepted papers, there was a variety of crops ranging from apples, oranges, and grapes, to low-growing crops such as vegetables, rice, melons, and strawberries. This observation demonstrates that all types of cultivations can cause MSDs to workers. Remarkably, low-growing crops constituted the majority of the studies presented in Table 1. These low heights of growing crops force the workers to stoop and kneel, in an iterative manner, with the intention of reaching them, thus, contributing in the onset of low back disorders and knee OA. The distribution of the agricultural manual operations according to the 27 selected investigations can be depicted in the pie chart of Figure 5.

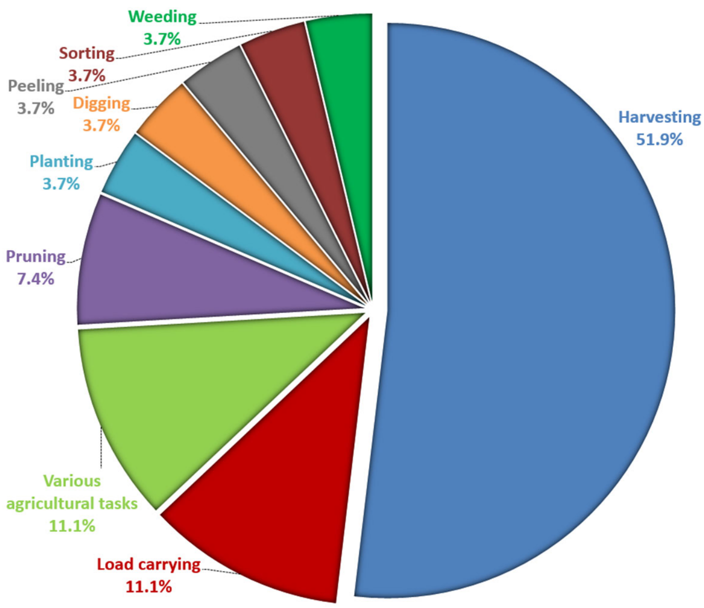

Figure 5. Distribution of the manual operations causing musculoskeletal disorders (MSDs).

Table 1. List of journal papers dealing with MSDs as a result of occupation with agricultural manual operations.

Reference	Operation	Crop	Methods	Risk Factors
Cecchini et al. [36]	Harvesting	Tomato	OCRA	Repetitive movements of the upper limbs
Silverstein et al. [47]	Harvesting	Coffee	EMG, Musculoskeletal Quest, discussions	Stooping, HCL
Ulrey & Fathallah [35,44,45]	Harvesting	Low-growing crops	WTD, EMG, MEMS accelerator	Stooping
Ulrey & Fathallah [46]	Harvesting	Low-growing crops	Musculoskeletal models	Stooping
Boubaker et al. [70]	Sorting	Vegetable	Analytical model	Repetitive movements of the upper limbs
Hudson et al. [74]	Weeding	-	Segment end point optical markers	Stooping
Meucci et al. [38]	Harvesting	Tobacco	Quest	GTS, pesticides, awkward postures
Młotek et al. [41]	Harvesting	Apple	EMG, Tekscan system	Repetitive movements and strains of the upper limbs
Fathallah et al. [55]	Load carrying	-	3D spinal EGM	HCL
Jena et al. [58]	Load carrying	-	Biomechanical model	HCL, ground inclination
Kang et al. [77]	Various tasks	-	Quest	Age, task type, ergonomic factors
Kumar et al. [69]	Peeling	Pineapple	Quest	Gender, age, working hours, experience
Pranav & Patel [48]	Harvesting	Orange	Polar heart rate monitor, Body pain sketch (Quest)	Repetitive movements, stooping
Udom et al. [39]	Harvesting	Rubber	Interview	Education, BMI, kneeling, pesticides
Berrio & Barrero [62]	Pruning	Flower	EGM, EMG, Borg scale	Rare pruner maintenance
Çakmak & Ergül [63]	Pruning	Sultana (grape)	Digital hand dynamometer	Anthropometric dimensions, ambient temperature
Houshyar & Kim [42]	Harvesting	Apple	NM Quest	Stooping, age
Jain et al. [43]	Harvesting	Wheat, rice	NM Quest, RULA	Stooping, age, gender, traditional tools
Juntaracena et al. [65]	Planting	Rice	Rotational rheometer, EMG, camera	Repetitive stooping, muddy terrain
Dewi & Komatsuzaki [68]	Digging	-	MTS, EMG, ECG, NM Quest	Repetitive stooping
Gómez-Galán [75]	Various tasks	Melon	Camera, OWAS	Kneeling, stooping
López-Aragón et al. [76]	Various tasks	Various crops	NM Quest	Age, gender
Pinzke & Lavesson [49]	Harvesting	Vegetable, strawberry	Quest, camera, interview	Kneeling, stooping with straight legs
Merino et al. [37]	Harvesting	Banana	NM Quest, dynamometer, IMU, EMG	Stooping, repetitive movements
Raczkiewicz et al. [57]	Load carrying	-	Quest	Early onset of menopause, age, BMI, repetitive HCL

BMI: Body Mass Index; ECG Electrocardiogram; EGM: Electrogoniometer; EMG: Electromyography; GTS: Green Tobacco Sickness; HCL: Heavy Carrying and Lifting; IMU: Inertial Measurement Unit; MEMS: Microelectromechanical Systems; MTS: Multichannel Telemetry System; NM: Nordic Musculoskeletal; OCRA: OCcupational Repetitive Action method; OWAS: Ovako Working Posture Assessment System; Quest: Questionnaire; RULA: Rapid Upper Limb Assessment; WTD: Weight Transfer Device.

The majority of the selected studies adopted interviews and special questionnaires, with the standardized Nordic questionnaires being the main choice (44.4%) [80]. Standardization is required in recording and analyzing the musculoskeletal symptoms. If not, it is very complicated to compare the findings of different investigations. In fact, questionnaires serve as instruments in order to scan MSDs for the benefit of work-related health care. The standardized Nordic questionnaire was designed so as to determine if MSDs take place among a given population and evaluate which of the nine selected body regions are affected mostly. Individuals have to answer to yes–no questions. More specifically, if the answer is "no", the participant proceeds to another body part. If the answer is "yes", the next questions take place that deal with duration, frequency, and medical intervention [81]. In this fashion, it should be mentioned that the questionnaires by themselves cannot provide clinical diagnosis. However, careful filtering of the reported MSDs by experts can serve for analyzing the environment of the work and optimal tool design. One of the limitations of the questionnaires is that recent MSDs are more likely to be remembered compared with the older ones. Also, the filling out situation at that time as well as the environment can influence the results [80].

Electromyography (EMG) was also utilized in the experimental studies, which were selected for the present analysis with an incidence of 33.3%. In general, EMG is used for quantifying the muscle activity. Understanding how much and when the muscles are active during the required agricultural task is very useful for physicians for the purpose of understanding the mechanism of the injury and provide suitable treatment and rehabilitation protocols. Data from EMG do not always align with real muscle force, particularly as the velocity of muscle contraction increases [82].

Cameras (11.1%) were also utilized for recording the postures acquired by the participants in order to be carefully analyzed by experts. Moreover, electrogoniometers (11.1%) were used, which convert the joint angle into a voltage, therefore making them suitable for measuring dynamic movements. Moreover, models were developed in three selected papers (11.1%) as an effort to simulate the real loads and motions occurring during agricultural operations. Also, other instruments, such as dynamometers, accelerators, and optical markers, were exploited. Finally, methodologies, such as Rapid Upper Limb Assessment (RULA) and OCcupational Repetitive Action (OCRA), were incorporated for evaluating the exposure of farmers to ergonomic risk factors.

The risk factors for the development of MSDs, which are illustrated in Figure 6 in the form of a bar chart, were noted to be highly related to stooping, namely, the prolonged trunk flexion. This posture is inherent in a lot of rural activities that should be performed near the ground level. In particular, the identification of stooping as a risk factor was found in the majority of the selected papers (51.9%). Taking into account the adverse consequences of this body posture on the low back, it can be explained why low back injuries are of epidemic proportion among agricultural workers worldwide [8,9,59]. More specifically, stooping is commonly used for high-energy tasks, as the tissues of the back support the upper torso and, thus, lower the needs in postural energy and provide more energy for the agricultural operation [8]. Nonetheless, stooping together with the intensive heavy work escalates the low back pain to a great extent.

From a biomechanical perspective, support of the lumbar spine during stooping is principally given by the passive viscoelastic connective tissues that gradually transfer loads from active muscles [83]. Sagittal bending of the trunk to maximal flexion includes the flexion–relaxation of the spine. Through this process, the active contraction concerning the muscles of lumbar extensor attains the physiological limit, whereas the flexion of the spine is entirely resisted via passive tissues [84]. Repetitive flexion of the spinal segments decreases the passive spinal tissue stiffness and enhances the intervertebral motion. This leads to the reduction of the intradiscal fluid amount. Considerable intradiscal fluid loss lessens the nucleus load-bearing capacity. This fact results in the loading transfer towards the sensitive fibers of annulus, thus causing higher stresses [8]. As a consequence, given that support during fully trunk bending is given from passive tissues, even small decrease of the stiffness of passive tissues, owing to sustained loading, can substantially diminish the stability of spine and escalate the vulnerability to injury [85]. Shin and Mirka [86] showed that a short break of thirty seconds in the midst of ten minutes of continued flexion can reduce the consequences of the viscoelastic creep. Furthermore, a field investigation during the harvesting of tomatoes by Miller and Fathallah [87] found similar results by introducing a rest break of one minute after every eleven minutes of labor.

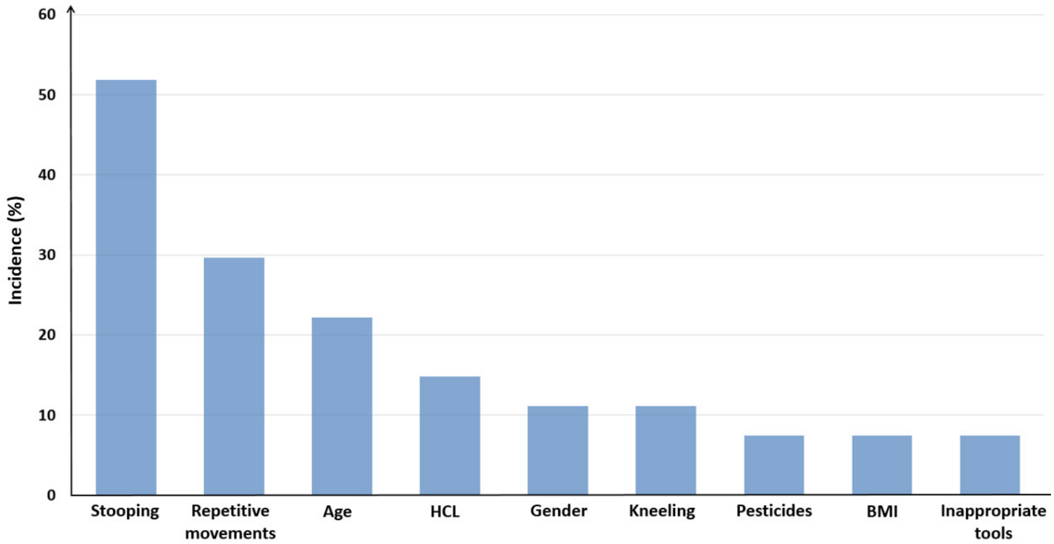

Figure 6. Incidence (%) of the main identified risk factors causing MSDs. The abbreviations HCL and BMI correspond to Heavy Carrying and Lifting and Body Mass Index, respectively.

As it was highlighted above, the repetitive nature of agricultural tasks, which appeared in several of the selected papers (29.6%), enhances the probability for developing MSDs. Fatigue of muscles and joints is the way of the body telling us to alter our working pattern. Performing the same movement over and over again, by also using certain and usually awkward postures, seems to provoke inflammation and pain. Besides, most of the time, agricultural workers have to keep the neck and shoulders in a fixed position for the purpose of exerting some force required for the task. Awkward postures include twisting of the wrist or arm and overexertion. Repetitive motion disorders normally occur in the wrists, hands, elbows, and shoulders. However, they can also take place in the back, neck, and ankles. Repetitive fatigue in hip and knees can lead to painful OA that is very common in rural workers, as it was elaborated in the section of “Introduction”.

The third most reported risk factor, with prevalence of 22.2%, was age. In general, surveys have demonstrated higher frequency of reported MSDs for older farmers than younger ones. Many times, agricultural workers leave their job owing to suffering from MSDs. There is also a number of them who continue to work after retirement, especially in small and family farms. According to Cassou et al. [88], biological changes associated with the aging process, namely, degenerative changes of ligaments, tendons, joints, and muscles, can result in the pathogenesis of MSDs. An overload regarding elderly farmers can be initiated because of the limited physical work capacity comparing to required workload. This may exacerbate the pathogenesis of MSDs [89]. As a consequence, older workers are more likely to have injury complaints when compared with the younger ones.

The fourth most stated risk factor with incidence of 14.8% was the heavy carrying and lifting (abbreviated as HCL in Figure 6). This type of manual operation entails prolonged heavy work which needs a lot of energy and strength. In the case of particularly bulky and heavy loads, even though a worker is able to lift the burden, strains are concentrated on the lifting contact, namely, the hands or fingers. Even in agricultural activities that do not involve heavy lifting, repetitive movements can increase the risk of MSDs [16]. Some commercial products exist with the aim of reducing loads on low back during trunk bending by transferring load towards the legs. These ergonomics products are called weight (or load) transfer devices and have been the subject of the articles authored by Ulrey and Fathallah [35,44–46]. Moreover, two ergonomic interventions, namely, “ergo bucket carrier” and “easy lift”, were successfully tested so as to handle water with buckets, which is very common in farms. Finally, an ergonomically designed bag was successfully tested instead of the currently used tied basket around the waist in coffee harvesting [47].

Gender and kneeling were presented with equal prevalence (11.1%). Regarding the former, gender differences in the development of MSDs have been consistently reported in epidemiological investigations [90]. For instance, women tend to have higher endurance, whereas they are more susceptible to movements that are low-load and repetitive. Besides, for the purpose of compensating their weaker strength, they may use the muscles at levels near their maximum capacity. The selected papers showed that women are more vulnerable to MSDs. As far as kneeling is concerned, which takes place during ordinary operations, such as harvesting, planting, weeding, and lifting, it can also lead to MSDs. Repetitive bending of the knee contributes to the development of knee OA as it was stressed above [19]. Knee OA affects the whole joint, namely, the cartilage, the bones (both femur and tibia), and the synovial fluid (or synovium). In a healthy knee joint, the synovium is more viscous at low shear rates, whereas it becomes highly elastic for larger shear rates. This property allows it to protect the cartilage from wear by providing lubrication. In a diseased knee joint, however, its lubrication properties gradually degrade, mainly because of hyaluronic acid loss. Additional risk factors for developing of OA are female gender and obesity [18]. Taking also into account that farmers tend not to visit a physician, old knee injuries, which have not be treated properly, can flare up again and hurt for the rest of their life. Of course, the same conclusion is drawn for all the MSDs.

Finally, exposure to pesticides, Body Mass Index (BMI), and inappropriate tools follow in the bar chart illustrated in Figure 6 with incidence of 7.4%, which corresponds to 2 papers. Pesticide poisoning constitutes a risk factor for several chronic health complications, as it may damage the nervous system, and thus intensify the pain perception [40]. Exposure to pesticides was highly associated with chronic low back pain in [38] regarding tobacco farmers. In addition, BMI, which is a measure of body adiposity, appears to be associated with the onset of MSDs [91]. In general, individuals with an increased BMI tend to exhibit more musculoskeletal discomfort than those with a lower BMI. Finally, inappropriate tools that are either poorly maintained or not ergonomic require larger amount of energy. This fact, in conjunction with the repetitive nature of the activities, enhances the likelihood for developing MSDs.

In a nutshell, the present results revealed that prolonged stooping has been investigated in most of the studies (51.9%). Repetitive movements are certainly a considerable risk factor (29.6%) and are associated with the discomfort on low back, arms, and shoulders. Repetition is very risky because of the very short cycles, which are iterated during the working time. The age of the worker is also a notable risk factor (22.2%), as identified in several studies, as farmers use to work even though they are overage and usually having experienced a host of musculoskeletal injuries. Heavy lifting and Carrying (14.8%) (HCL) plausibly reported in the selected papers. Gender (11.1%) and Body Mass Index (7.4%) (BMI) are also personal characteristics which affect the development of MSDs. Kneeling (11.1%) was also identified, which is very common during agricultural activities and increases the risk of developing chronic knee pain and OA [92]. Also, rarely maintained and non-ergonomically designed tools (7.4%) as well as pesticide exposure (7.4%) seem to contribute to musculoskeletal injuries. Another risk factor, however, with smaller incidence, was the working hours that demonstrated the need for frequent rest breaks. Finally, warming up, which has widely been examined in sports science to prepare soft tissues for the subsequent performance, can prevent the development of MSDs [74].

4. Discussion

In the present analysis, a systematic review was performed regarding the identification of the key risk factors associated with MSDs coming from manual agricultural operations. Furthermore, the main root causes were determined along with the evaluation of the current ergonomic interventions. As a consequence, the entire range of ergonomics was captured pertaining to agriculture, which is an industry that occupies the majority of workers worldwide and is notorious for subjecting them to arduous working conditions. For this purpose, 27 papers were selected according to stated exclusive criteria that assured the uniqueness of the present bibliographic review as well as the validity and up-to-date record in this field. The systematic survey led to the classification of the papers into subcategories, which represent the ordinary manual tasks.

The manual agricultural tasks are usually carried out under adverse weather and ground conditions. The most highly investigated rural activity during the last decade was harvesting, followed by load carrying, pruning, planting, digging, peeling (of pineapple), sorting, and weeding. Studies dealing with multiple agricultural activities were also detected. Interestingly, low-growing crops were investigated in the majority of the articles. This fact is related to the relatively low height, in terms of human body configuration, of the crops and the consequent stooping and kneeling positions that workers must maintain. Both stooping and kneeling, along with heavy carrying and lifting, were identified as potential risk factors for pathogenesis of MSDs. The repetitive nature of these actions deteriorates the pain and accelerates the onset of tissue injuries. Especially repetitive stooping seems to be responsible for the low back injuries, which are of epidemic proportion among agricultural workers. Personal characteristics, such as age, gender, and BMI, were also identified as potential risk factors. In addition, pesticide poisoning and inappropriate tools contribute to the development of MSDs. Finally, frequent rest breaks were suggested by a number of researchers, as well as frequent maintenance of the agricultural tools. The ergonomically designed tools along with special load transfer devices (in the form of suits) were observed to lessen MSDs. Finally, even relatively "small changes" in the design of common equipment, have been observed to make a "big difference" in the reported comfort of workers [20].

Overall, more targeted research efforts are required based on the anthropometric characteristics and social policy and culture of each nation. For example, an ergonomic intervention may be beneficial in a specific country, while the same intervention can cause additional MSDs to workers due to the different anthropometric characteristics in another country. Although some risk factors are similar among several agricultural activities and commodities, each kind has its own ergonomic dangers and musculoskeletal injury complications. This means that although most ergonomic interventions are based on proven strategies, every task should be separately addressed.

Definitely, automation is expected to replace most of the demanding agricultural manual operations and duplicate the adaptability of human beings in the near future. However, a number of barriers, ranging from social [3] and ethical [93] aspects, to technological [94] and monetary [95] aspects, still prevent a wide assimilation of robotic technologies in agricultural production systems. In any case, occupational health problems and safety is a major scientific discipline either for improving current operational systems or for designing human-centered future-envisioned robotized systems.

4.1. Study Strengths and Limitations

The major strength of the present systematic review is the capture of the current progress in the field of ergonomics in agriculture, as the selected articles were published within 2010–2019. The relatively high impact factor of the journals also guaranteed the reliability of the present results.

The main limitation of this investigation, however, is the fact that non-English research studies were excluded. Agriculture is definitely the primary job of people living in developing countries that use a different language from English. Therefore, an important amount of data is conjectured to have been lost, which, however, is compensated by the large geographical distribution of the contributing organizations.

4.2. Policy Directions

Finally, based on the present literature survey on ergonomics in agriculture as well as the own experience of the authors, the following policy directions are briefly suggested as preventing measures towards mitigating the impact of manual agricultural operations to labor health and safety.

- Reprioritization of the safety and health measures in agriculture.
- A systematic international strategy for the purpose of increasing the awareness of the risk factors related to MSDs due to agricultural occupation.

- An international effort to assure access to medical care, as rural workers are usually emigrants with inadequate insurance cover that self-treat the musculoskeletal injuries [18].
- Re-determining the practical limits pertaining to the main risk factors, such as working hours and maximum carried load.
- Identifying the less intensive postures for each task and educating agricultural workers via simple guides, by taking also into account the sociocultural characteristics of each nation.

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