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Effect of Fruit Weight and Fruit Locule Number in Bell Pepper on Industrial Waste and Quality of Roasted Pepper

Marcos Guerra [1], Rosa María Gómez [2], Miguel Ángel Sanz [3], Álvaro Rodríguez-González [4] and Pedro Antonio Casquero [4,*]

1 Research Group of Engineering and Sustainable Agriculture (GUIIAS), School of Agricultural and Forest Engineering (EIAF) (Campus de Ponferrada), Universidad de León, Avenida de Astorga s/n, 24401 Ponferrada, Spain; mgues@unileon.es
2 School of Agricultural and Forest Engineering (EIAF) (Campus de Ponferrada), Universidad de León, Avenida de Astorga s/n, 24401 Ponferrada, Spain; rosamarygomez59@gmail.com
3 Sensory Analysis Laboratory, Agricultural Technological Institute of Castilla and León—Junta de Castilla y León, Ctra. Burgos km 119, 47071 Valladolid, Spain; sancalmi@itacyl.es
4 Research Group of Engineering and Sustainable Agriculture (GUIIAS), Natural Resources Institute (INMARENBIO), School of Agricultural and Forest Engineering (EIAF), Universidad de León, Avenida de Portugal 41, 24071 León, Spain; alrog@unileon.es
* Correspondence: pacasl@unileon.es

Abstract: Bell pepper (*Capsicum annuum* L.), one of the most consumed vegetables worldwide, shows great differences between its diverse varieties. These differences affect the fruit type, size and shape. Food preservation techniques prolong the availability of sweet pepper. Roasted pepper is a product marketed with the European recognition of Protected Geographical Indication 'Pimiento Asado del Bierzo'. The objective of this work was to analyse the effect of the fruit weight and fruit locule number of the industrial fresh pepper on quality and roasted pepper yield. Large trilocular fruits and large tetralocular fruits reached higher roast yield and uniformity than small trilocular fruits. Regardless of fruit locule number and fruit weight, the overall quality of all the samples of roasted pepper was categorised as very good. Large tetralocular and large trilocular fruits are the most appropriate peppers for industrial purposes, whereas small trilocular fruits should be intended for the fresh product market. This easy method of sorting bell pepper fruit attending to fruit weight will decrease the amount of pepper waste in the industrial roasting process (around 18%), while maintaining the high overall quality of the final product. Moreover, the faster peeling of large peppers will also contribute to increasing the productivity of the industrial processing of roasted pepper.

Keywords: pepper locules; fruit weight; overall quality; roast yield; skin peeling; sensory quality

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1. Introduction

Food preservation techniques need to be improved to reduce the losses during harvesting and marketing. These techniques support the provision of enough food for the continuously growing population [1]. The process of roasting prolongs the availability of bell pepper (*Capsicum annuum* L.) as a transformed product in the diet, so pepper can be consumed all year round [2]. Roasted pepper is protected by the European Community regulation as a 'Protected Geographical Indication', 'Pimiento Asado del Bierzo' [3].

Pepper is one of the most consumed vegetables worldwide. Global pepper production in 2020 was estimated at 36.14 million tons cultivated on 2.07 million ha (FAOSTAT). Its nutritional and sensory attributes, its characteristic pungency and aroma, together with a large variety of colours, shapes and sizes, favour the use of peppers in food processing [4–6]. These differences affect, among other characteristics, the fruit type, size and shape [5–7]. According to Ali and Kelly [8], the number of locules of pepper fruits, which is increased by high pre-anthesis temperatures, is an important component of the fruit shape and size.

A wide range of variability in morphology was observed in the transverse sections of pepper varieties, so the plurilocular ovary in *C. annuum* is usually bilocular, trilocular or tetralocular. This heterogeneity in the ovary chambers suggests phylogenetic diversity among these varieties [7].

Plant breeding carried out with industrial pepper considering quality-related criteria was found to be useful to obtain fruit that meet the canning industry requirements, which are an elongated shape and three-loculed (trilocular) or four-loculed (tetralocular) fruits, so 96% of the fruit from the pepper landraces from El Bierzo for roasting had three or four locules [9]. This contributed to achieving higher roast yields and more uniform roasting [10]. However, further research is needed to determine which types of peppers, among those with different shapes and sizes, maximise the roast yield during the roasting process, while maintaining the high quality standards of the final product. Furthermore, it is generally known that the processing of peppers generates a large amount of waste, and agro-industrial waste represents a major challenge for the environment [11]. Thus, increasing the roast yield will decrease the amount of waste from the industrial processing.

The objective of this work was to analyse the effect of size and fruit locule number in industrial fresh pepper on the quality and yield of roasted pepper.

2. Materials and Methods

2.1. Plant Material

As a means of replicating the experiment over space, a bell pepper (*C. annuum* L.) landrace from El Bierzo (León, Spain), 'PB-0012' (selected according to agronomic and fruit quality attributes in collaboration with PGI of 'Pimiento Asado del Bierzo' [2]), classified as C3 pepper type according to Pochard [12], was harvested at three locations in El Bierzo with different soil fertility levels (Table 1). Crop management in the three cultivation sites was according to 'Protected Geographical Indication', 'Pimiento Asado del Bierzo' [3]. The pepper fruit was harvested at commercial maturity in October 2019 from the plants of the three cultivation sites, and then the fruit was classified after harvest into three classes according to fruit weight and fruit locule number. The samples were stored in plastic containers immediately after harvest for 3 days, at 16 °C and 70% relative humidity, in order to improve the sensory quality of roasted pepper in terms of colour [13].

Table 1. Geographical and soil characteristics of the sites where pepper plants were grown.

Site	Geographical Characteristics			Soil Characteristics				
	Lat.	Long.	Alt. (m)	N (g·kg^{-1})	P (mg·kg^{-1})	Ca^{2+} (g·kg^{-1})	Mg^{2+} (g·kg^{-1})	K^+ (g·kg^{-1})
A	42°33′ N	6°35′ W	512	1.9	24.50	1.16	0.13	0.21
B	42°32′ N	6°31′ W	580	2.4	119.14	2.07	0.16	0.30
C	42°33′ N	6°44′ W	455	1.8	62.44	0.36	0.04	0.12

2.2. Experimental Design

The study involved a one-factor experiment regarding morphological characteristics of pepper fruit (3 levels), namely fruit weight and fruit locule number. With the aim of studying the effect of fruit weight and fruit locule number in industrial pepper on quality and yield of roasted pepper, pepper fruit of different weights with different numbers of locules were grouped after harvest into the 3 predominant classes: large (more than 200 g in weight) four-loculed (tetralocular) peppers (1), large three-loculed (trilocular) peppers (2) and small (less than 200 g in weight) trilocular peppers (3) (Figure 1). Since the number of locules per fruit is correlated with the fruit weight [14], it was difficult to find small fruits with 4 locules. Later, the mean weight, length and maximum breadth of the fruit were determined (Table 2).

(a) (b)

(c) (d)

Figure 1. Side view of tetralocular pepper (**a**) and trilocular pepper (**b**), and bottom view of tetralocular pepper (**c**) and trilocular pepper (**d**).

Table 2. Morphological characteristics of industrial fresh pepper.

	Fruit Weight (g)	Range of Fruit Weight (g)	Fruit Length (cm)	Fruit Maximum Breadth (cm)
Large tetralocular fruit	297.1 ± 31.9 a [1]	213–370	13.67 ± 0.42 a	8.62 ± 0.52 a
Large trilocular fruit	280.8 ± 56.8 a	202–360	15.14 ± 1.62 a	8.17 ± 0.46 a
Small trilocular fruit	153.0 ± 21.7 b	120–199	11.19 ± 0.92 b	6.55 ± 0.54 b

[1] Values are expressed as mean ± standard deviation. Means within the same column followed by the same letter are not significantly different at $p < 0.05$ (LSD test).

2.3. Roasting Technique

After harvest, lots of 24 pepper fruit per experimental unit were roasted in a wood-fuelled steel-sheet hob according to the traditional method of roasting used in the El Bierzo region [2]. The sheet hob, a traditional roasting technique, was made up of a 15 mm thickness steel sheet with propane as a fuel source for heating purposes (30 min; 200 °C). The peppers, placed on their sides on the steel sheet, were turned occasionally until they were completely charred all over. After roasting, roast yield before peeling was calculated as the quotient between roasted pepper before peeling weight and fresh pepper weight. Then, the peppers were manually processed by hand in the traditional way, as described by Casquero et al. [13], and roast yield was calculated as the quotient between roasted pepper weight and fresh pepper weight [2]. Ease of skin peeling was evaluated on a 5-point scale (1–5), depending on the ease of peeling, where 1 = very hard to peel; 5 = very easy to peel [9].

2.4. Sensory Analysis

Sensory analyses were carried out in the Agricultural Technological Institute of Castilla and Léon (ITACyL, Valladolid, Spain) following the protocol described in our previous work [2], so sensory descriptors were classified into the categories of appearance, texture, taste and after-taste. Overall quality (OQ) of samples was valued by means of the general quality equation described by Sanz et al. [15].

2.5. Soil Analysis

Soil samples were randomly taken using a soil probe to a depth of 50 cm in each of the cultivation sites. Then, soil cores were mixed to make a composite sample of each cultivation site. Total nitrogen was analysed by the Kjeldahl method. Potassium, calcium and magnesium were estimated by the inductively coupled plasma atomic emission spectroscopy (ICPAES) technique [16]. Phosphorus (Olsen) was determined using the extraction method [17].

2.6. Statistical Analysis

The results were subjected to a one-factor analysis of variance (ANOVA) in a system of randomised blocks with three repetitions. Mean comparisons were performed using the Fisher's Least Significant Difference (LSD) test to examine differences ($p < 0.05$) among the types of fruit with different morphological characteristics. All analyses were performed using SAS software (SAS Institute Inc., Cary, NC, USA).

3. Results

3.1. Morphological Characteristics of Industrial Fresh Pepper

Significant differences among locations were not found for fruit weight, fruit length and fruit maximum breadth (data not shown). However, significant differences among types of pepper were found for morphological characteristics, where the fruit weight, fruit length and fruit maximum breadth of large tetralocular fruits and large trilocular fruits were higher than those for small trilocular fruit (Table 2).

3.2. Roast Yield

Significant differences among types of industrial pepper were not found for roast yield before peeling, so the weight of the samples of the roasted pepper before peeling represented, after roasting, values between 71.7 and 74.0% of the initial weight of the industrial fresh pepper. However, significant differences were found in roast yield (after peeling) among types of pepper, where large tetralocular fruits and large trilocular fruits reached a higher roast yield (46.7 and 47.0%, respectively) than small trilocular fruit (39.7%) (Table 3). In regard to ease of skin peeling, large trilocular fruits peeled more easily (4.0 on a 5-point scale) than small trilocular peppers (2.3 on a 5-point scale).

Table 3. Effect of morphological characteristics of the fruit on roast yield and peeling of roasted pepper.

	Roast Yield before Peeling (%)	Roast Yield after Peeling (%)	Peeling (1–5)
Large tetralocular fruit	72.3 a [1]	46.7 a	3.0 ab
Large trilocular fruit	74.0 a	47.0 a	4.0 ab
Small trilocular fruit	71.7 a	39.7 a	2.3 b

[1] Means within the same column followed by the same letter are not significantly different at $p < 0.05$ (LSD test).

3.3. Sensory Properties

In general, sensory descriptors were not affected by the type of pepper (Table 4). However, sensory descriptor uniformity was influenced by the type of pepper, so large tetralocular fruits and large trilocular fruits reached a higher value for this sensory descriptor (3.33 and 3.50 on a 5-point scale, respectively) in comparison to small trilocular peppers (2.67 on a 5-point scale). Regarding OQ, all three types of pepper obtained a qualification of very good.

Table 4. Effect of morphological characteristics of the fruit on sensory properties of roasted pepper.

Sensory Descriptor	Type of Fruit		
	Large Tetralocular Fruit	Large Trilocular Fruit	Small Trilocular Fruit
Colour	3.58 a [1]	3.75 a	3.42 a
Uniformity	3.33 a	3.50 a	2.67 b
Charred remains	3.42 a	3.42 a	3.79 a
Juice	3.25 a	3.42 a	3.50 a
Seeds	4.42 a	4.46 a	4.33 a
Hardness	2.83 a	2.46 a	2.54 a
Cohesiveness	3.33 a	2.92 a	2.50 a
Bitterness	2.33 a	2.58 a	2.50 a
Smokiness	2.75 a	2.75 a	2.67 a
Overall quality	19.27 a	19.93 a	18.98 a

[1] Means within the same sensory descriptor (row) followed by the same letter are not significantly different at $p < 0.05$ (LSD test).

4. Discussion

Differences in roast yield before peeling were not significant among types of pepper, so weight loss at this stage varied between 26.0% for large trilocular fruits to 28.3% for small trilocular fruits (Table 1). A great part of the weight loss that the pepper fruit underwent before peeling could be attributed to water losses during the heating and roasting of the pepper fruit. However, it should be pointed out that part of the water that the pepper fruit lost during the whole roasting process was held inside the pepper fruit, and it was not released until the fruit was opened during the peeling process. Moreover, water loss is not the only loss that the pepper fruit underwent during the process of roasting, since the roasting of the pericarp of the fruit also contributes to increasing the weight loss during this process.

On the other hand, the greatest loss of weight that the pepper suffered in the whole roasting process happened during the process of peeling. At this stage, not only water (the part of water that the pepper fruit lost during the roasting process but was held inside the pepper fruit), but a great proportion of the vegetal parts of the pepper fruit, which are considered waste, such as the pedicel, skin, seeds, calyx and placenta, were separated from the pericarp, which is the edible part of the pepper fruit. Simonovska at al. [18] estimated the average weight of the stalk to be 10.26% of the whole red hot pepper fruit, whereas Guillen et al. [19] determined that the placenta represents 10% of the fruit in *C. chinense* and *C. baccatum*. Regarding the seeds, the index is 23% in *C. chinense* and 5% in *C. baccatum*. Fernando and Amaratunga [1] pointed out the pericarp as the major component affecting the weight of chili pods, with 48.44% of the total weight of the fruit, whereas Guillen et al. [19] stated that the pericarp represents 63 and 85% of the fruit, for *C. chinense* and *C. baccatum*, respectively.

In our experiment, large peppers, regardless of the number of locules, lost a smaller proportion of their weight compared to small peppers, so small trilocular fruit had the lowest roast yield of all the types of pepper, with only 39.7% of the weight of the fresh pepper contributing to the final product. Thus, large tetralocular fruits and large trilocular fruits achieved around 18% more weight of the final product than small trilocular fruit (46.7 and 47% compared to 39.7%, respectively), which decreased the industrial waste during this process. It is well known that agro-industrial waste represents an increasing global concern [11]. Only in Spain, around 60,000 t of peppers are processed every year, and the solid waste produced accounts for 50–60% of the total processed biomass [20]. Bharath et al. [21] found a highly significant link between the fruit weight of *Capsicum chinense* Jacq. and placenta size, so it appears that small peppers did not lose more weight because they have proportionally larger placentas than large peppers. After peeling, part of the water that the pepper lost during the process, which was held inside the pepper fruit, was finally released from the fruit. According to Raffo et al. [22], water loss in stored peppers is related to the surface-to-volume ratio. Since the fruit surface area/fresh weight ratio is highest in immature fruit, permeance to water vapour of fruit skin and the rate of water loss in bell pepper decreased with the increase in fruit size and ripeness [23]. Water losses during the process of roasting at high-temperature values of around 300 °C [2] may be also related to the surface-to-volume ratio, since large fruit, with a lower surface-to-volume ratio, suffered lower weight losses than small fruit.

Besides weight loss, other aspects such as colour, pungency or aroma are affected during the processing of pepper. The colour, pungency, aroma and nutritional value of chilies are essential factors that make them desirable as a food additive in many parts of the world [24,25]. The red colour of chilies is mainly due to carotenoid pigments [26,27]. Roasting techniques, such as far-infrared radiation, can improve the colour of chili pods and their components [1]. Moreover, Newell et al. [28] and Rodriguez et al. [29] stated that colour development depends on the initial composition of sugars and amino acids and roasting time and temperature. Roasting also causes caramelisation or Maillard browning of the surface of food, which is considered by some as flavour enhancement [29]. Capsaicinoids, which are alkaloid compounds, give the characteristic pungency in hot chili peppers [1]. Among the capsaicinoid components, capsaicin is the most abundant, followed by dihydrocapsaicin and nordihydrocapsaicin [23]. It has been shown that the total phenolic content, capsaicinoids and carotenoids are significantly increased after the grilling of fresh peppers, leading to an increase in the antioxidant activities [30,31]. In the same direction, various studies suggested that cooking methods such as roasting increase the accessibility of carotenoids [32]. Moreover, pepper is one of the most frequently consumed food sources globally, providing significantly greater amounts of bioaccessible, bioactive compounds [33]. Processing methods such as boiling, roasting, drying and frying have been observed to enhance bioaccessibility [34,35]. Cooking methods of food can influence bioactive compounds' bioaccessibility, mainly through changes and disruption of the cell wall structure, leading to the release of these compounds, which implies higher bioaccessibility [35–37].

According to the ease of skin peeling results, the operation of peeling was easier to perform for large trilocular fruits in comparison to small trilocular peppers, so peeling small trilocular peppers meant more time needed for this operation, due to both the more difficult process of peeling itself and the lower yield of small peppers in comparison to large peppers.

As regards uniformity, different approaches have been proven to be effective to increase the value of this sensory descriptor in roasted pepper. Thus, in our previous work [13], higher uniformity was achieved by means of storage, so long-term stored peppers obtained better qualification regarding uniformity in comparison to peppers that were not stored before roasting, since storage allows peppers to reach a similar ripening stage. An improvement in the uniformity of pepper fruit can also be obtained by means of appropriate growing techniques [38]. In the present experiment, small trilocular peppers obtained a lower value of uniformity in comparison to large trilocular fruits and large tetralocular fruits. It would be reasonable to expect that fruit weight at harvest is related to a particular stage of fruit development. Díaz-Pérez et al. [23] found different stages of maturity among pepper fruit harvested with a wide range of sizes. Thus, small fruit, which could be at an earlier stage of development than large fruit, provided a roasted pepper with less uniformity than large fruit. Thus, it seems that the uniformity of peppers in our experiment was achieved thanks to the more advanced stage of ripening in the large peppers in comparison to small peppers, so size/age was the factor that allowed the peppers to achieve higher uniformity.

All the above information regarding the morphological characteristics of the pepper fruit will be useful for growers, so that they can manage pepper plantations to harvest industrial fresh pepper that meets the requirements to improve both the roast yield and quality of roasted pepper. Furthermore, this leads to a decrease in the amount of pepper waste in the industrial roasting process. On the other hand, small trilocular fruit, which will not be appropriate for industrial purposes because of the high industrial waste, should be intended instead for the fresh product market, since they are still categorised as high-quality peppers.

5. Conclusions

The weight of pepper fruit, rather than shape, had the greatest effect on the roast yield of industrial pepper. In view of this, large tetralocular and large trilocular fruits are the most appropriate pepper for industrial purposes, whereas small trilocular fruits should be intended for the fresh product market. This easy approach of sorting pepper fruit attending to fruit weight will decrease the amount of pepper waste in the industrial roasting process (around 18%), while maintaining the high overall quality of the final product. Moreover, the faster peeling of large peppers will also contribute to increasing the productivity of the industrial processing of roasted pepper.

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