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온실에서 방울토마토 수확작업시 작업자의 생리학적 및 생체역학적 반응 측정

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Measurement of Worker's Physiological and Biomechanical Responses during the Cherry Tomato Harvesting Work in a Greenhouse

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Abstract

Physiological signals such as body temperature, heart rate, blood pressure and heart rate variability and biomechanical workload for stress analysis were investigated during the cherry tomato harvesting work in a greenhouse. The skin temperatures raised 0.05℃/min, 0.03℃/ min, and 0.08 ℃/min in standing, stooping and squatting postures, respectively. Breath rate significantly increased from 18 to 28 breaths/min during the cherry tomato harvesting work. As the heart rate during the work ranged from about 72 to 110 beats/min (bpm), the cherry tomato harvesting work appeared to be a light intensity task of less than 110 bpm. The worker's average energy consumption rate in three positions during 43 min working time was 65.74 kcal (91 kcal/h in 70 kg). This was a light intensity of work, compared to 75 kcal/h in 70 kg of basic metabolic energy consumption rate of a worker with 70 kg weight; The maximum shear force on the disk (L5/ S1) due to static workload in the cherry tomato harvesting work was 446 N in the stooping posture, 321 N in the squatting posture and 287 N in the standing posture. Acute stress index expressed with the heart rate variability, increased parasympathetic activation up to about 70 while workers were doing most agricultural work in this study. This study provided a system to measure quantitatively workers' physiological change, kinematics and kinetic factors without any restrictions of space in the greenhouse works.

Keywords : Physiological and biomechanical responses, Cherry tomato harvesting work, Greenhouse

1. INTRODUCTION

Though agricultural mechanization is advancing in Korea, the portion of manual work is still high in the greenhouse. Most of the hazards of work-related injury such as farmer's disease and musculoskeletal problems remain, due to the presence of uncomfortable work posture in yield-oriented jobs, and the fact that there exist conditions of overexertion, long time work, and insufficient rest time. Work-related musculoskeletal disorders have recently been receiving much attention as a major occupational disorder. Labour performed in restricted areas such as greenhouses include many tasks that require proper posture in raising the arm above shoulder , and the stress of repeatedly moving one's hands can add strain to the waist, neck, shoulders, hands/wrists, and lower body. This is especially the case in

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harvest work, which is considered to be the most dangerous of agricultural tasks (Choi *et al.*, 2007a). Specially, the particularly high prevalence of musculoskeletal disorders among field crop harvesters was reported. Greenhouse work has the characteristic of requiring a distinct posture, and it is considered that various hazardous causes of musculoskeletal disorders exist in greenhouse agriculture, but in reality, just how much greenhouse cultivators are exposed to musculoskeletal disorders has yet to be sufficiently investigated. According to research conducted by the Rural Development Administration (2004) in Korea, the percentage of farmers with musculoskeletal disorders with observable symptoms is 84-92%, a number about 2.4 times higher than what appears in non-farmers, and differences in the prevalence of symptoms among various types of work were reported, including works in orchards (67%), crop fields (60%), and animal husbandry (37%). In another research study, the percentage of fruit growers with symptoms of musculoskeletal disease was reported to be 73.3%. The disease symptoms appeared in various body parts including legs (47.7%), waist (40.9%), and shoulders (36.6%). The particularly high prevalence of musculoskeletal disorders among field crop harvesters was reported; thus, understanding the causes and ways to improve this situation is needed.

In the field of human engineering, measurement systems frequently used to predict the workers' workloads were Ovako working posture analysis system (OWAS), rapid upper limb assessment (RULA), rapid entire body assessment (REBA), etc. As qualitative measurement systems, these systems gave comfort to the observer, who could diagnose the degree of workload simply by the posture of subjects. These measurement systems, however, didn't provide the observer with quantitative figures of the subject's workloads. Equipments to measure the workloads quantitatively were not available. Electromyography (EMG) of the subject's muscle and mechanical analysis with force plate were suitable for measuring workloads in the laboratory, but not in the field because these were so complex that they could induce the disturbance to subjects. To overcome these problems, Son et al. (2010) tried to establish a quantitative analysis system to measure physiological index of subjects, heart rate, and heart rate variability (HRV), etc., and they evaluated the system using an angular acceleration sensor for measure the workload. Continuous measurement of farm workers' physiological signals was required to analyze their workloads and stresses.

Therefore, the objective of this study was to measure workers' physiological and biomechanical responses quantitatively during the cherry tomato harvesting work in a greenhouse. To assess whether quantitative analysis for this farm work would be possible with this system, work postures are divided into three types - stand, stoop and squat. A worker's heart rate, pulse, temperature, physical activity, HRV and angular acceleration of a trunk was measured at each posture, and analyzed to evaluate the system.

2. MATERIALS AND METHODS

A. A system to measure worker's responses in greenhouse work

This study consisted of two parts: 1) physiological response measurements [heart rate, pulse rate, blood pressure, body temperature, physical activity, heart rate variability (HRV)] and 2) a biomechanical response measurement system as shown in Fig. 1: (a) a temperature sensor for respiration number counting, a heart rate ECG sensor (Polar), and a HRV, ECG sensor (P-trainer); (b) three physical activity measurement sensors (wrist, waist and ankle), 5 multi-axis motion sensors, and a wireless communication device (Xbus); (c) a data logger for a temperature sensor; [A: view of frontal plane (anterior), B: view of frontal plane, C: view of frontal plane (posterior)].

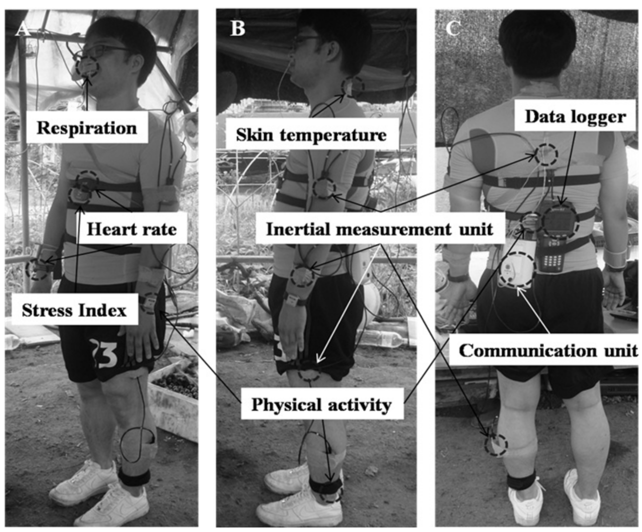

Fig. 1 Photo view of a measurement system used in this study.

All signals from the devices were collected simultaneously through a customized system. A thermocouple (skin temperature sensor, PS-2131, PASCO®, USA) was used to measure body temperature. Also, a thermistor temperature sensor, PS-2135, PASCO®, USA) was used to measure respiration rate. The temperature was measured near the worker's respiratory region at the entrance of the nose. An athlete training system (Polar RS400, USA) was used for heart rate monitoring and memory. The Polar output data was logged at 1, 4, 12, and 60 times min^{-1}. This system consisted of a transmitter (Polar WearLink® 31 transmitter, Polar RS400) and a running computer. A physical activity monitoring system (Actical, Germany) composed of a 3-axis acceleration sensor, measured activity rates. The hardware included a device which records motion data, the Actical activity monitor, and the ActiReader. The Actical was designed for recording physical activity. The Actical activity monitors were worn on the hip (waist), ankle and wrist as shown in Fig. 2. (A: stand harvesting, B: stoop harvesting, and C: squat harvesting). The physiological data of subjects are shown in Table 1.

Table 1 Physiological data of subjects. Three subjects were participated in cherry tomato harvesting work in a greenhouse

	Height (cm)	Weight (kg)	Body mass index (BMI)
Subject 1	170	78	26.99
Subject 2	175	72	23.51

Fig. 2 Photo view of cherry tomato harvesting work during 45 min: three different postures of trunk flexion.

B. Determination of acute stress index

The P-trainer (Mentech Co., Korea), a memory-less device for stress analysis using R-R interval from electrocardiogram (ECG) signal, was used. The device can calculate acute stress index using heart rate variability, a physiological factor. Based on HRV, acute stress index (Choi, 2007b) was defined as

$$Acute\ stress\ index = (T_{LF/HF} + T_{HR}) / 2 \qquad (1)$$

where: $T_{LF/HF}$= standard index of the autonomic nervous system balance rate [LF/HF] ; *HF* = parasympathetic activation rate, [HF, high frequency power (0.15 - 0.4 Hz) scale value of the natural logarithm (ms^2)] ; LF = sympathetic activation rate, [LF, low frequency power (0.04 - 0.15 Hz) scale value of natural logarithm (ms^2)] ; THR = standard index of heart rate [beats per minute (bpm)]. Spectral analysis decomposes R-R interval time series into its sinusoidal components. The software calculates the total power of all frequency regions and the power in three different frequency regions (VLF, LF and HF). Each of the frequency regions has different physiological meanings. The factory defaults of the software are based on recommendations from an international scientific committee; the limits are 0.04, 0.15 and 0.40 Hz. The VLF (very low frequency) region includes power values below 0.04 Hz (HR fluctuations that last more than 25 s). The LF (low frequency) region includes values between 0.04 - 0.15 Hz (HR fluctuations that last 7 - 25 s) and the HF (high frequency) region includes values between 0.15 - 0.40 Hz (HR fluctuations that last 2.5 - 7 s). In certain situations, such as paced breathing, it might be necessary to change these frequency limits slightly. The maximum frequency that can be included is 0.50 Hz.

C. Determination of human motion

A 3-axis motion sensor (X-bus Kit, Xsens Co., Netherlands) combines a set of inertia moment unit (MTx's), a communication device (Xbus Master), and a wireless transceiver enabling completely ambulatory measurement of human motion. The MTx's provide drift-free 3D orientation as well as 3D acceleration, 3D rate of turn (gyro rate), and 3D earth-magnetic field. The Xbus Master samples and sends synchronous MTx data to the mobile PC or PDA. The data is recorded using MT Manager or the MT Software Development Kit (SDK).

D. Biomechanical analysis of dynamic back load

The load on a worker's lumbar disc (L5/S1) can be

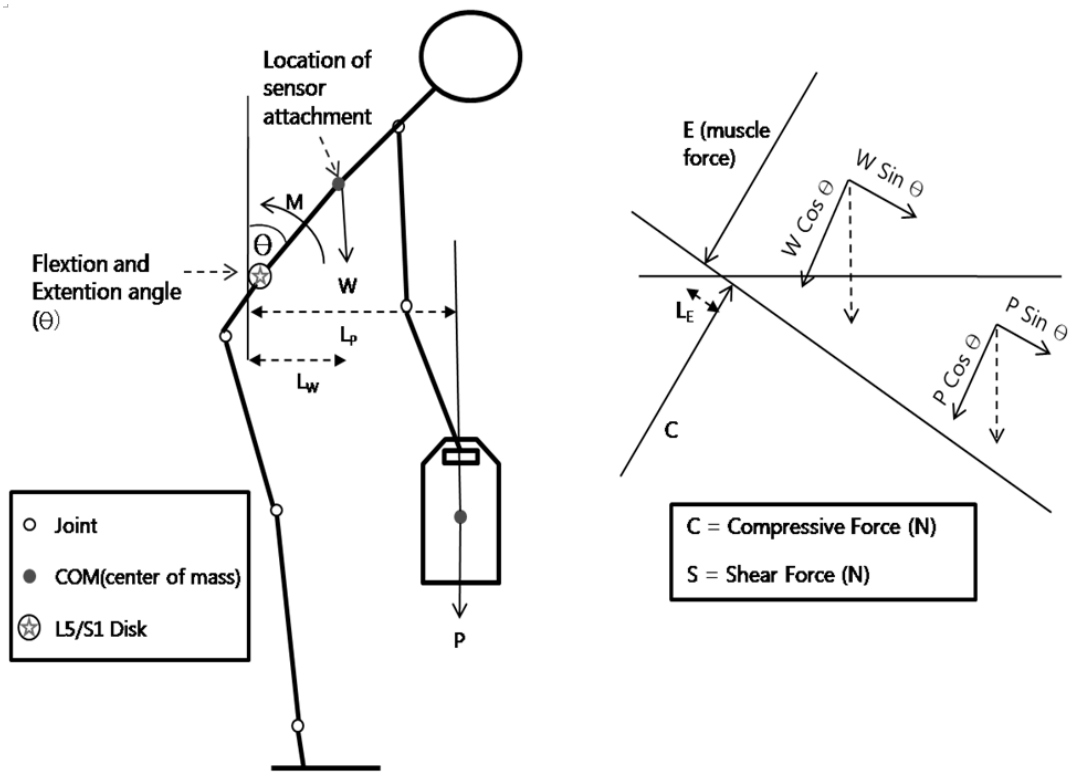

Fig. 3 Free-body diagram for calculation of the back load.

calculated when a worker who weighs 70 kg lifts a 20 kg object. The spine is flexed approximately θ. While working, the three principal forces acting on the lumbar spine at the lumbosacral level are: 1) the force produced by the weight of the upper body (W) (approximately 65% of the force exerted by the total body weight); 2) the force produced by the weight of the object (P); and 3) the force produced by contraction of the erector spine muscles (E), which has a known direction and point of application but an unknown magnitude (Fig. 3).

The magnitude of (E) can be found by using the dynamic equation for moments. Dynamic equation of Eq. (2), (3), and (4) (Nordin and Frankel, 2001) may be expressed as following below :

$$\sum M = I \times \alpha, (W \times L_W) + (P \times L_P) - (E \times L_E) = I \times \alpha$$

$$\therefore E = \frac{(W \times L_w) + (P \times L_p) - I \times \alpha}{L_E} \quad (2)$$

$$\sum F_y = 0, W \times \cos\theta + P \times \cos\theta + E - C = -mr\omega^2$$

$$\therefore C = W \times \cos\theta + P \times \cos\theta + E + mr\omega^2 \quad (3)$$

$$\sum F_x = 0, W \times \sin\theta + P \times \sin\theta - S = mr\alpha$$

$$\therefore S = W \times \sin\theta + P \times \sin\theta - mr\alpha \quad (4)$$

where: W = the force produced by the weight of the upper body (N) : approximately 65% of the force exerted by the total body weight ; P = the force produced by the weight of the object (N) ; E = the force produced by contraction of the erector spine muscles (N) ; LW = the lever arms of the forces produced by the weight of the upper body (m) ; L_P = the lever arms of the forces produced by the weight of the object (m) ; L_E = the lever arms of the forces produced by contraction of the erector spine muscles (m) ; θ = the trunk angle when the maximum dynamic loading act on the disc (degree) ; C = the total compressive force acting on the disc (N) ; S = the shear component for the reaction force on the disc (N). This study's participant characteristics from anthropometric information according to each subject of 3-axis inertia moment of subject's trunk from Chandler *et al*. (1975) were considered. Also, dynamic moment (torque) was calculated using selected inertia moment and angular acceleration from the motion sensor on the back in the three direction. Therefore, the moment against the waist can be expressed as Eq. (5).

$$M = I \cdot \alpha \tag{5}$$

where: M = torque (N·m); I = inertia moment (kg·m^2); α = angular acceleration (rad/ s). After the sensors were attached and verified, workers performed a randomized sequence of trials, during which they harvested cherry tomato at each of three different postures. During each trial, workers harvested cherry tomatoes in the greenhouse and were asked to keep their posture uniform during a certain amount of time. The workers harvested cherry tomatoes while holding each posture for 15 min, for 45 min of total work.

3. RESULTS AND DISCUSSION

A. Skin temperature

A system for measuring skin temperature was set using skin temperature sensors. Through the changes in temperature worker's respiration rate could also be measured (Fig. 4).

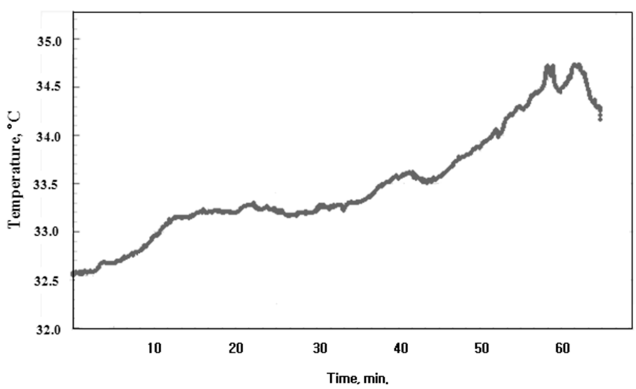

Fig. 4 Change of skin temperature during cherry tomato harvesting.

A worker's skin temperature rose from 32.6 to 34.7℃ while continually harvesting cherry tomatoes. Working times were separated into three general groups, comparing starting temperatures with later temperatures. The skin temperatures raised by 0.05, 0.03, and 0.08℃/min in standing, stooping (bending at the waist), and squatting postures, respectively. Through these results, it was thought that the change in skin temperature was little in the harvesting work of cherry tomato.

B. Respiration rate

Changes in respiration rate were observed by a quick-response temperature sensor, thermistor, near the nostril of subjects, which can measure temperature changes by the respiration. The changes in respiration measured by the thermistor were shown in Fig. 5.

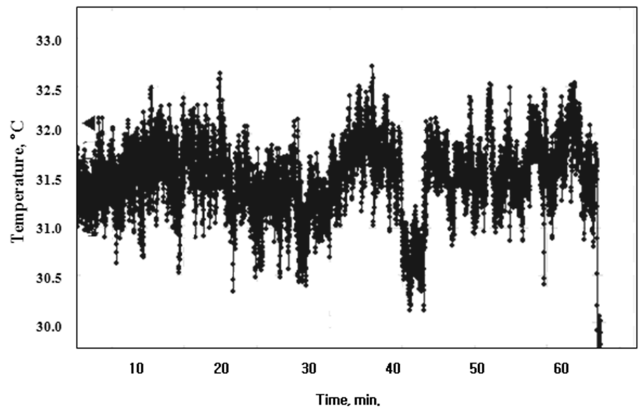

Fig. 5 Change of respiration temperature during cherry tomato harvesting.

With this temperature changes, respiration rate per minute was calculated, by counting the peaks of temperature changes in each minute. The change in respiration rate is shown in Fig. 6.

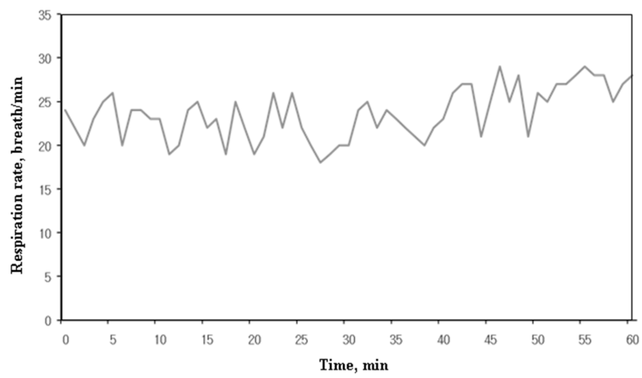

Fig. 6 Change of respiration rate during cherry tomato harvesting.

In cherry tomato harvesting, the respiration rate per minute increased continuously and decreased according to the level of work performed, with a range of about 18 to 28 breaths/ min. The average respiration rate during the harvesting work in a squatting posture was 24 breaths/min, which was highest value among three postures.

C. Heart rate

The heart rate increased according to cherry tomato harvesting time and postures as shown in Fig. 7.

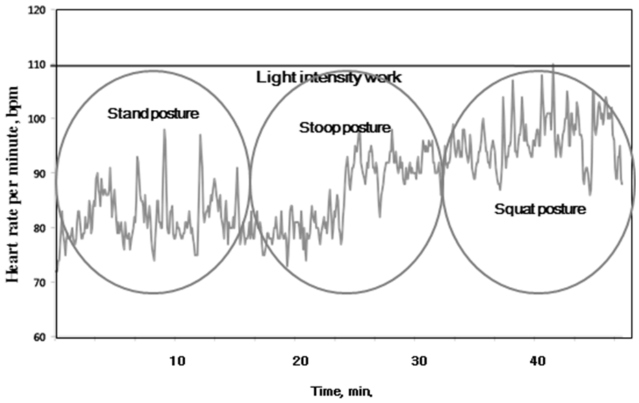

Fig. 7 Heart rate change during cherry tomato harvesting work.

As the heart rate during the work ranged from about 72 to 110 beats/min (bpm), thus the cherry tomato harvesting work appeared to be a light intensity task of less 110 bpm. The heart rates in the standing and stooping postures were ranged from about 72 to 100 bpm, while the heart rate in the squatting posture from about 85 to 110 bpm. The average heart rate in standing and stooping posture was 82 and 86 bpm, respectively, and in the squatting posture 96 bpm. This result indicates that the work in the squatting posture is work of high intensity compared to the works of other postures.

D. Physical activity

According to the changes of physical activity while harvesting cherry tomatoes (Fig. 8), the average energy consumption rate (including metabolic energy) of physical activities from the wrist, waist, and ankle were 1.194, 0.936, and 1.230 kcal/h·kg, respectively.

The results of change in overall physical activity showed insignificant differences in the wrist and ankle, and movement in the waist was small. In cherry tomato harvesting, wrist and ankle movement was brisk. While harvesting, the worker's average energy consumption rate during 43 min intervals in three positions was 65.74 kcal (91 kcal/h in70 kg). This is a light intensity of work, compared to 75 kcal/h of basic metabolic energy consumption rate of a worker with 70 kg weight.

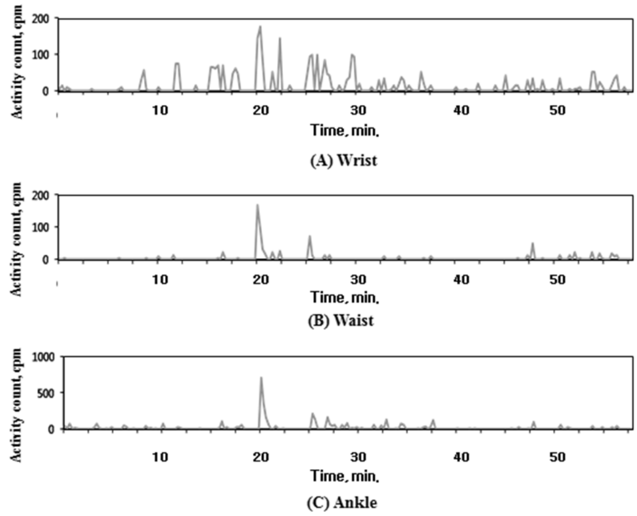

Fig. 8 Change of average physical activities for the wrist, waist, and ankle.

E. Workload on spine

The maximum shear force on the disk (L5/S1) due to static workload in the cherry tomato harvesting work was 446 N in the stooping posture, 321 N in the squatting posture and 287 N in the standing posture. The work in the stooping posture showed the hardest compared to those of the squatting and standing postures. Individual changes in kinetic workload were observed tri-axially using three motion sensors in places associated with cherry tomato harvesting. The changes in angular speed according to working time showed various transformations according to work postures. The maximum resultant moment of kinetic movement in the upper body was measured. It was 0.005 N·m in the standing posture of harvesting, 0.003 N·m when harvesting in the stooping posture, and 0.005 N·m when harvesting while in the squatting posture. In our previous study, when workers lifted 10 kg box, the maximum resultant moment of the upper body was 99 N·m (Son *et al*., 2010). However, in this study the maximum resultant moment of the upper body was 0.005 N·m. As the dynamic workload in the cherry harvesting work was not significant regardless of work postures compared to static workload on spine, the harvesting work in the greenhouse could be considered as a static work.

F. Acute stress index

The results of a worker's acute stress index based on HRV displacement in cherry harvesting, were obtained using

Table 2 Results of physiological signals and biomechanical load in the greenhouse work of cherry tomato harvesting

Items		Cherry Tomato Harvesting		
		Stand posture (15min.)	Stoop posture (15 min.)	Squat posture (15min.)
Skin Temperature (℃/ min)		0.05	0.03	0.08
Heart Rate increasement (bpm)		22	25	25
Net Physical Activity (kcal/ h·kg)	wrist	0.36	0.26	0.23
	waist	0.52	0.04	0.23
	ankle	0.26	0.28	0.17
Energy Consumption Rate (kcal/ h·kg)	wrist	1.35	1.24	1.15
	waist	1.01	0.90	1.16
	ankle	1.09	1.30	1.08
Max Resultant Dynamic Moment on Waist (N·m)		0.005	0.003	0.005
Max Shear Force on Disk due to Static Work Load, (N)		287	446	321
Avg. Heart Rate (bpm)		81.8	85.9	96.0
Avg. Respiration Rate (breaths/ min)		22.7	21.8	26.1
Avg. Acute Stress Index		30.0	54.2	77.9

the p-trainer™. The harvesting work in standing and stooping postures produced acute stress indices of less than 70 (30 ± 17.76 and 54 ± 21.93, respectively), but the acute stress index of harvesting work in the squatting posture was found to be far greater (77.9 ± 13.98) as shown in Fig. 9.

As the acute stress index of this work in the squatting posture exceeded 70, it was a stressful, hard work.

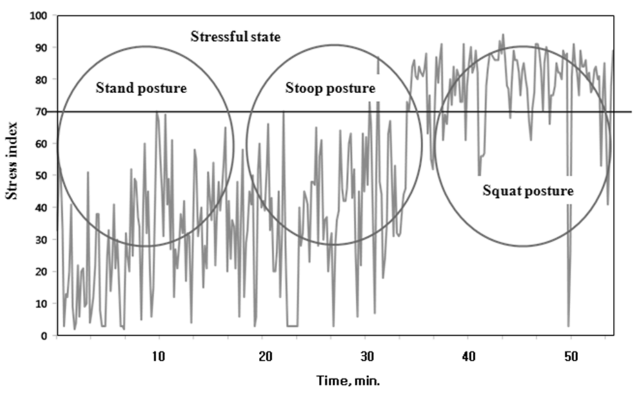

Fig. 9 Plots of acute stress index verse time in cherry tomato harvesting.

4. CONCLUSIONS

In this research, the measurement system which was constructed in previous study was used to calculate farm worker's workloads quantitatively, and evaluated whether this system was suitable in the site of farm work or not, especially during the cherry tomato harvesting work in a greenhouse. The experiment was conducted in three postures. The conclusions were as followings:

(1) The skin temperature during the work of cherry tomato harvesting increased from 32.6 to 34.7℃, and the average skin temperature increase per minute was 0.035℃/min.
(2) The average respiration rate during cherry tomato harvesting work was 23.5 ± 3.0 breaths/min. The respiration rates in three postures of stand, stoop and squat during cherry tomato harvesting work were 22.7 ± 2.2, 21.8 ± 2.2 and 26.1 ± 2.2 breaths/min, respectively. The respiration rate in the squatting posture was significantly high.
(3) The average heart rate during the greenhouse work of cherry tomato harvesting was 91 bpm. Heart rate increased while performing greenhouse work, but it showed mainly a light intensity work. The average heart rates in the three postures of stand, stoop and squat during the cherry tomato harvesting works with initial heart rate of 72 bpm, were 81.8 ± 4.33, 85.9

± 6.06 and 96.0 ± 5.81 bpm, respectively. The squat posture heart rate was significantly high.

(4) The energy consumption rate of physical activity from the wrist was significantly higher than those from the other body parts. The energy consumption rate of cherry tomato harvesting using 3-axis accelerometers on the wrist in the standing, stooping and squatting postures were 1.350, 1.236 and 1.46 kcal/h·kg, respectively.

(5) The dynamic moment of a trunk during cherry tomato harvesting in the greenhouse reached a maximum of 0.005 N·m. The maximum static shear force on a L5/S1 disk was 446 N, while the maximum allowable shear force was 1,870 N. The squat posture could cause significantly high damage on the waist because of long term static postures.

(6) The squatting posture caused significantly stressful state, indicating an acute stress index of about 70. The average acute stress index of the three postures of cherry tomato harvesting was 58.1 ± 31.03. The average acute stress index in the three postures of stand, stoop and squat during cherry tomato harvesting tasks were 30.0 ± 17.76, 54.2 ± 21.93 and 77.9 ± 13.98, respectively. The squatting posture showed a significantly high acute stress index compared to those of other postures in the greenhouse work.

(7) It was confirmed that this system was suitable for quantitatively measuring the workload of cherry tomato harvesting work in a greenhouse, and could measure the worker's signals on the spot of farm work. This system can be used to measure and calculate a worker's physiological signals in a greenhouse work, and give helps to analyze the workload in various farm works and prevent the disorders caused by the farm works.

Acknowledgements

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