Ergonomic device to harvest Castilla-Blackberry

F Maradei¹, P Franco¹ and J M Castellanos²

¹Universidad Industrial de Santander, Colombia
²Universidad Pontificia Bolivariana, Bucaramanga, Colombia

javier.castellanos@upb.edu.co

Abstract. Agriculture is one of the major economic activities in Colombia, counting for almost 47% of all country exportations. Considering Santander province, Castilla-Blackberry is one the most common agro-alimentary crops in the area (northeastern region of the country), but this particular cultivar presents thorns that rend harvesting difficult and increase the risk for skin or subcutaneous injuries. Other important issues of the harvesting processes are related to a rapid deterioration of the picking gloves, the homogeneous distribution of the fruit throughout the bush and the transportation of the harvested fruits during this activity (total load can be as high as 13 kg). In addition, the pinch gesture used to pick the fruit and the low back strain due to the heavy loads are responsible for hand pain and low back pain in this workers population. This work presents an experimental validation and a theoretical evaluation of a new ergonomic device to harvest Castilla-Blackberry, through a direct comparison with the traditional harvesting method. This new tool looks forward to reducing loads on the low back and to avoid cutaneous cuts. The experimental validation involved seven subjects in a real crop environment. Each participant, picked blackberry fruits in the morning hours, using both traditional elements and the new harvesting device. Meanwhile, posture data (articual angles variation) and hand cuts (gloves wear) were recorded. The new device supports up to 13 kg with a transfer system that reduces the intradiscal load in about 85.13%. Likewise, the pinch gesture was substituted with a supinate natural-hand closing gesture without detriment of the number of harvested fruits. Statistical analysis of trunk flexion does not evidence significant differences between both methods (p-value = 0.92), however, it was found a reduction in trunk flexion when the new device is used on sloping grounds. On the other hand, gloves wear analysis showed a decrease on the number of cuts and the washable materials used in the new device lead to a reduction of the annual use of new gloves in about 96.16%. In conclusion, the new device improves blackberry harvesting when biomechanical and physical risks are considered. Hence, it could be a viable alternative to be implemented in close collaboration with the concerned community, ensuring its appropriation of knowledge and promoting better labor conditions.

1. Introduction
Agriculture has been a worldwide engine that has allow overcome critical states of food shortage, poverty and unemployment, especially in developed countries. In Colombia, a positive expectation has been arisen because annual production of Castilla-Blackberry is about one hundred thousand tons per year [1]. Santander is a region located to the northeastern area of Colombia and it is the second larger blackberry producer of this country [2]. About 90% of the harvesting areas are mainly located in small towns like Piedecuesta, Floridablanca, Charta and Matanza [3]. On the other hand, there is evidence that agricultural activities can produce severe injuries due to postural behaviors, which are adopted by workers while performing harvesting activities. Most of the time, these behaviors cause musculoskeletal pain in back, shoulders, arms and hands; with a high prevalence [4–10]. This state of affairs suggests a worker population -normally smallholders- performing their tasks under painful conditions; unfortunately, 60% of this people are informal workers, which means that most of them do not have health care or security services. This situation exacerbates social problems and negatively compromises the sustainable development of Colombia [11]. Likewise, this country has troubling indicators of...
poverty for this population; 80% of them are smallholders with a very low annual income. Adding a long national social conflict to the overall picture, rural communities are vulnerable and exhibit inadequate standards of living [3].

The blackberry crop is manually harvested all around the Santander region because there are not suited tools to perform this activity. A preliminary work performed by one of the authors back in 2015, revealed that 72 workers in the Piedecuesta municipality exhibited musculoskeletal symptomatology and identified several contributing factors to this pathology. On one hand, features of this cultivar must be taken into consideration: irregular stems, presence of thorns and saw-toothed around the margins leaves rend difficult the harvesting task and increase the risk of skin or subcutaneous injuries. In addition, the pinch gesture to pick the fruit is performed uninterrupted [12]. Besides, this bush can grow as much as 3 meters in height and their fruits grow all over the plant. In consequence, the worker must adopt non neutral postures of the trunk and arms to reach the fruits at different zones (sometimes at the ground level or at the highest part of the bush) [12]. The last will explain the high prevalence reported in the preliminary work; 63.9% of participants alleged low back pain and 49.3% shoulders pain in the previous year.

Likewise, the review of the current technology showed that there are not manual tools for blackberry harvesting. The closest activity is harvesting of Brambleberry and Wild rose hip, where has been used a fruit picker that features a metallic or plastic comb [13]. This manual tool serves to pick and collect all fruits in a particular area at the same time. Afterwards, fruits are transferred to a larger container. Unfortunately, this device cannot be used with blackberries because the bush continuously grows fruits and the harvester must only pick the ripe ones and let the unripe in the plant [1].

On that basis, there is a clear need for technical solutions allowing to reduce pain perception and the possible occurrence of musculoskeletal disorders, while maintaining high levels of productivity. Blackberry harvesting is currently performed by rural communities on a weekly basis all year round, which means that activity demands are constant and repetitive during their entire working life. Consequently, this study looks forward to validating a new Castilla-Blackberry-harvesting system aiming to reduce not only loads on worker’s back but also to avoid cutaneous cuts on his hands.

2. Materials and methods
To verify that the designed system allows reducing back loads and cutaneous cuts in workers, a single factor experiment (A), named “Harvesting system”, was designed; this factor influences two variables: Back load (Y1) and cutaneous cuts (Y2).

2.1. Independent variable description
Factor A is composed by two treatments: “Traditional method” and “New harvesting system”.

- Traditional method. Workers keep a plastic basket in front of their bodies, normally below the hips level, which is held using a riata or a rope on one shoulder and passing behind the back. This container stores the harvested fruit until is full, functioning as an intermediate stock system. The total weight of this set can be as high as 13 kg when the basket is full of fruits. Also, workers use black latex gloves in their hands to avoid being harm by the bush thorns (See Figure 1, left side).
• New harvesting system -SeCura-. The designed system is composed by an intermediate stock subsystem that distributes the load on both hips using two different deposits, hence dividing the total load on both legs. The system also features two gloves made of polymeric materials (See Figure 1, right side).

![Figure 1. Traditional method to harvest Castilla-blackberry (left side) and SeCura system (right side)](image)

2.2. Dependent variables description
The response to the load on the back (Y1) was studied using a biomechanical model of the back for every treatment (Traditional method and SeCura). On first place, the average back flexion was computed for every participant as a function of every treatment. Afterwards, the general average flexion was calculated for every treatment.

Likewise, response Y2 -i.e. cutaneous cuts- was studied by means of the gloves-material wear. Every participant used new gloves at the beginning of the experiment in both treatments.

2.3. Experiment description
Table 1 exhibits the demographic description of 72 Castilla-blackberry harvesters, working in the rural area of Piedecuesta Municipality. The procedure used to determine these anthropometrical data is described in another study of the northeast-region population of Santander [14]. Hence, this work involved participants with the same somatometric features as it is shown in Table 2.

| Workers Population | Gender       | Height (m) | Weight (kg) | BMI   | Dominant hand |
|--------------------|--------------|------------|-------------|-------|---------------|
| N=72               | 55.6% male   | 1.6        | 66.3        | 24.31 | 97% right     |
|                    | 55.4% female |            |             |       | 3% left       |
### Table 2. Demographic description of the participants on this study (April, 2017)

| Study participants | Gender | Height (m) | Weight (kg) | BMI     | Dominant hand |
|--------------------|--------|------------|-------------|---------|---------------|
|                    | M      | 1.7        | 75          | 25.95   | left          |
|                    | M      | 1.7        | 95          | 32.87   | Left          |
|                    | F      | 1.67       | 55          | 19.72   | right         |
| N=7                | F      | 1.68       | 70          | 24.80   | right         |
|                    | F      | 1.64       | 60          | 22.31   | right         |
|                    | F      | 1.58       | 52          | 20.83   | right         |
|                    | M      | 1.7        | 62          | 21.45   | right         |
| Total              |        | 1.667      | 67          | 24      | 72% right     |
|                    |        |            |             |         | 28.5% left    |

As a first step, each participant was informed about the details of the experiment, declaring as well that enrolment in the study was voluntary. Then, participants gave their authorization to make the experiment and to collect data. Immediately before the harvesting activity begins, optical markers were installed to indicate the following points in the sagittal view: Greater trochanter, iliac, acromial, radial and styloid ulnar (See figure 2). In the posterior view, optical markers were installed on the L5 and T12 vertebrae.

The experimentation was performed on a real Castilla-blackberry plantation under real conditions; a video camera was used for recording the harvesting activity in both treatments, while time employed in every test was fixed on three hours.

Flexion and extension of the back were determined using the articular angles indicated by the optical markers by means of an image processing procedure in the Kinovea® Software. Three hours of video per participant were analyzed with a frequency of three frames per second. The load on the back -i.e. on L5-S1 vertebrae- was calculated using the Biomechanical model proposed by Irving Herman [15], which considers that the force exerted by the erector muscle forms a 12 degrees angle with the longitudinal axe of the column (See figure 3). To compute the intradiscal force at different positions during the harvesting process, it was considered that the maximal load of the basket- serving as intermediate stock in the traditional method- was 13 kg. Besides, this weight is supported by the shoulder. On the contrary, there is no load transferred to the back when using SeCura system.

### 3. Results

#### 3.1 Flexion and extension of the back

Descriptive analyses of data show that flexion and extension angles of the back are lower on SeCura, however, there are not significant differences in the flexion angle (p-value = 0.92) or in the extension angle (p-value=0.07). It is important to outline that zero degrees extension and flexion angles were computed with SeCura System, which yields higher standard deviations than the traditional method (See Table 3).
Figure 2. Visual markers location and back flexion angle on one video frame

Figure 3. Biomechanical model used to compute intradiscal loads

Table 3. Comparative results for back flexion and extension angles in both treatments (N=7)

|                  | Traditional Method | SeCura  |
|------------------|--------------------|---------|
|                  | Flexion (°)        | Extension (°) | Flexion (°) | Extension (°) |
| Mean Values      | 14.99              | 6.15    | 14.23       | 2.62          |
| Maximal value    | 29.12              | 9.14    | 48.6        | 9.24          |
| Minimal value    | 4.83               | 2       | 0           | 0             |
| Standard deviation (SD) | 8.3    | 3.1     | 18.0        | 3.6           |
3.2. Intradiscal load on L5-S1 vertebrae

Table 4 shows that intradiscal load on L5-S1 vertebrae is reduced in about 85.13% when harvesters use SeCura system. Likewise, the study reveals significant differences (p-value=0.002) between traditional method and SeCura.

|                      | L5-S1 Intradiscal load (N) |
|----------------------|-----------------------------|
|                      | Traditional Method          | SeCura                    |
| Mean values (13 kg on the back) | 2818.69                     | 419.06                    |
| Maximal value        | 5353.73                     | 1357.7                    |
| Minimal value        | 926.31                      | 0.0                       |
| Standard deviation (SD) | 1508.81                     | 509.93                    |

3.3. Wear of gloves material

Cutaneous cuts were evaluated using gloves wear after three hours of harvesting with both methods.

![Figure 4. Comparison between glove wear for both treatments (SeCure and Traditional method)](image)

Figure 4 shows a graphical comparison between gloves used for each treatment (Traditional method and SeCure). It can be observed wear and big perforations in latex gloves (Traditional method), especially on fingers-tips and dorsal zones. Castilla-blackberry harvesters usually change these gloves every 15 days; however, perforations can appear at the beginning of this interval. On the contrary, SeCure gloves did not undergo perforations and cuts were minimal. Additionally, they have been made of washable materials that allow their reuse for long periods of time. Considering that SeCure gloves are changed once a year, the estimated reduction on current gloves replacement rate is 96.16%.

4. Discussion and conclusions

This work looked forward to evidence whether SeCura system -designed as a tool to harvest Castilla-Blackberry- was able to reduce back load as well as cutaneous cuts in harvesters. According to the ergonomic analysis of the blackberry harvesting activity, there is evidence of musculoskeletal loads in this particular population. Their causes are related to the heavy weight of the basket used as intermediate stock in the traditional method, as well as the presence of thorns all over the blackberry cultivar.

Several studies show that there is strong evidence that lifting of heavy loads and performing movements with loads are associated with an increased risk of low back pain [16]; this pathology occurs
due to the loads on the musculoskeletal system and the adopted postures[17]. In consequence, when the intermediate stock container is no longer supported by the back, loads on the trunk-musculoskeletal system are -as it is shown in this study- immediately reduced.

The designed system avoids additional loads to the back because the harvested fruit and the container weights are directly transferred to the worker’s heaps; this allows to reduce the intradiscal load in about 85.13% when it is compared to the traditional system.

In relation with adopted postures -i.e. flexion and extension of the back- influencing the presence of low back pain[16], this study did not found differences between both treatments (p-value=9.92). Therefore, the weight of the intermediate stock system in the traditional harvesting method and the necessary muscles coactivity to keep equilibrium and support the load [18] are the factors that directly influence the intradiscal load.

Likewise, literature indicates that the maximal load supported by the L5-S1 articulation is 3400N [19]; this study found heavy loads –near to this maximal value- when the traditional method is employed (2819.9N on average). The results obtained agree well with literature, which indicates that a 10 kg load produces internal loads between 2820N and 7260N[20]. Nonetheless, loads computed with SeCura system were 419.06N on average.

Finally, the designed system offers a long-duration reusable glove; when compared with latex gloves use, the annual rotation of the former is 96.16% lower that the latter. This contributes to reduce the environmental impact of wasted latex gloves. Besides, substitution of latex gloves can contribute to reduce other skin pathologies. According to literature, latex contact produces dermatitis and the allergic prevalence to this material is 1% [21]. Many harvesters acknowledge that they do not use this kind of gloves due to this allergic pathology, situation that increases the risk of cutaneous cuts and biological contamination of the harvested fruits.

References
[1] Rativa C M G, Medellín L A C and Trujillo M M P 2016 Rendimiento y calidad de la fruta en mora de Castilla (Rubus glaucus Benth), con y sin espinas, cultivada en campo abierto en Cajicá (Cundinamarca, Colombia) Revista Facultad de Ciencias Básicas 6 24–41
[2] Betancurt E, García E, Giraldo M, Quejada O, Rodriguez H and Arroyave I 2014 Manual técnico del cultivo de maracuyá bajo buenas prácticas agrícolas Servicio Nacional de Aprendizaje (SENA). Medellín-Colombia
[3] Ministerio de Agricultura y Desarrollo Rural 2006 Desarrollo de la fruticultura en Santander
[4] Adams M A, McMillan D W, Green T P and Dolan P 1996 Sustained Loading Generates Stress Concentrations in Lumbar Intervertebral Discs Spine 21 434
[5] Rejoyce S, Dina. A and Arhin A 2013 Occupational health hazards and safety of the informal sector in the metropolitan area of ghana Research on humanities and social science 3 87–99
[6] Grzywacz J G, Arcury T A, Mora D, Anderson A M, Chen H, Rosenbaum D A, Schulz M R and Quandt S A 2012 Work organization and musculoskeletal health: clinical findings from immigrant Latino poultry processing and other manual workers Journal of occupational and environmental medicine 54 995–1001
[7] Hagberg M and Wegman D 1987 Prevalence rates and odds ratios of shoulder-neck diseases in different occupational groups. *Occupational and Environmental Medicine* **44** 602–610

[8] Norman R, Wells R, Neumann P, Frank J, Shannon H, Kerr M and others 1998 A comparison of peak vs cumulative physical work exposure risk factors for the reporting of low back pain in the automotive industry *Clinical biomechanics* **13** 561–573

[9] Pal P, Milosavljevic S, Gregory D E, Carman A B and Callaghan J P 2010 The influence of skill and low back pain on trunk postures and low back loads of shearers *Ergonomics* **53** 65–73

[10] Silverstein B A, Bao S S, Fan Z J, Howard N, Smith C, Spielholz P, Bonauto D and Viikari-Juntura E 2008 Rotator cuff syndrome: personal, work-related psychosocial and physical load factors *Journal of occupational and environmental medicine* **50** 1062–1076

[11] Semana 2012 Los pilares olvidados de la tierra *Revista Semana*

[12] Fathallah F A 2010 Musculoskeletal disorders in labor-intensive agriculture *Applied ergonomics* **41** 738–743

[13] Muñoz O and Cattan M 2007 Equipamiento para la recolección de rosa mosqueta silvestre

[14] Maradei F, Correal F E and Peña A A 2008 Estudio de valores antropométricos para la región nororiental colombiana. *Revista UIS Ingenierías* **7** 153–167

[15] Irving P H 2007 *Physics of the human body* (springer)

[16] Marras W S, Lavender S A, Leurgans S E, Rajulu S L, Allread S W G, Fathallah F A and Ferguson S A 1993 The Role of Dynamic Three-Dimensional Trunk Motion in Occupationally-Related *Spine* **18** 617–628

[17] Bernard B P, Health N I for O S and and Prevention C for D C and 1997 Musculoskeletal disorders and workplace factors: a critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper extremity, and low back *Musculoskeletal disorders and workplace factors: a critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper extremity, and low back*

[18] van Dieën J H, Dekkers J J, Groen V, Toussaint H M and Meijer O G 2001 Within-subject variability in low back load in a repetitively performed, mildly constrained lifting task *Spine* **26** 1799–1804

[19] Arjmand N, Amini M, Shirazi-Adl A, Plamondon A and Parnianpour M 2015 Revised NIOSH Lifting Equation May generate spine loads exceeding recommended limits *International Journal of Industrial Ergonomics* **47** 1–8

[20] González Jemio F, Mustafá Milán O and Antezana Arzabe A 2011 Alteraciones biomecánicas articulares en la obesidad *Gaceta Médica Boliviana* **34** 52–56

[21] Gaspar Carreño M, Arias Pou P, Rodríguez Berges O, Gamundi M and Carbonell Tatay F 2011 Revisión sobre el uso de guantes en los hospitales. *El Farmacéutico Hospitales*