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Ergonomic evaluation of hand tools used in grape pruning activities in vineyards

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Abstract

Grape farming is a labour-intensive operation, with pruning as one of the tasks performed with hand tools. Most of the tropical countries use locally made and commercially available hand pruning tools for grape pruning. Different pruning tools used in India were selected for ergonomic evaluation and refinement was made based on the physiological responses of the subjects. The comparison between the commercially available Economy tool (M_2), Maharashtra tool (L_1) and Karnataka tool (L_2) model pruner shows that the model Economy tool (M_2) gives better performance. Economy tool (M_2) model is highly preferred by the grape farmers due to its high performance and more comfort than Maharashtra tool (L_1) and Karnataka tool (L_2) model. This is due to standard material, shape of the pruner slightly bent for easy handling. The physiological responses were measured and compared between the ergo refined pruning tool (EM_3) and other selected pruning tools. Ergo refined pruning tool (EM_3) registered lower values for heart rate, oxygen consumption, energy expenditure when compared to other selected pruning tools. It was also observed that cutting frequency and area coverage for selected pruning tool varies from 11 to 24 cuts/ min and 750 to 1350 m^2/ h. Ergo refined pruning tool (EM_3) registered 24 cuts/ min and 1350 m^2/ h when compared with other pruning tools. A full hand loop was fitted below the lower handle to improve grip and uniformly apply force throughout the pruning operation, resulting in increased area coverage and frequency of cut.

Key words: Ergonomics, heart rate, hand tools, grape pruning, evaluation, refinement

Introduction

Grapes (*Vitis vinifera*) are one of the most important commercially-significant crops in India, ranking 9th in global production (Shikamany, 2001; Gade *et al*., 2014). Grape is grown in India in three distinct climatic zones: tropical, subtropical, and hot tropical. India has variously coloured, white, seeded, unseeded, large and small grape varieties.

Hand pruning in the winter is critical in vineyards of small farms. In India, only manual labour and locally made, commercially available pruning tools are used to prune trees. Grape pruning with locally made and commercially available pruning tools requires dynamic postures which are ergonomically unfavourable. Knowledge of stress-strain analysis while pruning and harvesting wine grapes will aid in reducing the risk of cumulative trauma disorders (CTD) in vineyard workers' upper limbs.The information obtained can be applied in the ergonomic redesign of pruning tasks and pruning tool to reduce incidence of trauma (Wakula *et al*., 2000). Roquelaure *et al.* (2004) revealed that exposure assessment plays a greater role in determining the priorities for ergonomic intervention, surveillance of health and exposure must nevertheless be combined to predict the risk of MSDs.

Grape producers complained about decreasing availability of qualified labor for pruning and tying and indicated that these should be mechanized. Utilization of a mechanical pruner could lower the manual labor necessary for the operation (Morris, 2000). Studies on ergonomics and pruning tool design were aimed at observing the accumulation of stress to the operator (Paivinen *et al*., 2000; Haapalainen *et al.,* 2000). Manual jobs that require repetitive movements aggravate the risk factor if they are performed with high grip forces (Seth *et al.,* 1999, Miller *et al*., 1995). Tekin, *et al*. (2012) evaluated the performances of two different machines used for pruning in viticulture in the Aegean region of Turkey. They found that local pruning machines provided higher performance as compared to imported machinery. In India, large machines or any machine involved in grape cultivation are not used. Hence mostly small hand tools are commonly used for major operations in grape cultivation.

With the introduction of ergonomically refined hand tools it becomes essential for its successful adoption in grape farming. The use of ergonomically refined hand tools has a significant benefit to agriculture in terms of having safe, healthy and productive workers. The drudgery in pruning and harvesting has made grape farming unattractive. In most tropical countries, farmers spend more time on using hand or with simple tools, than any other farming task. Tool design (weight, shape, fit to the user and the task), workstation design (size, shape and layout), and the way tasks are scheduled are all key factors in making hand tool use safe and risk-free. To reduce the risk for work related musculoskeletal disorders and to reduce the drudgery in pruning hand tools, it is essential to introduce ergonomically refined hand pruning tools for grape cultivation.

Methods and materials

The pruning operation was carried with conventional type pruners (Farmers local hand tool) and commercially available selected pruning hand tools were ergonomically evaluated with selected

ten male subjects in grape fields located at Jaathavara hosahalli village, Chickbellapur district, Karnataka, Madhampatti village in Coimbatore district and Anamalaiyanpatti village in Theni district.

Selection of grape pruning tools: For the present investigation, the pruners commercially available in different regions of Tamil Nadu and South India were procured and selected for ergonomical evaluation. The different models of grape pruners collected are shown in Fig. 1 and their specifications are furnished in Table 1.

Table 1. Specification of the selected grape pruning tools

Details	Economy tool (M_2)	Maharashtra too1(L_1)	Karnataka tool (L_2)
Weight (g)	220	220	280
Over all dimension, mm	185 x 69 x 17	200 x 50 x17	235 x 120 x 10
Type of material	Stainless steel With non-slip plastic grip handles	Stainless material	TMT steel bar
Quality of finishing	Good	Poor	Poor
Type of blade	High carbon steel	High carbon steel	Leaf spring steel
Type of springs system	Leaf spring system	Constant force spring	Leaf spring system

Selection of subjects: Ten male subjects were (contract grape vine pruning workers) selected for the investigation based on the age and fitness in Theni, Coimbatore and Chickbellapur districts of Tamil Nadu and Karnataka. The subjects were screened for normal health through medical investigations and were selected with minimum age 24 and maximum age of 39 and had their experience of more than five years in grape pruning operations.

Ergonomical evaluation of the selected grape pruning tools: Selected ten male subjects were examined in the laboratory condition by indirect assessment of oxygen uptake and the maximum heart rate attainable by the subjects was computed as suggested by Astrand (1960) and Maritz *et al.* (1961). Ergonomical evaluation of the selected grape pruning pruners was conducted for assessing their suitability with the ten selected subjects. The evaluation was carried out in terms of the following physiological parameters: Heart rate (HR) and oxygen consumption rate (OCR), Energy cost of operation, Acceptable Work Load (AWL), Limit of Continuous Performance (LCP), Overall Discomfort Rating (ODR), Body Part Discomfort Score (BPDS) and Rapid Upper Limb Assessment Score (RULA).

Results and discussion

Ergonomical assessment of the selected grape pruning tools: Field experiment was conducted during the month of April to November 2018 with three selected grape pruning tools *viz.*, commercially available Economy tool (M_2), local made tools from Maharashtra pruning tool (L_1) and Karnataka pruning tool (L_2). The field selected for trial had sharad seedless variety in Jaathavara hosahalli village in Chickbellapur District of Karnataka and muscat hamburg variety in anamalayanpatti village and madhampatti village of theni and Coimbatore Districts. The subjects were trained well for the operation of the pruning with the hand tools. The temperature and relative humidity varied from 28 to 36 °C and 30 to 64 percent respectively during the period of evaluation. The trial was conducted between 7.30 AM and 5.00 PM and the subjects were asked to report at the field at 7.00 AM. Each trial started with taking five minutes data for physiological responses of the subjects while resting under shade. After the rest period of half an hour, the selected subjects operated the pruning tool. Each trial was conducted for a period of 30 minutes. During the trail the heart rate was measured with the computerized heart rate monitor. The same procedure was repeated for all the subjects.

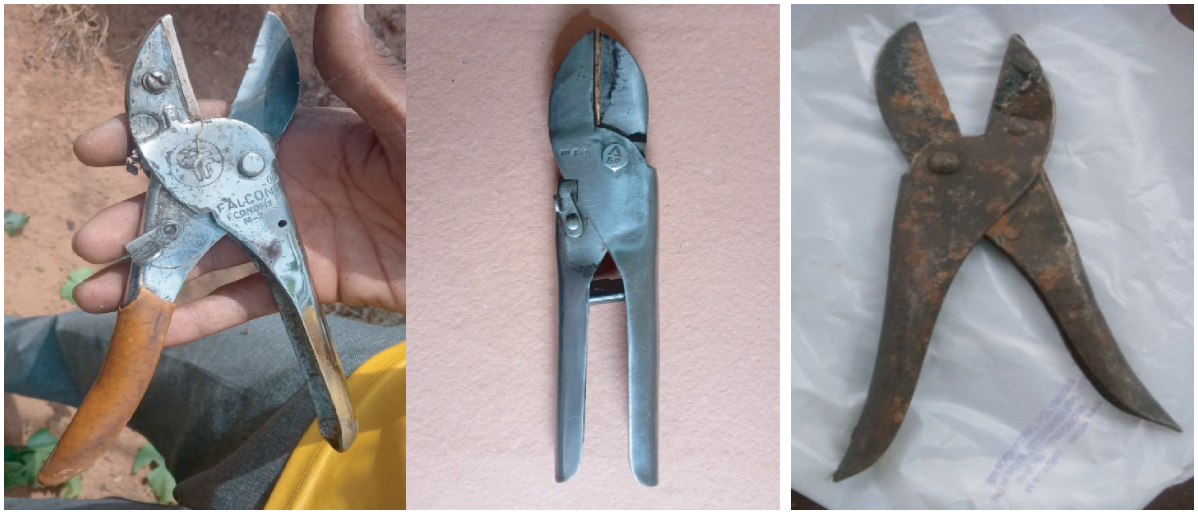
Physiological response of subjects: The physiological response of all the selected male subjects for pruning operation with the selected pruning tool was measured and furnished in the Table 2.

Table 2. Physiological response of subjects for pruning operation

Pruning operation with selected pruning tool	Heart rate, beats min^{-1}	VO_2, L min^{-1}	Energy expenditure, KJ min^{-1}	Energy grade of work
Economy tool (M_2)	96.5	0.579	12.09	Light
Maharashtra tool (L_1)	99.9	0.601	12.54	Light
Karnataka tool (L_2)	109.3	0.706	14.74	Moderately heavy

The above table shows that the heart rate, oxygen consumption and mean energy expenditure for grape pruning operation was low in the Economy tool (M_2) and was graded as “light" compared with other tools.

Acceptable work load (AWL) and limit of continuous performance (LCP): To ascertain whether the operation of



Commercially available Economy tool (M_2) Maharashtra tool (L_1) Karnataka tool (L_2)

Fig. 1. Grape pruning tools selected for ergonomic evaluation

selected tools for pruning operation is within the acceptable workload (AWL), the increase in heart rate of the subjects over resting values (ΔHR) of pruning operation with selected pruning tool was calculated and presented in the Table 3.

Table 3. Mean values of AWL & ΔHR of selected subjects for pruning operation with selected pruning tools

Pruning operation with selected pruning tool	Mean values of AWL		Mean values of ΔHR	
	Oxygen consumption rate as percent of VO_2 max (%)	Acceptable workload (35% VO_2 max)	Δ HR beats |min^{-1}	LCP 40 beats min^{-1}
Economy tool (M_2)	31.49	<AWL	20.8	<LCP
Maharashtra tool (L_1)	32.71	<AWL	22.7	<LCP
Karnataka tool (L_2)	36.85	>AWL	33.6	<LCP

The OCR for selected pruning tools was less than acceptable workload limit for Economy (M_2) and Maharashtra tool (L_1) and slightly more than acceptable work load limit for Karnataka tool (L_2). The calculated value of work pulse values for grape stem pruning operation with all the selected pruning tools was less than recommended LCP value of 40 beats min^{-1}, which is a clear indicative of the fact that with selected pruning tools, pruning operation could be performed for longer duration without adequate rest.

Overall discomfort rating (ODR) and body part discomfort score (BPDS): The overall discomfort scores and Body Part Discomfort Score (BPDS) of each of the ten male subjects were assessed after performing the pruning operation with the selected pruning tools. The mean values of Overall Discomfort Rating (ODR) and Body Part Discomfort Score (BPDS) of the subjects are furnished in Table 4.

Table 4. Overall discomfort and body part discomfort score rating of selected subjects after performing the pruning operation with selected pruning tools

Pruning operation with selected pruning tool	ODR		BPDS	
	Score	Scale	Body part experiencing pain	Score
Economy tool (M_2)	4.2	<Moderate discomfort	Light pain in right shoulder, Clavicle right, Neck, right arm,	14.36
Maharashtra tool (L_1)	4.8	<Moderate discomfort	Light pain right shoulder, Clavicle right, Neck, wrist and palm fingers in right arm	21.43
Karnataka tool (L_2)	6.5	>Moderate discomfort	Light pain right shoulder, Clavicle right, Neck, more pain in the wrist and palm fingers in right arm	27.86

From the rating of perceived exertion of the subjects, the ODR scale for Karnataka tool (L_2) is higher than Economy tool (M_2) and Maharashtra tool (L_1). This might be due to the higher cutting force required with Karnataka tool (L_2). The lower value of BPDS for Economy tool (M_2) is due to lighter weight, sleeve for handle. The relatively higher BPDS value for Maharashtra tool (L_1) is due to improper handle design and the lack of sleeve leads, which causes hand slippage due to sweating. The Karnataka tool (L_2) had the highest BPDS, which could be attributed to direct pressure or "contact stress," which refers to direct contact between a hand palm and a hard edge or surface of the pruning tool, causing discomfort and pain. Similarly, pressure points contact between the palm and any hard surface can interfere with pruning efficiency, causing discomfort to the operator with a pruning hand tool. The pressure points can inhibit nerve function and blood flow, potentially leading to permanent injury.

Ergo refinement of economy (EM_3) pruning tool: The conventional tools made of stainless steel without quality finishing in the edges, shape of pruner is straight without hand grips, there is more chances of slippage from the hand and very hard to compress frequently while pruning this is because of spring used in the pruner are locally made without standards. From the selected tools it is observed that the when grip is slippery, accomplishing of the same task will be difficult. Hence one common improvement is to provide a collar or stop on the grip which can reduce grasping force and also to cover the grip with a material that provides higher friction in cases where the force applied is coaxial to the grip. Among the selected models of grape pruning tools, the Economy (M2) was chosen for further ergonomic refinement as it yielded lower value of measured physiological responses. The primary interface (and often the only interface) between human and a hand tool is the grip. Common problems, whether the tool is powered or manual, include: wrong size of the grip, too slippery for the task, hard edges or protrusions, inappropriate for the task. To achieve the higher pruning efficiency, the wrist has to be kept in optimal position to minimize grasping force and eliminating pressure points. A full hand loop was fitted below the lower handle of the economy tool (M_2) for enhancement of grip to get uniform application of force throughout the pruning operation. In addition to this modification, hand gloves were provided to the subjects to pull the pruned vine stems from the plants. Normally pruning of grape vines is performed by the cutting tool in the right hand and pulling the pruned vine stem in the left hand. These two operations are done simultaneously which causes bruises in the left palm. The ergo refined pruning tool (EM_3) is shown in Fig. 2. The ergo refined pruning hand tool (EM_3) with handle modification adds more comfort, grip, and protection from slipping than the super cut (M_3) type pruner (Table 5). The study showed that compared to the economic pruning tool, the ergo refined tool (EM_3) achieved 95.2 beats min^{-1}, 0.566 l min^{-1}, 11.81 KJ min^{-1}, 30.31 and 20.8 percent AWL and LCP (M_2).

Table 5. Comparison between the economy tool (M_2) and ergo refined tool (EM_3)

Parameter	Economy tool (M_2)	Ergo refined tool (EM_3)
Mean heart rate, beats min^{-1}	96.9	95.2
VO_2, L min^{-1}	0.581	0.566
Energy expenditure, KJ min^{-1}	12.13	11.81
Oxygen consumption rate as percent of VO_2 max (%)	31.85	30.31
Acceptable workload (35% VO_2 max)	<AWL	<AWL
ΔHR beats min^{-1}	20.8	20.8
LCP 40 beats min^{-1}	<LCP	<LCP

Measurement of vine cutting frequency & area coverage with selected pruning tool: The subjects were asked to prune the grape field with selected pruning tool for one hour and the area

Fig. 2. Ergo refined grape pruning tool with gloves

is measured. The mean average value is presented in the Table 6. This increase in area coverage and frequency of cut is due to a full hand loop fixed below the lower handle for improved grip and uniform force application throughout the pruning operation.

Table 6. Measured values of frequency of cut and area coverage

Pruning operation with selected pruning tool	Number of cuts per minute (Average value)	Area coverage per hour
Economy tool (M_2)	21	1275 m^2/ h
Maharashtra tool (L_1)	19	1150 m^2/ h
Karnataka tool (L_2)	11	750 m^2/ h
Ergo refined (EM_3)	24	1350 m^2/ h

When compared to the economy pruning tool, only low and on par values of ergonomic parameters were recorded (M_2). The subjects felt more at ease using the ergo refined pruning tool (EM_3) because of the lower handle's closed loop grip, which distributes uniform force and allows more hand and forearm muscles to be brought into play, providing more strength to do the job throughout the pruning operation.

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