Selective Tea Plucking Machine to Reduce The Labor Involvement

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ABSTRACT

Tea (Camellia sinensis) is a perennial crop and their leaves are the economically most important part in tea manufacturing process. Sri Lanka produces tea throughout the year and the total tea production is about 320 million kilograms per annum. The bud including the third leaf should be plucked manually or using mechanical means and taken to the factory where it is processed, in order to obtain good quality tea. Since, tea plucking is a labor intensive process; it has become one of the major problems in tea industry as labor is so expensive and scarce. Therefore, this study was aimed to introduce an efficient and affordable mechanical method for selective plucking of tea. Main components of this machine were shoots selector, directing roller to direct selected leaves to the cutter, cutter, collector, battery and motor. Selecting only the suitable shoots for plucking by the machine itself is the most salient feature of this machine. Machine weighs 6.5 kg and the total cost of production is about LKR 12000. The performances of the machine (T_2) were evaluated compared to manual plucking (T_1), TRI cutting shear (T_3) and one of the Japanese non selective tea harvesters (Kawasaki) (T_4) separately, using the same operator. Actual field capacities of T_1, T_2, T_3 and T_4 were 0.014 ha/hr, 0.021 ha/hr, 0.015 ha/hr and 0.026 ha/hr, respectively while theoretical field capacities were 0.023 ha/hr, 0.029 ha/hr, 0.023 ha/hr and 0.035 ha/hr respectively. Field efficiencies recorded as 60.8%, 72%, 65.2% and 74.3% respectively. The data from the evaluation of all the harvesting methods were analyzed with the T test using SAS software with $p < 0.05$ significant difference. The newly constructed selective tea harvester could be efficiently used as to replace the manual harvesting which utilize more time and labor.

KEYWORDS: *Selective Harvesting, Tea Harvester, Tea Production*

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1 Introduction
Tea is an aromatic beverage produced in Sri Lanka which considerably contributing to the GDP and, many people are engaging in tea industry as their occupation in many ways. Tea cultivations is speeded over a vast area of the up country, mid country and low country. Tea is prepared by pouring hot or boiling water over cured leaves of the *Camellia sinensis*, an evergreen shrub native to Asia. After water, it is the most widely consumed beverage in the world. The tea beverage is derived from young shoots harvested frequently during the growing season from tea bushes. The frequency of harvest depends primarily on the temperature, the incidence of drought and the shoot standard as specified by the processor for an identified market.

Traditionally, in most developing countries, harvesters (often locally known as "pluckers") pluck the shoots (typically two or three unfurled leaves and the unopened terminal bud) by hand. This can be a selective and skilful process involving between 140 and 190 individual hand actions per minute. The tea harvesting is mechanized in many South-east Asian countries. They adopted their crops to non - selective large scale harvesters. Most of them are used to harvest tea with minimum labor (Teaman, 2009). The tea harvesting is less mechanized in Sri Lanka due to several reasons: availability of few machines in small scale level such as TRI cutting shear and Japanese non selective tea harvester (Teaman, 2009). Because of their non - selectivity, these machines are not much popular in Sri Lankan tea industry. As the selectivity and efficiency is highly concerned in tea harvesting, mechanization should be oriented in such a way to full fill those requirements.

1.1 Statement of the Problem
Although, tea industry contribute lot, to the GDP of Sri Lanka, still there is no an efficient selective harvester in order to increase the efficiency. As the labor cost is very high and scarcity of skilled labor is highly affected for the production, by introducing an affordable, efficient, durable selective type harvester to the Sri Lankan tea industry, the time taken for the harvesting and labor consumption can be reduced as well as quality of export tea and productivity can be increased.

1.2 Objectives of the Study
The general objective of this study is to introduce a power operated selective tea harvester in order to increase the profitability by reducing the labor involvement and cost. Specific objectives are to design and develop a power operated selective harvester for tea and evaluate the performance of the harvester compared to hand plucking, TRI plucking shear and Japanese non selective tea harvester.

2 Review of Literature
Tea is one of the most popular beverages in the world and consumed by a large number of people. Owing to its increasing demand, tea is considered to be one of the major components of world beverage market. The global market for hot beverages (coffee and tea) is forecasted to reach US$ 69.77 billion in value and 10.57 million tons in volume by the year 2015. Tea cultivation is confined only to certain specific regions of the world due to specific requirements of climate and soil. Majority of the tea producing countries are located in the continent of Asia where China, India, Sri Lanka are the major producers. African tea growing countries are located mostly around the tropical regions where Kenya, Malawi, Rwanda, Tanzania, Uganda are major producers (Hertog and, Kromhout, 1995).

Camellia sinensis is native to mainland China, South and Southeast Asia, but it is today cultivated across the world in tropical and subtropical regions. It is an evergreen shrub or small tree that is usually trimmed to below two meter when cultivated for its leaves. It has a strong taproot. The flowers are yellow-white, 2.5 - 4 cm in diameter, with 7 to 8 petals. The seeds of *Camellia sinensis* and *Camellia oleifera* can be pressed to yield tea oil, a sweetish seasoning and cooking. The leaves are 4-15 cm long and 2-5 cm broad.
The tea leaves of new tea plant are ready for harvesting in five years. The growth of the plant is not uniform throughout the year. The environment where the plant is growing has a great influence in the plant for the production of new buds and leaves and also the number of harvesting. In some places tea have a dormant winter period and a growing season. Harvesting is mostly done by women and each day they are set with a quota or a set amount of leaves to be picked. 30kg per day is the harvesting of an experienced plucker (Green, 2010).

As the first step for the manufacturing of quality Ceylon tea, approximately 300,000 estate workers in Sri Lanka pluck millions of tea leaves by hand every day. What largely counts to maintain the best quality tea in Sri Lanka is that unlike in other countries, where the tea is plucked by machines but in Sri Lanka the tea is handpicked. When the tea is plucked by hand, only the bud and the two leaves are plucked, which have the flavor and aroma (Black tea exports, 2015).

Mechanical harvesting of tea in Central and southern African region and Argentina started mechanizing of tea harvesting in early 1970's. Shortage of labor leads to mechanizing of tea harvesting among the member countries of Tea Research Foundation of Central Africa. South Africa was the first among them to start using machine. Most of the estates tried shear plucking as a part of cost reduction. Majority has banned this method since the productivity was not as expected and the bushes were damaged. In most of the estates hand held machines were used since they are suited for hilly terrain. These machines were single or double man operated (Green, 2010).

The subject, Machine Design is the creation of new and better machines and improving the existing ones. A new better machine is one which is more economical in the overall cost of production and operation. The process of design is long and time consuming one. From the study of existing ideas, a new idea has to be conceived. The idea is then studied keeping in mind its commercial success and given shape and form in the form of drawings. In the preparation of these drawings, care must be taken of unavailability of resources in money, in men and in materials required for the successful completion of the new idea into an actual reality. In designing a machine component, it is necessary to have a good knowledge of many subjects such as Mathematics, Engineering mechanics, Strength of Materials, Theory of Machines, Workshop Processes and Engineering Drawing (Khurmi and, Gupta, 2006).

All possibilities should be evaluated objectively and the most promising ones selected for further consideration. The machine performances are important to know how well the machine does the job to which it is designed for, and whether it is profitable or not. Field capacity and field efficiency are two factors which measure the machine or equipment performances. Field capacity has reference to the time of utilization of machine. It compares the actually spent time in the field and total time spent. Field efficiency gives an idea about wasted time during the field work. It is calculated as percentage. Field capacity has reference to the time and area of utilization of the machine (Roth *et al.,* 1975).

3 Methodology

All the designing and fabricating work was carried out at the Engineering workshop, Department of Agricultural Engineering and Soil Science, Faculty of Agriculture, Rajarata University of Sri Lanka. Evaluation of the performances compare to manual plucking, TRI plucking shear and Japanese non selective type machine were carried out at the experimental tea plots of Tea Research Institute, Rathnapura.

A preliminary study was carried out to determine some important measurements of tea plant in order to get the optimum dimensions for the machine. This study was conducted at the Tea Research Institute, Rathnapura. Determining the optimum shoot height is important because it is helping for selecting the suitable shoots to be plucked by the machine to be applicable for any field. Thickness of the shoot stalks of shoots which are in harvesting level was measured in order to determine the space between teeth of the shoot selector as the thickness of the shoot stalks is very important for the selectivity of the machine according to the selectivity mechanism of this machine. 500g of suitable shoots were collected from different varieties and the average heights of them from the plucking table were taken in order to determine the dimensions of the shoot selector of the machine as the machine should be designed in such a way, which can be avoided plucking of unsuitable shoots. Maximum recorded thickness of the shoot stalks among 500g of suitable shoots taken for the preliminary test was considered as the suitable thickness of the shoot stalks for the designing of the machine.

3.1 Components of the Machine

This machine is consisted of shoots selector, cutter, directing roller, collector, battery and motor. Shoots selector is at the front edge of the machine and the function of it is to prevent entering unsuitable shoots to the cutter. The average shoot height of suitable shoots was used to determine front height of the shoot selector (X). The maximum diameter of suitable shoot stalks was selected as the gap between teeth of the selector (Y). It was made with aluminum as it is non corrosive and light in weight. According to the ergonomic principals and the capacity of the motor, the width of the shoot selector (Z) was determined.

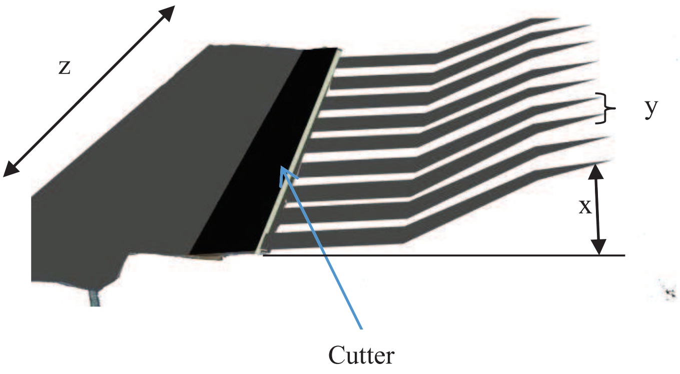

Figure 1: Shoot Selector

The cutter was designed to cut the shoots selected by the shoot selector. It is done by shearing the shoot between cutter - blade and directing roller. The cutter must be non - corrosive, high strength, durable, and facilitated the manufacturing. A stainless steel sharp blade was selected as the cutter. The width of the blade is same as the width of the shoot selector.

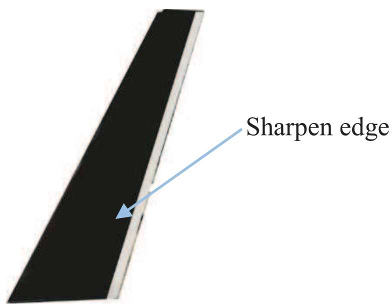

Figure 2: cutter

The directing roller is used to convey all the selected shoots to the cutter and loading cut shoots to the collector. Average height of the mature shoots was used as the designing parameter of this component. This roller is consisted of two plywood wheels, four aluminum connecting tubes, center axel, and rubber sheet. Aluminum vertical tubes have been used in order to minimize the weights. Center axel was fabricated from iron, considering the strength of the conveyor. The width of the conveyor roller was taken as the width of the cutter.

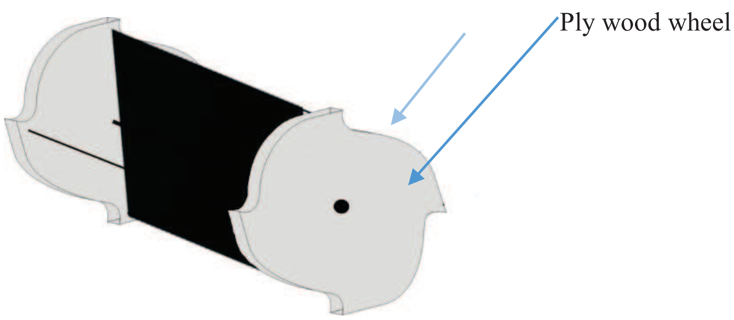

Figure 3: Conveyor roller

The function of the collector is collecting the shoots temporarily after cutting until unloaded to the bag. A thin aluminum sheet was used to fabricate this part in order to keep the weight of the machine at an optimum range. A motor (500 W) operating with three speeds was selected to rotate the directing roller. It was directly coupled with the center shaft of the roller at right hand side. As the power source to operate the motor, a 12V, 7A lead acid batter was selected.

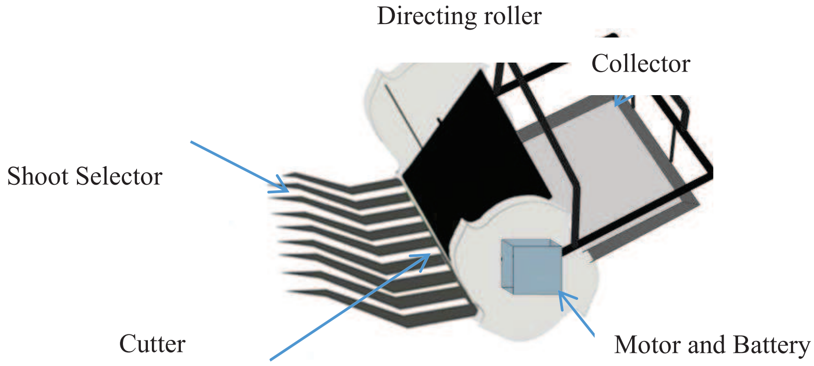

Figure 4 : Drawing of the machine with all components

After the manufacturing process of the prototype, a preliminary trial was carried out to identify the practical problems. After given the required remedies for each identified problem, the machine was tested again for other problems. This procedure was repeated, until the machine reaches to a satisfactory level with minimum practical problems.

After the preliminary trial which carried out to give the required modifications, a proper evaluation was conducted at TRI, Rathnapura. A field with one week after harvesting was selected for the evaluation. Twenty plots were selected and the plot size was 10 m x 2 m as including 25 plants. Four treatments as manual plucking (T_1), newly constructed selective machine (T_2), TRI cutting shear (T_3) and one of the Japanese non selective tea harvesters (Kawasaki) (T_4)were evaluated and five replicates from each treatment were carried out. At each and every trial, time taken to complete a plot, time taken to complete a row, row length, number of suitable leaves on the plucking table before harvesting, number of harvested leaves, number of harvested unsuitable leaves, number of damaged leaves and number of remaining suitable leaves on the plucking table after harvesting were measured.

The theoretical field capacity, actual field capacity, field efficiency, damaged leaves percentage, selectivity and immature leaves harvesting percentage of each method were calculated using following equations. The data from the evaluation was analyzed with the T test using SAS software with $p < 0.05$ significant difference.

$$\text{Theoretical Field Capacity (ha/hr)} = \frac{[\text{Row length (m)} \times \text{Cutting width (m)}]\ 36}{\text{Time taken to complete a row (s)} \times 100} \quad (1)$$

$$\text{Actual Field Capacity (ha/hr)} = \frac{20 \times 36}{\text{Time taken to complete a plot} \times 100} \quad (2)$$

$$\text{Field efficiency (\%)} = \frac{\text{Actual Field Capacity (ha/hr)}}{\text{Theoretical Field Capacity (ha/hr)}} \times 100 \quad (3)$$

$$\text{Damage leaves \%} = \frac{\text{No: of damaged leaves}}{\text{No: of total leaves}} \times 100 \quad (4)$$

$$\text{Selectivity (\%)} = \frac{\text{Number of harvested unsuitable leaves}}{\text{Total number of suitable leaves before harvesting}} \times 100 \quad (5)$$

$$\text{Immature leaf harvesting (\%)} = \frac{\text{Number of harvested unsuitable immature leaves x 100}}{\text{Total number of immature leaves}} \quad (6)$$

4 Results and Discussion

4.1 Preliminary Study

Average suitable shoot height of 100 shoots, 29.5mm was used to determine the front height of the shoot selector. Maximum thickness of 100 suitable shoots, 4mm was used to determine the space between two teeth. According to the results of the preliminary test, shoots which have grown up to 30 mm, considered as immature shoots and above that point, considered as suitable for plucking. As the machine is a selective one, it should be able to select only the mature shoots. Therefore, the front height of the shoot selector should be 30 mm in height. The maximum stalk width of mature shoots has been recorded as 5mm and thinner shoots can be considered as immature and should not be plucked. Therefore, to facilitate the selecting suitable shoots, the gap between two teeth was set as 5 mm. The speed of the motor should be tally with the forward speed of the operator and harvesting rate of the machine. Therefore, adjustability of the motor speed is very important. It helps to reduce the damages to the harvested shoots and reduce the un-harvested suitable shoots on the plucking table. Therefore, the speed of the selected motor can be adjusted at three stages as 50, 65 and 80 rpm.

Since, this machine is a hand held one, the weight of the machine should be at an optimum range in order to meet the ergonomic requirements. But, in this prototype designing, it was somewhat difficult to keep the weight of the machine at a favorable range as some used materials are not very suited with the design. The total weight of the machine was 6.5 kg and this weight can be further reduced by using lighter and standard materials. The width of the machine was 600 mm and it is compatible with other dimensions and facilitates the handling ergonomic principles.

4.2 Fabrication of the Prototype

Dimensions of the machine was finalized as given in the table 1.

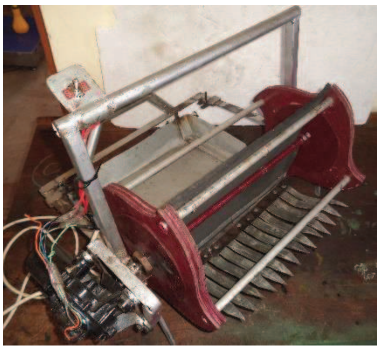

Plate 01: Machine with all components

Table 1. Specifications of the machine

Design parameters	Dimensions
Shoot selector front height	30 mm
Shoot selector distance between pair of teeth	5 mm
Motor speed	50 65 & 80 rpm
Battery	Low weight – 4 kg
Machine weight	Low – 6.5 kg
Machine width	600 mm

4.3 Performance Evaluation of the Machine

Table 2. Comparison with other plucking machines

Methods	Actual field Capacities	Theoretical Field Capacities	Field Efficiencies
Manual plucking	0.014 Ha/hr	0.023 Ha/hr	60.8%,
Newly constructed selective tea harvester	0.021 Ha/hr	0.029 Ha/hr	72%
TRI cutting shear	0.015 Ha/hr	0.023 Ha/hr	65.2%
Japanese non selective tea harvesters	0.026 Ha/hr	0.035 Ha/hr	74.3%

The table 2 shows the field capacities and field efficiencies of four harvesting methods that used for the comparison. According to the experiment, although Japanese non selective tea harvesters (Kawasaki) shows the highest actual field capacity (0.026 ha/hr) and high field efficiency (74.3%), it is coming under non-selective machines and the selectivity of it is very poor. When compare the selective plucking type machines, newly constructed selective tea harvester showed comparatively higher actual field capacity (0.021 ha/hr) than the other types such as hand plucking and TRI cutting shear. In addition to that, newly constructed selective tea harvester shows higher field efficiency of 72% and higher selectivity than manual plucking (60.8%) and TRI cutting shear (65.2%).

After analyzing the results, it was revealed that, there was a significance difference ($p<0.05$) among harvesting methods. Manual type harvesting shows highest selectivity (96.65%) than other methods, as the plucker harvest only suitable shoots in this method. Here, Japanese non selective tea harvesters (Kawasaki) also shows 88.15% selectivity, because of, it harvest all the suitable and non - suitable shoots and the number of non - suitable shoots in the harvest had very low at the experiment. The reason for this is TRI maintain their tea fields in standard manner and there is very low number of unsuitable shoots on the plucking table. TRI cutting shear is considered as a non - selective type harvester, but it also has shown 93.96% selectivity due to the above mentioned reason. It is very important to mention that, although other methods have shown considerable selectivity, newly constructed selective tea harvester is the only machine, with the automatically selecting mechanism with higher selectivity which was recorded as 93.4%.

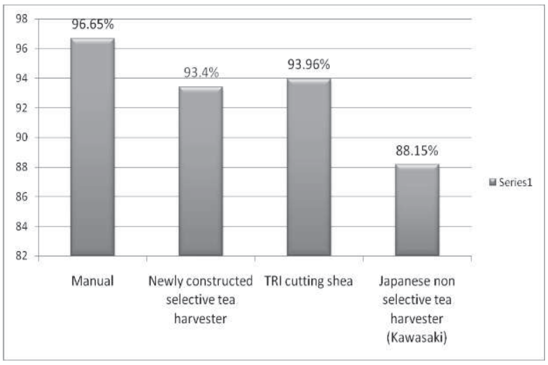

Chart 1: Comparison of tea selectivity

According to the experiment there was a significant difference between four methods ($p<0.05$). Manual harvesting and TRI cutting shear show lowest damage leaves percentage than other methods as19.8% and 19.4% respectively. Other two machines show nearly same damage leaves percentage values. Japanese non selective tea harvesters (Kawasaki), showed high damage leaves percentage due to non selective cutting method. The newly constructed selective tea harvester shows high damage leaves percentage due to drawbacks of cutting system and conveying process.

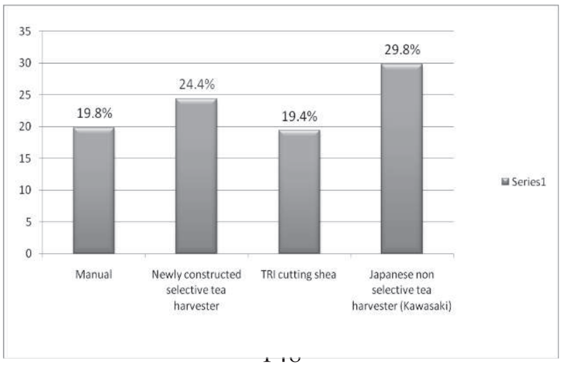

Chart 2: Comparison of damaged leaves percentage

Immature leaves harvesting will reduce the harvest at the next harvesting. Therefore it is a very important parameter of a harvesting machine. According to experiment there was a significantly difference between four method ($p<0.05$). Manual type harvesting shows lowest immature leaves harvesting percentage (3.35%) than other methods while Japanese non selective tea harvesters (Kawasaki) shows the highest (11.85%). Newly constructed selective tea harvester and TRI cutting shear show 6.6% and 6.04% respectively. Newly constructed selective tea harvester also showed a lower immature leaves harvesting percentage due to the controlling of the immature leaves plucking by the height of the shoot selector.

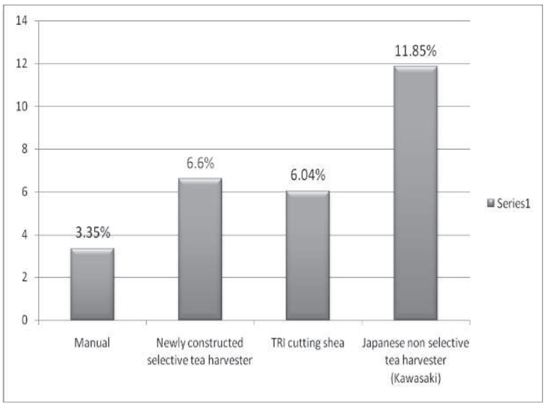

Chart 3: Comparison of immature leaves harvesting percentage

5 Conclusions and Recommendations

According to the results, it can be concluded that newly constructed selective tea harvester, can be effectively used to replace the manual power from tea harvesting activity. The selectivity of the machine is satisfactory and it can be further improved to reach to the selectivity of manual harvesting method. The cutting mechanism of the new tea harvester should be changed or improved, in order to minimize the damaged leaves percentage. But, when it compare with manual harvesting, the damage leaves percentage of the new tea harvester is very low. The weight of the machine should be reduced by using light and standard materials and collection of harvested shoots can be replaced by a pneumatic conveyor in order to minimize the damages.

References

Black tea exports, (2015). Tea Processing, Retrieved on July 10, 2015 from: http://www.ceylonblacktea.com/tea_producing_process.html

Greens, S. (2010). Harvesting Tea leaves – An Ancient Art form, Retrieved on April 23, 2015 from: http://technology.adrpublications.com/index.php/JoARICE/article/view/6

Hertog, M. G., and Kromhout, D. (1995). Flavonoid intake and long-term risk of coronary heart disease and cancer in the seven countries study. Archives of Internal Medicine, 155(4), 381-386.

Khurmi, R. S., and Gupta, J. K. (2006). A Text Book of Machine Design. Eurasia Publishing House (PVT.) LTD, Ram Nagar, New Delhi, pp 341-968.

Roth, L.O., Crow, F.R., and Mahoney, G.W.A. (1975). An Introduction to Agricultural Engineering. AVI Publishing Company Inc.

Teaman, (2009) Introduction to Harvesting or Plucking of Tea Shoots, Retrieved on July 10, 2015 from: http://tea-plucking.blogspot.com