Catalan virgin olive oil Protected Designations of Origin. Physicochemical and major sensory attributes

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ABSTRACT

Catalonia, located in the northeast of Spain, comprises five extra virgin olive oil (EVOO) protected designations of origin (PDOs). Despite the proximity between them, these PDOs represent unique pedoclimatic conditions and traditional olive cultivars that are briefly reviewed in the present manuscript. In addition to the compliance with quality standards fixed by product specifications, EVOOs show singular and distinctive composition and sensory profiles. With the aim to describe the characteristics of Catalan EVOOs, their sensory and analytical traits have been reviewed with the support of data collected between 2009-2017 in more than 42 milling facilities from the five Catalan PDOs, within the frame of official surveys launched by the Catalan Government.

Introduction

Catalonia encompasses a region located in the northeast of Spain, and like other European regions, it has a wide diversity of agri-food products, as a result of its environment and traditionally used processing methods. Currently, this area comprises five protected designations of origin (PDOs) of virgin olive oil (VOO). "Les Garrigues" (LG), which was first created as a designation of origin under the name "Borges Blanques" in 1975 [1] and regulated in 1977,[2] was the first ever Catalan PDO of VOO. Its final name “Les Garrigues” was adopted in 1993.[3] “Siurana” (S) was the second PDO to be recognized in 1977.[4] In 1996, both PDOs were registered[5] pursuant to Article 17 of Regulation (EEC) No 2081/92,[6] and successively amended.[7-8] In 2005 and 2008, the European Union recognized the designations “Oli de Terra Alta” (TA)[9] (amended in 2016),[10-11] and “Oli del Baix Ebre-Montsià” (BEM), [12] respectively. The last Catalan PDO to be recognized in 2015 was “Oli de l’Empordà” (E).[13] S and LG PDOs represent the higher production of VOO, ranging between 4.000 and 7.000 tonnes/year, and 1.000 and 5.000 tonnes/year, respectively; while the production of the rest of the Catalan PDOs is in general lower than 300 tonnes/year[14] (**Figure 1**).

Olive cultivars

As in other Mediterranean countries, the olive groves in North-Eastern Spain have a high genetic diversity, including more than 50 varieties,[15] which concentrate close to their area of origin and show a limited geographical dispersion. However, more than 85% of the Catalan production is concentrated in four autochthonous olive cultivars: 'Arbequina' (representing about 50% of the cultivated area), ‘Morrut’, ‘Sevillenca’ and ‘Empeltre’. Secondary cultivars,

such as ‘Farga’, ‘Argudell’, ‘Verdiell’ and ‘Rojal’, account for around 12.5% of the olive groves.[15] ‘Arbequina’ is concentrated in LG and S PDOs, and represents the main cultivar in their VOOs (**Table 1**). ‘Morrut’ and ‘Sevillenca’ are prevalent in BEM PDO, where they are cultivated together with ‘Farga’. In traditional orchards of BEM, there is not a predominance between ‘Morrut’, ‘Sevillenca’ or ‘Farga’, and it is reflected by the varietal composition of the corresponding PDO VOOs (**Table 1**). ‘Empeltre’ is the main cultivar in TA PDO, while ‘Argudell’ is the predominant cultivar in E PDO.

All these Catalan olive cultivars present different pomological and agronomical characteristics (**Table 2**). They comprise early maturation cultivars such as ‘Empeltre’, ‘Sevillenca’ and ‘Farga’ and late maturation ones, such as ‘Morrut’ and ‘Argudell’. Also VOOs obtained from these cultivars, even if influenced by agronomical and technological conditions, harvest year and date, present some typical compositional traits (**Table 2**). ‘Morrut’, ‘Empeltre’ and ‘Rojal’ oils are usually characterized by medium polyphenol content, bitter index and higher oxidative stability, in contrast to oils from ‘Arbequina’, ‘Argudell’, ‘Sevillenca’ and ‘Farga’ that are lower in all those parameters. Moreover, oils obtained from ‘Farga’ olives usually have higher oleic acid and lower linoleic acid content than the rest. [23-24]

Pedoclimatic conditions

Genetic factors linked to the traditional olive cultivars have a relevant effect on the characteristics of PDO for VOOs. There is a large consensus about the role played by soil and climate characteristics on gene expression and, finally, on VOO’s characteristics. On top on this, distinctive pedoclimatic conditions of each PDO region influence the olive groves

production to such an extent that VOOs produced from the variety 'Arbequina' feature different sensory and compositional profiles depending on them being produced in LG or S PDO. Despite the proximity of the geographical areas covered by the Catalan PDOs, particularly those in the South, their pedoclimatic conditions show relevant differences. Geographical differences in soil type, as related to geological, climatic and topographic factors according to the World Reference Base soil classification are listed in **Table 3**. LG and TA areas are dominated by Calcisols (soils with significant accumulation of secondary calcium carbonates, and generally developed in dry areas); while S, BEM and E territories have a higher soil diversity, also including Leptosols (shallow soils over hard rock or gravelly or highly calcareous material), Fluvisols (young soils in alluvial, lacustrine and marine deposits showing layering of the sediments), and Regosols (weakly developed mineral soil in unconsolidated materials). [25]

Regarding the climate, latitude, altitude and mean temperature have been pointed out to be highly correlated with some VOO compositional features, such as fatty acids and total polyphenol content.[26] Catalan PDO regions present differences in altitude, rainfall and temperature (**Table 3**). Inland regions such as LG and TA present higher mean altitude and temperature span (as the difference between mean temperature during the warmest and the coldest months) and lower mean temperature. On the other hand, in coastal areas mean temperatures are slightly higher and, particularly in BEM and E, altitude and temperature spans are lower.[27-28] Likewise, annual rainfall is scarce in LG and progressively more abundant in BEM, S, TA and E, respectively.[27]

Characteristics of Catalan PDOs EVOOs according to product specifications

Both the production process and EVOO characteristics of each PDO must comply with the corresponding product specifications.[16-21] **Table 1** summarizes the main characteristics of each PDO production. The olive cultivars used in each PDO that reflect the composition of the traditional olive groves, together with the processing operations determine the quality and the uniqueness of each EVOO. In many cases, the quality level required to be considered within a PDO designation is slightly higher than that fixed by EU Regulation for EVOOs,[29] as occurs for free acidity, peroxide value or absorption at 270 or 232 nm. The most recent PDOs include a more detailed list of characteristics to define their VOOs, comprising fatty acid composition and numerical sensory scores[30-32] , and all the PDOs define some typical secondary attributes[33,34] (**Table 1**). However, and despite the mentioned specifications guaranteeing certain quality and typical traits of PDO EVOOs, these attributes on their own do not allow the description of the features these products have.

With the aim to describe the characteristics of Catalan EVOOs, sensory and analytical traits of these EVOOs have been reviewed below. Data were collected in the period 2009-2017 within the frame of official surveys launched by the Catalan Government and implemented by the Institut de Recerca i Tecnologia Agroalimentària (IRTA). [35] Controls and sampling were carried out in technical visits to more than 42 milling facilities from the five Catalan PDOs, allowing the characterization of up to 98 samples from BEM, 179 from E, 494 from LG, 302 from S and 87 from TA geographical regions. Physicochemical indices, fatty acid composition, colour and sensory profile were the parameters monitored in Catalan VOOs.

Physicochemical and sensory characteristics of EVOOs produced in Catalan PDO regions

Figure 2 shows the evolution of physicochemical quality indices EVOOs produced in four PDO geographical areas in Catalonia during the period 2009-2017. Although some fluctuation occurs depending on the crop year, these indices are usually far below the maximum value established for EVOO by EU Regulation,[29] particularly concerning the peroxide value and free acidity. The slightly higher acidity values for BEM and E could be related to the higher prevalence of olive fly and anthracnose in these areas.

Regarding EVOO sensory attributes, geographical area and harvesting year have a relevant influence on both gustative/tactile attributes, such as bitter, pungent and astringent (mouthfeel associated to the presence of polar phenolic compounds[36]) ; and aroma notes, such as fruity and green (**Figure 3**). As expected, bitter, pungent and astringent attributes - which are all linked to the presence of phenolic compounds- show similar trends as related to the harvesting year. The influence of water availability on phenolic content in plant tissues is well known, and the negative effect of accumulated rainfall on EVOO phenols' concentration has been specifically described in LG EVOOs.[37-38] According to Romero et al.,[37] secoiridoid compounds in LG may range between 100 and 270 mg kg^{-1} and between 80 and 215 mg kg^{-1} depending on the crop season in early harvest and late harvest oils, respectively. According to this, the highest values of bitter, pungent and astringent attributes in LG, S, TA and BEM EVOOs correspond to seasons 2009, 2016 and 2017 (**Figure 3**), characterized by scarce rainfall and higher annual temperatures. [27] EVOOs produced in seasons 2010, 2013 and 2014 (with more rains and lower mean temperatures)[27] showed the lowest intensities of these attributes. The evolution of these parameters is different in

140 oils from E, probably due to the singular pluviometry pattern of this geographical area, which
141 presented a higher accumulated rainfall in 2010 and 2011 seasons. [27]
142 The intensity of fruity attribute ranges usually between 4 and 6, and in LG and S it seems to
143 be less influenced by the crop season than in BEM and E (**Figure 3**). In some cases, the fruity
144 note in EVOOs shows the same trend than the bitter attribute. Fruity notes are mainly given
145 by volatile compounds produced by the lipoxygenase pathway during the oil extraction,
146 which are related to cultivar, pedoclimatic and technological conditions.[39,40]
147 The official panel of Catalonia has developed an algorithm that allows calculating a global
148 sensory score based on the panel output.[30,31] This global sensory score, based on the
149 median intensities of VOO sensory attributes, and expressed on a scale from 0 to 9,, is
150 included in BEM PDO specifications (**Table 1**)The global sensory score evaluated in PDO
151 EVOOs produced in the period 2009-2017 tends to be quite constant around 7 points,
152 regardless the crop season.
153 Secondary sensory notes contribute to define PDO EVOO characteristic traits. The official
154 tasting panel from Catalonia includes an open descriptor called “other positive attributes” in
155 the profile sheet, where sensory descriptors identified by more than 33% of the sensory
156 assessors are listed.[35] Aroma attributes such as ripe and green fruity are usually present in
157 EVOOs of all the PDO under evaluation, with a prevalence of the green (detected by over
158 70% of the assessors) over the ripe note (detected by less than 33% to 50% of the assessors),
159 in particular in BEM oils (**Figure 4**). Likewise, the median of the assessors detecting the ‘grass’
160 attribute is usually over 33% in all the PDOs, in particular in BEM and E EVOOs, while BEM
161 oils present more frequently the ‘artichoke’ attribute. These results might be due to the main

cultivars used in these regions. Two of the three main cultivars from BEM ('Morrut' and 'Farga') are described as greener in aroma than the third ('Sevillenca'), whereas 'Arbequina', the main olive cultivar in S, is described as less green.[41]

In most of the cases, the production of EVOO takes place from October to January, and the harvest date can play a relevant role on some of the oil characteristics. In particular, the date of production in each geographical area can influence EVOO sensory profile (**Figure 5**). The intensity of fruity and green notes show slightly decreasing trends in EVOO produced in LG and S regions, as related to the harvest date, in favour of ripe fruity note. As well, bitter intensity tends to decrease throughout the crop season and with the increase of the olive fruit ripeness, as previously reported. [42]

EVOO colour, resulting from the composition in chlorophylls and carotenoids, also depends on olive cultivar and pedoclimatic conditions, and it is expected to vary according to the PDO. Colour characteristics were determined by applying the CIELAB colorimetric system.[43] S and BEM oils are characterized by lower values of *a* (-10.26 and -10.53, respectively), indicating a stronger green colour and higher levels of chlorophylls,[44] in contrast to LG and E (-8.92and -7.27, respectively) (**Figure 6**). The highest and lower medians of *b*, related to the yellow colour given by carotenoids, [44] were found in BEM (106.04) and E (110.03), and in TA (63.03) EVOOs, respectively. The latter are characterized by a higher luminosity (*L*) (94.62), probably due to a lower total pigment content. Reported values of total chlorophylls and carotenoids in LG EVOOs range between 0.8-9.2 mg kg^{-1} and 2.3-9.6 mg kg^{-1}, respectively. These values are similar to those reported for other Spanish VOOs, depending on the maturity index of olive fruits. [45,46]

184 Geographical factors not only affect physicochemical parameters and sensory profile, but
185 they can also have an impact on EVOO major compounds. This can be observed as fatty acid
186 composition of EVOOs produced in the different PDO regions differ in most of the cases
187 (**Table 4**). In particular, it can be stressed that even EVOOs produced from the same
188 'Arbequina' cultivar in the neighbour regions LG and S present significant differences.
189
190 Physical, chemical, and sensory features in particular are factors conditioning consumer
191 preferences, and allow distinguishing EVOOs produced in specific PDOs. Although EVOO
192 traits may vary with the crop year and the fruit ripening, the genetic, pedoclimatic and
193 processing factors are crucial in the definition of strict EVOO characteristics. Catalan PDO oils
194 -obtained from six main olive cultivars grown under specific and distinctive pedoclimatic
195 conditions- present typical composition and sensory profiles that allow their differentiation.
196 A more detailed knowledge of the characteristics of differentiated-quality productions
197 would favour their valorisation and protection, improving their image and increasing the
198 consumer confidence. For this reason, further studies to objectively define the
199 characteristics of PDO oils would be desirable.
200
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References

[1] ORDEN de 28 de octubre de 1975 por la que se reconoce la denominación de origen Borjas Blancas. BOE No 278 de 20 de noviembre de 1975.

[2] ORDEN de 10 de mayo de 1977 por la que se reglamenta la Denominación de Origen "Borjas blancas" y su Consejo regulador. BOE No 166 de 13 de julio de 1977.

[3] ORDRE de 9 d'agost 1993, per la qual es canvia el nom Denominación d'Origen Borges Blanques pel de Denominació d'Origen les Garrigues. DOGC No 1784 de 16 d'agost de 1993.

[4] ORDEN de 21 de julio de 1977 sobre reconocimiento de la Denominación de Origen "Siurana". BOE No 218 de 12 de septiembre de 1977.

[5] Commission Regulation (EC) No 1107/96 of 12 June 1996 on the registration of geographical indications and designations of origin under the procedure laid down in Article 17 of Council Regulation (EEC) No 2081 / 92.

[6] Council Regulation (EEC) No. 2081/92 of 14 July 1992 on the protection of geographical indications and designations of origin for agricultural products and foodstuffs

[7] Commission Regulation (EC) No 1902/2004 of 29 October 2004 amending the specification of a name appearing in the Annex to Regulation (EC) No 1107/96 on the registration of geographical indications and designations of origin (Les Garrigues)

[8] Commission Regulation (EC) No 2156/2005 of 23 December 2005 amending the specification of a protected designation of origin listed in the Annex to Regulation (EC) No 1107/96 (Siurana) (PDO)

[9] Commission Regulation (EC) No 205/2005 of 4 February 2005 supplementing the Annex to Regulation (EC) No 2400/96 on the entry of certain names in the Register of protected designations of origin and protected geographical indications (Valdemone — [PDO], Queso Ibores — [PDO], Pera de Jumilla — [PDO], Aceite de Terra Alta or Oli de Terra Alta — [PDO], Sierra de Cádiz — [PDO], Requeijão Serra da Estrela — [PDO], Zafferano dell'Aquila — [PDO], Zafferano di San Gimignano — [PDO], Mantecadas de Astorga — [PGI] and Pan de Cea — [PGI])

[10] Publication of an amendment application pursuant to Article 50(2)(a) of Regulation (EU) No 1151/2012 of the European Parliament and of the Council on quality schemes for agricultural products and foodstuffs (2016/C 291/10)

[11] Commission Implementing Regulation (EU) 2016/2212 of 6 December 2016 approving non-minor amendments to the specification for a name entered in the register of protected designations of origin and protected geographical indications (Aceite de Terra Alta/Oli de Terra Alta (PDO))

[12] Commission Regulation (EC) No 112/2008 of 6 February 2008 registering certain names in the Register of protected designations of origin and protected geographical indications (Nošovické kysané zelí (PDO), Pardubický perník (PGI), Aceite del Baix Ebre-Montsià or Oli del Baix Ebre-Montsià (PDO))

[13] Commission implementing Regulation (EU) 2015/385 of 3 March 2015 entering a name in the register of protected designations of origin and protected geographical indications [Oli de l'Empordà/Aceite de L'Empordà (PDO)]

[14] Generalitat de Catalunya, Departament d'Agricultura, Ramaderia, Pesca i Alimentació. Productes amb el reconeixement comunitari de DOP. Available at: http://agricultura.gencat.cat/ca/ambits/alimentacio/distintius-origen-qualitat-agroalimentaria/dop/productes-reconeixement-comunitari/ (accessed July 2018)

[15] A. Ninot, W. Howad, J.F. Hermoso, E. Martí, M. Rovira, I. Batlle, A. Romero, *Revista de Fruticultura* **2017**, *56*, 14.

[16] Expediente de la Denominación de Origen "Les Garrigues", available at Departament d'Agricultura, Ramaderia, Pesca, Alimentació i Medi Natural – Generalitat de Catalunya: http://agricultura.gencat.cat/web/.content/al_alimentacio/al02_qualitat_alimentaria/normativa-dop-igp/plecs-vigor/pliego_condiciones_ue_dop_les_garrigues.pdf (accessed july 2018)

[17] Expediente de la Denominación de Origen "Siurana", available at Departament d'Agricultura, Ramaderia, Pesca, Alimentació i Medi Natural – Generalitat de Catalunya: http://agricultura.gencat.cat/web/.content/al_alimentacio/al02_qualitat_alimentaria/normativa-dop-igp/plecs-vigor/pliego_condiciones_siurana_inicial.pdf (accessed july 2018)

[18] Solicitud de modificación de un pliego de condiciones. Denominación de Origen "Siurana", available at Departament d'Agricultura, Ramaderia, Pesca, Alimentació i Medi Natural – Generalitat de Catalunya: http://agricultura.gencat.cat/web/.content/al_alimentacio/al02_qualitat_alimentaria/normativa-dop-igp/plecs-vigor/dop_siurana_pliegocondiciones_ampliacion_territorial.pdf (accessed july 2018)

[19] Pliego de condiciones de la denominación de origen protegida “Oli de Terra Alta” / “Aceite de Terra Alta”, available at Departament d’Agricultura, Ramaderia, Pesca, Alimentació i Medi Natural – Generalitat de Catalunya: http://gencat.cat/alimentacio/pliego-aceite-terra-alta/pliego_condiciones_aceite_terra_alta_modificacion.pdf (accessed july 2018)

[20] Pliego de condiciones de la denominación de origen protegida "Aceite del Baix Ebre - Montsià" u "Oli del Baix Ebre - Montsià"”, available at Departament d’Agricultura, Ramaderia, Pesca, Alimentació i Medi Natural – Generalitat de Catalunya: http://agricultura.gencat.cat/web/.content/al_alimentacio/al02_qualitat_alimentaria/normativa-dop-igp/plecs-vigor/pliego_condiciones_UE_oli_BEM.pdf (accessed july 2018)

[21] Pliego de condiciones de la denominación de origen protegida "Oli de l’Empordà”-“Aceite de l’Empordà”, available at Departament d’Agricultura, Ramaderia, Pesca, Alimentació i Medi Natural – Generalitat de Catalunya: http://gencat.cat/alimentacio/modificacio-plec-oli-emporda/plec-condicions-modificacio-enviar-ue-03-2017.pdf (accessed july 2018)

[22] J. Tous, A. Romero, J.F. Hermoso, In *Los aceites de oliva de Cataluña*, (Eds: J. Boatella, J. Contreras), Edicions 62, Barcelona, Spain, **2008**.

[23] A. Ninot, J.F. Hermoso, E. Martí, M. Rovira, I. Batlle, A. Romero, In *L’oli d’oliva a Catalunya. Dossier tècnic nº 80 Generalitat de Catalunya*, **2015**. Available at: https://ruralcat.gencat.cat/documents/20181/160840/DLFE-38201.pdf/606b0378-2b45-4b78-9971-adf84fa5bbe4 (accessed july 2018)

[24] A. Ninot, J.F. Hermoso, A. Romero, I. Batlle, *J. of the Amer. Pomological Soc.* **2018,** *72,* 21.

[25] Soil Atlas of Europe, European Soil Bureau Network. European Commission, Office for Official Publications of the European Communities, L-2995 Luxembourg, **2005**. Available at: https://esdac.jrc.ec.europa.eu/Projects/Soil_Atlas/Download/Atlas.pdf (Accessed July 2018)

[26] R. Aparicio, G. Luna, *Eur. J. Lipid Sci. Technol.* **2002**, *104,* 614

[27] Idescat. Anuari estadístic de Catalunya. Available at: https://www.idescat.cat/pub/?id=aec&n=124 (Accessed July 2018)

[28] Atles Climàtic de Catalunya 1961-1990, Barcelona: Departament de Medi Ambient i Institut Cartogràfic de Catalunya, **1997**. Available at: http://www.meteo.cat/climatologia/atles_climatic/ (Accessed July 2018)

[29] Commission Regulation (EEC) No 2568/91 of 11 July 1991 on the characteristics of olive oil and olive-residue oil and on the relevant methods of analysis and subsequent modifications, and subsequent modifications.

[30] A. Romero, A. Calvo, J. Tous, Uso de muestras de referencia para verificar la fiabilidad de un panel de cata de aceites acreditado por ISOP17025. **2009**, V IBEROLAB-2009. Available at: http://www.iberolab.org/opencms/opencms/congreso/IberolabV2009/Comunicaciones/comunicaciones2.html (accessed October 2018)

[31] A. Romero, Caracterización y diferenciación de los aceites vírgenes de oliva de la comarca del Priorat (Tarragona), dentro del mercado global de aceites de la variedad 'Arbequina', PhD Thesis, 2011. Available at: https://www.tdx.cat/bitstream/handle/10803/77835/Tjra1de1.pdf?sequence=1&isAllowed=y (accessed october 2018).

[32] Commission implementing Regulation (EU) 2016/1227 of 27 July 2016 amending Regulation (EEC) No 2568/91 on the characteristics of olive oil and olive-residue oil and on the relevant methods of analysis

[33] COI/T.20/Doc. no. 22, November 2005. Method for the organoleptic assessment of extra virgin olive oil applying to use a designation of origin.

[34] A. Romero, A. Claret, L. Guerrero, In *Olive oil sensory science* (Eds: E. Monteleone, S. Langstaff), John Wiley & Sons Ltd, Oxford, UK, **2014.**

[35] A. Romero, E. Marti, J.F. Hermoso, J. Tous, *Vida Rural*, **2011**, *334*, 14

[36] M. Servili, S. Esposto, R. Fabiani, S. Urbani, A. Taticchi, F. Mariucci, R. Selvaggini, G. F. Montedoro, Inflammopharmacology, **2009**, *17*, 76.

[37] M.P. Romero, M.J. Tovar, T. Ramo, M.J. Motilva, *JAOCS,* **2003**, *80*, 423

[38] M.P. Romero, M.J. Motilva, In *Olives and Olive Oil in Health and Disease Prevention (Eds:* Victor R. Preedy and Ronald Ross Watson), Elsevier, Academic Press, London, UK, **2010***.*

[39] F. Angerosa, *Eur. J. Lipid Sci. Technol*., **2002**, *104*, 639.

[40] P. Reboredo-Rodríguez, C. Gonzalez-Barreiro, B. Cancho-Grande, J. Simal-Gandara, *J. Agric. Food Chem.*, **2013**, *61*, 5252.
[41] A. Romero, J. Tous, L. Guerrero, In *Variedades del olivo en España (Libro II: variabilidad y selección),* (Eds: L. Rallo, D. Barranco, J.M. Caballero, C. Del Río, A.Martín, J. Tous, I. Trujillo) Ediciones Mundi-Prensa, Madrid, Spain, **2004**.

[42] J.R. Morelló, M.P. Romero, M.J. Motilva, *J. Agric. Food Chem*. **2004,** *52,* 6002.

[43] S. Vichi, A. Romero, J. Tous, J. Caixach, *J. Agric. Food Chem*. **2011,** *59,* 4705.

[44] M.N. Criado, M.P. Romero, M. Casanovas, M.J. Motilva, *Food Chem*. **2008,** *52,* 873.

[45] G. Beltrán, M.P. Aguilera, C. Del Rio, S. Sánchez, L. Martínez, *Food Chem*. **2005,** *89,* 207.
[46] A.M. Inarejos-García, S. Gómez-Alonso, G. Fregapane, M.D. Salvador, Food Res. Int. **2013**, *50*, 250.

Figure legend

Figure 1. Annual producion of VOO with PDO (tonnes VOO/year) 2009-2016. Data provided by Generalitat de Catalunya.[14]

Figure 2. Physicochemical quality indices of EVOOs produced in four PDO geographical areas in Catalonia during the period 2009-2017. Median values for each geographical zone and significance of the differences between them calculated by Kruskal-Wallis test (different letters indicate significant differences according to pairwise comparisons). The statistical significance of the differences according to the crop year within each zone is also indicated (*p* values). LG: "Les Garrigues"; S: "Siurana"; BEM: "Oli del Baix Ebre-Montsià"; E: "Oli de l'Empordà". The upper line in the graphics indicates the maximum value established for EVOO by EU Regulation.[28]

Figure 3. Principal sensory attributes of EVOOs produced in four PDO geographical areas in Catalonia during the period 2009-2017. Median values of sensory scores for EVOOs of each geographical zone and significance of the differences between them calculated by Kruskal-Wallis test (different letters indicate significant differences according to pairwise comparisons). The statistical significance of the differences according to the crop year within each zone is also indicated (*p* values). LG: "Les Garrigues"; S: "Siurana"; BEM: "Oli del Baix Ebre-Montsià"; E: "Oli de l'Empordà".

Figure 4. Secondary sensory attributes of EVOOs produced in four PDO geographical areas in Catalonia during the period 2009-2017, expressed as the percent of sensory assessors able to perceive the note. The statistical significance of the differences (*p* values) according to the geographical zone calculated by Kruskal-Wallis test is also indicated (different letters indicate

412 significant differences according to pairwise comparisons). The line in the graphics indicates
413 the 33% of assessors perceiving the sensory note. LG: “Les Garrigues”; S: “Siurana”; BEM:
414 “Oli del Baix Ebre-Montsià”; E: “Oli de l’Empordà”.

415 **Figure 5.** Values of fruity, green, bitter (as median of the intensity), ripe fruity (as the percent
416 of sensory assessors able to perceive the note) according to the harvesting period (EVOO
417 produced in four PDO geographical areas in 2009-2017). The statistical significance of the
418 differences (*p* values) according to the harvesting month calculated by Kruskal-Wallis test is
419 also indicated (different letters indicate significant differences according to pairwise
420 comparisons). LG: “Les Garrigues”; S: “Siurana”; BEM: “Oli del Baix Ebre-Montsià”; E: “Oli de
421 l’Empordà”.

422 **Figure 6.** Chromatic ordinates of EVOO produced in Catalan PDO geographical areas in 2014-
423 2015). Values of a*, b* and L for EVOOs of each geographical zone and significance of the
424 differences between them calculated by Kruskal-Wallis test (different letters indicate
425 significant differences according to pairwise comparisons). The statistical significance of the
426 differences according to the geographical zone is also indicated (*p* values).. LG: “Les
427 Garrigues”; S: “Siurana”; BEM: “Oli del Baix Ebre-Montsià”; E: “Oli de l’Empordà”.

428

Table 1. Characteristics of EVOOs produced in Catalan PDOs and some production conditions as reported by the product specifications [12-17]

	Les Garrigues (LG) [16]	Siurana (S)[17-18]	Oli de Terra Alta(TA)[19]	Oli del Baix Ebre-Montsià (BEM)[20]	Oli de l'Empordà (E)[21]
Olive cultivar	'Arbequina' ≥ 90% 'Verdiell'	'Arbequina' ≥ 90% 'Rojal' 'Morrut'	'Empeltre' (main cultivar) 'Arbequina' 'Morrut' 'Farga'	'Morrut' 'Sevillenca' 'Farga'	'Argudell' ≥ 51% 'Argudell'+'Arbequina' ≥95% 'Curivell' 'Llei de Cadaqués'
Orchard density	100-120 trees/Ha	125-300 trees/Ha		70-200 trees/Ha	100-500 trees/Ha
Irrigation	-	Partially irrigated	Mainly rain-fed	Mainly rain-fed	Mainly rain-fed
Harvesting system	Hand-picked olives	Hand-picked olives; trunk shakers; inverted umbrella	Hand-picked olives; trunk shakers	Hand-picked olives; trunk shakers; inverted umbrella	Stick shaker; harvesting net; trunk shakers
Fruit crushing		Within 48 h	Within 48 h	Within 48 h	Within 48 h
Acidity (% oleic acid)	< 0.5	< 0.5	≤ 0.5	≤ 0.8	≤ 0.8
Peroxide value (mEq O_2/kg)	≤ 15	≤ 15	≤ 18	≤ 18	≤ 20
K270	≤ 0.15	≤ 0.15	≤ 0.20	≤ 0.20	≤ 0.22
K232	-	-	≤ 2.50	≤ 2.00	≤ 2.50
Moisture (%)	≤ 0.1	≤ 0.1	-	≤ 0.2	-
Impurities (%)	≤ 0.1	≤ 0.1	-	≤ 0.1	-
Stability-Rancimat 120ºC (h)	-	-	-	-	≥ 6; mean: 9
Oleic acid (%)	-	-	-	-	Mean: 67 (Range: 60-75)
Linoleic acid (%)	-	-	-	-	Mean: 13 (Range: 8-18)
Palmitic acid (%)	-	-	-	-	Mean: 14 (Range: 11-18)
Global sensory score[a]	-	-	-	6.5	-
Fruity	Fruity (INS[b])	Fruity (INS)	≥ 2.5 (median of intensity)	Fruity (INS)	Green; medium or robust[c]; mean: 5 (range: 4-7)[c]
Bitter	Bitter (INS); Sweet (LHO [d])	Bitter (INS); Sweet (LHO)	≤ 6 (median of intensity)	medium intensity[c]	medium; mean: 4 (range: 3-6)[c]
Pungent	-	-	≤ 6 (median of intensity)	medium intensity[c]	medium; mean: 4 (range: 3-6)[c]
Astringency	-	-	-	medium intensity	-
Balance[c]	-	-	-	-	Well balanced[c]
Secondary attributes[e]	Almond (EHO [f])	Almond (EHO)	Almond; walnut	Rich in green secondary attributes (not specified)	Cut grass; walnut; tropical fruits; green fruits; artichoke; almond

Colour	greenish (EHO) to yellow (LHO)	greenish (EHO) to yellow (LHO)	Green or greenish yellow (EHO) to pale yellow or old gold (LHO)	Greenish yellow (EHO) to golden yellow (LHO)	-

[a]: global sensory score, on a 0-9 scale, estimated by the official panel of Catalonia by means of an algorithm based on the panel's outputs, according to Romero et al.; [30,31] [b] intensity not specified;[c]: according to EU Regulation 2016/1227; [32] [d]: late harvest oils; [e]: according to IOC document COI/T.20/Doc. no. 22, 2005; [33] [f]: early harvest oils

Table 2. Agronomical and pomological characteristics of the principal olive cultivars in Northeastern Spain and some compositional characteristics of the corresponding VOOs. [22-24]

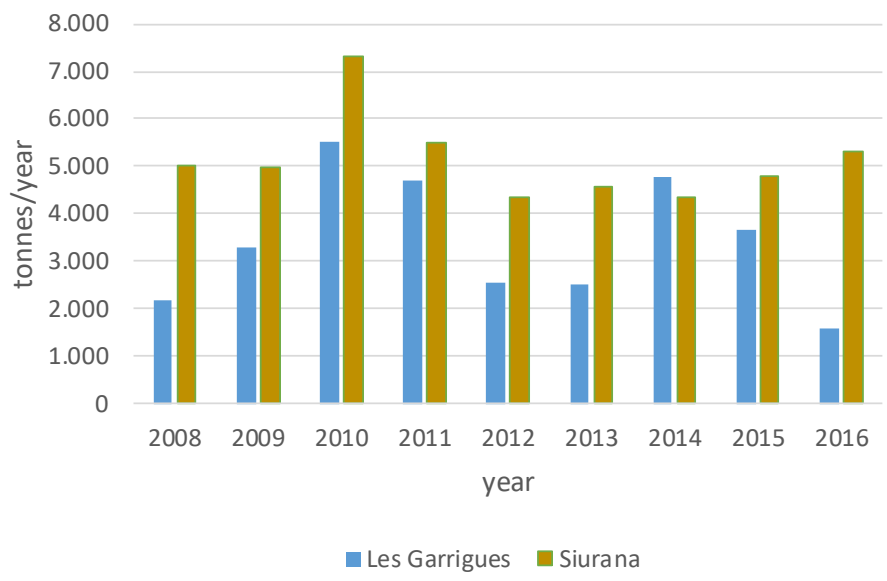
	'Arbequina'	'Morrut'	'Sevillenca'	'Empeltre'	'Farga'	'Argudell'	'Rojal'
Fruit maturation	Medium	Late	Early	Very early	Early	Medium-late	Medium
Fruit size (g)	1.2	3.0	2.9	3.1	2.0	2.2	1.9
Pulp/stone ratio	3.4	3.7	4.6	5.5	3.0	5.6	4.6
Total polyphenols (mg/kg of caffeic acid)	228	348	182	339	202	301	290
Bitter index (K_{225})	0.185	0.251	0.158	0.399	0.147	0.312	0.227
Stability-Rancimat 120ºC (h)	7.2	6.7	4.5	10.3	17.5	9.1	5.9

Table 3. Some pedoclimatic characteristics of Catalan PDO regions.

	Les Garrigues (LG)	Siurana (S)	Oli de Terra Alta (TA)	Oli del Baix Ebre-Montsià (BEM)	Oli de l'Empordà (E)
Soil type [25]	Calcisol	Leptosol. Fluvisol. Regosol	Calcisol	Leptosol. Fluvisol. Regosol	Leptosol. Fluvisol. Regosol
Mean altitude (m)[27]	405	190	515	91	76
Annual rainfall (2009-2017) (mm) [27]	367	455	521	430	623
Annual mean T (2009-2017) (˚C) [27]	14.1	15.7	14.5	16.3	15.6
Mean minimum T (2009-2017) (˚C) [27]	8.6	10.4	9.4	12.3	10.2
Mean maximum T (2009-2017) (˚C) [27]	20.5	21.6	20.6	21.1	21.6
T span (˚C) [28]	19-20	14-18	16-18	13-16	13-16

Table 4. Fatty acid composition (%) of EVOOs produced in Catalan PDO geographical areas, during the period 2000-2011. Significance of the differences between geographical regions calculated by Kruskal-Wallis test (different letters indicate significant differences according to pairwise comparisons).

Fatty acid	Mean % ± SD					
	Les Garrigues (LG) (n=35)	Siurana (S) (n=29)	Oli de Terra Alta (TA) (n=87)	Oli del Baix Ebre-Montsià (BEM) (n=43)	Oli de l'Empordà (E) (n=19)	*p*
C16:0	12.6±0.88 b	14.7±1.57 c	11.8±0.94 a	13.1±1.78 b	13.9±2.44 bc	<0.05
C16:1	1.0±0.11 b	1.4±0.36 a	1.0±0.14 b	1.2±0.72 b	1.6±0.56 a	<0.05
C17:0	0.1±0.02 b	0.1±0.00 b	0.1±0.02 b	0.1±0.07 b	0.2±0.06 a	<0.05
C17:1	0.2±0.04 c	0.2±0.00 c	0.2±0.04 b	0. 3±0.12 b	0.4±0.07 a	<0.05
C18:0	20.±0.13 b	1.9±0.17 b	1.6±0.16 a	2.0±0.43 b	1.8±0.47 ab	<0.05
C18:1	74.0±1.60 a	70.4±2.89 b	74.0±2.18 a	67.8±6.35 b	67.4±4.17 a	<0.05
C18:2	9.0±0.67 c	9.8±1.32 bc	9.9±1.60 b	13.9±4.61 a	12.8±3.01 ab	<0.05
C18:3	0.5±0.02 c	0.6±0.05 c	0.6±0.07 b	0.9±0.20 a	1.3±0.43 a	<0.05
C20:0	0.4±0.04 a	0.4±0.04 a	0.3±0.04 c	0.3±0.06 b	0.3±0.07 bc	<0.05
C20:1	0.3±0.03	0.3±0.02	0.3±0.04	0.3±0.06	0.3±0.08	-
C22:0	0.1±0.00	0.1±0.00	0.1±0.01	0.1±0.05	0.1±0.05	-


8.000
7.000
6.000
5.000
4.000
3.000
2.000
1.000
0
tonnes/year
2008
2009
2010
2011
2012
2013
2014
2015
2016
year
Les Garrigues
Siurana

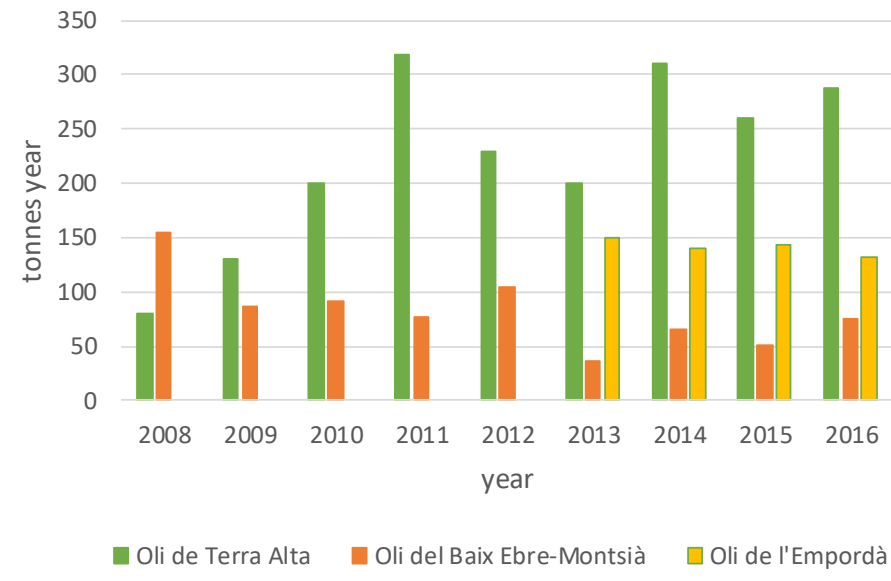

350
300
250
200
150
100
50
0
tonnes year
2008
2009
2010
2011
2012
2013
2014
2015
2016
year
Oli de Terra Alta
Oli del Baix Ebre-Montsià
Oli de l'Empordà

Figure 1.

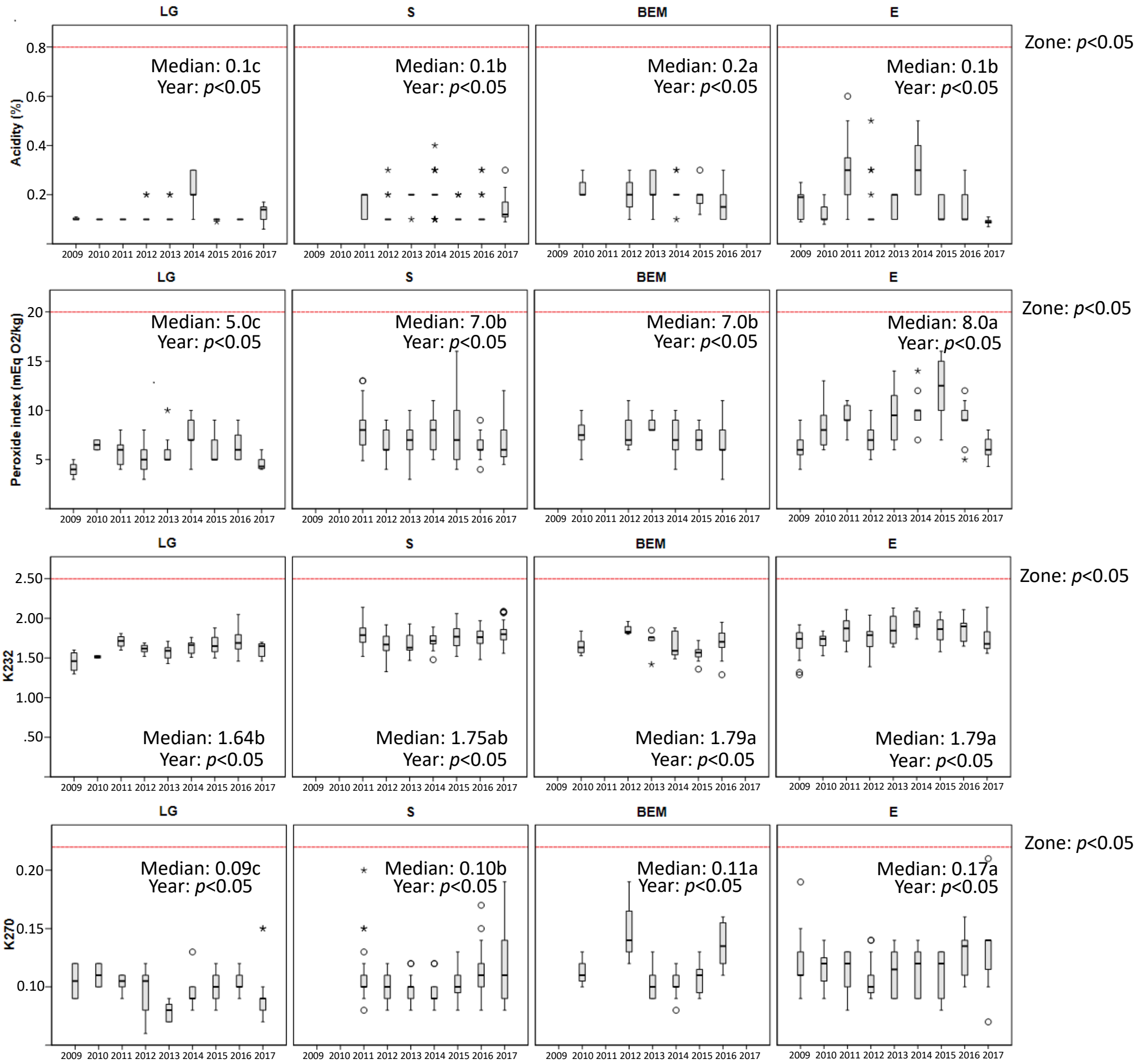

LG
S
BEM
E
Acidity (%)
Median: 0.1c
Year: p<0.05
Median: 0.1b
Year: p<0.05
Median: 0.2a
Year: p<0.05
Median: 0.1b
Year: p<0.05
Zone: p<0.05
Peroxide index (mEq O2/kg)
Median: 5.0c
Year: p<0.05
Median: 7.0b
Year: p<0.05
Median: 7.0b
Year: p<0.05
Median: 8.0a
Year: p<0.05
Zone: p<0.05
K232
Median: 1.64b
Year: p<0.05
Median: 1.75ab
Year: p<0.05
Median: 1.79a
Year: p<0.05
Median: 1.79a
Year: p<0.05
Zone: p<0.05
K270
Median: 0.09c
Year: p<0.05
Median: 0.10b
Year: p<0.05
Median: 0.11a
Year: p<0.05
Median: 0.17a
Year: p<0.05
Zone: p<0.05
2009 2010 2011 2012 2013 2014 2015 2016 2017

Figure 2

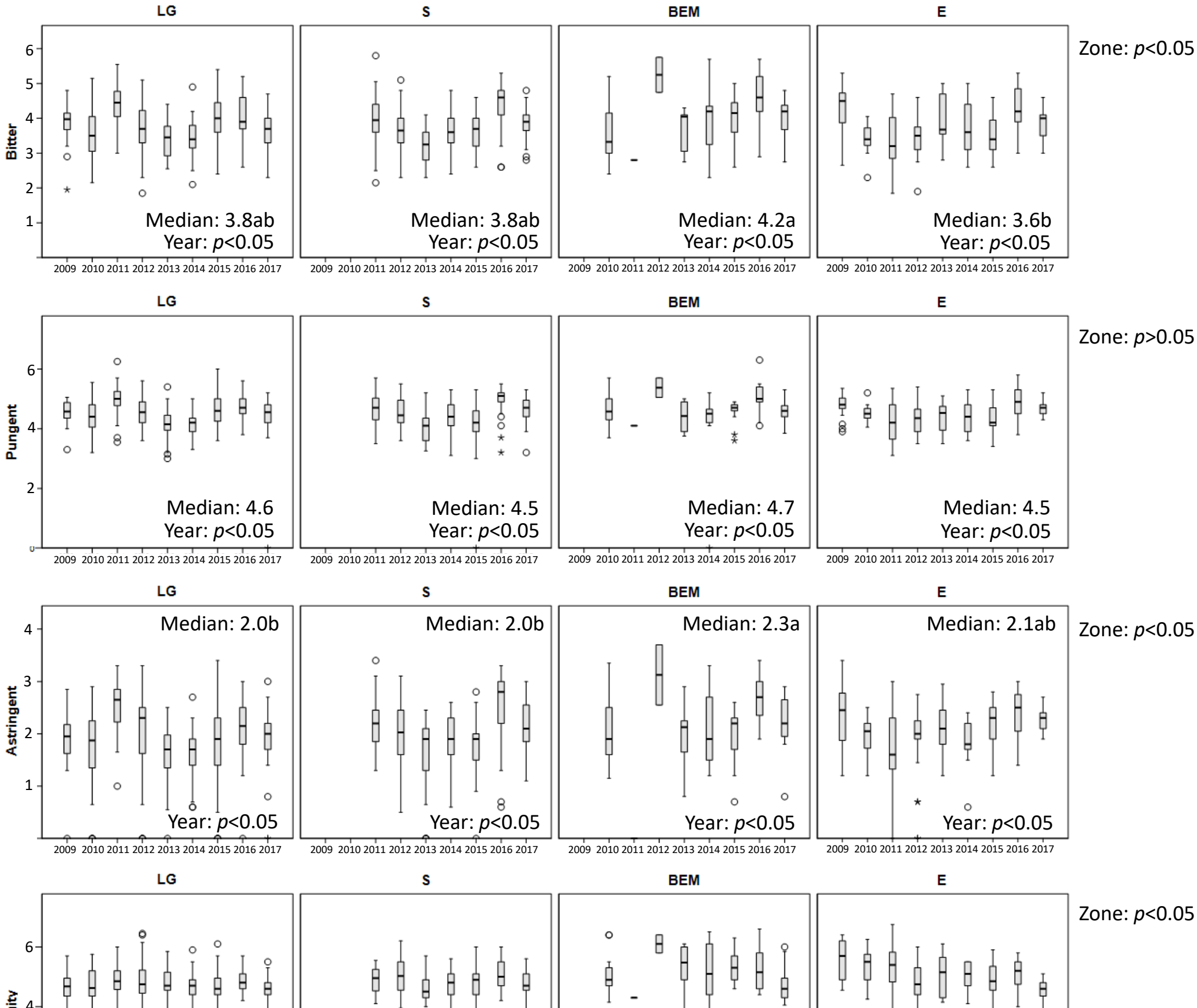

LG
S
BEM
E
Bitter
Median: 3.8ab
Year: p<0.05
Median: 3.8ab
Year: p<0.05
Median: 4.2a
Year: p<0.05
Median: 3.6b
Year: p<0.05
Zone: p<0.05
Pungent
Median: 4.6
Year: p<0.05
Median: 4.5
Year: p<0.05
Median: 4.7
Year: p<0.05
Median: 4.5
Year: p<0.05
Zone: p>0.05
Astringent
Median: 2.0b
Year: p<0.05
Median: 2.0b
Year: p<0.05
Median: 2.3a
Year: p<0.05
Median: 2.1ab
Year: p<0.05
Zone: p<0.05
Fruity
Median: 4.7c
Year: p<0.05
Median: 4.9b
Year: p<0.05
Median: 5.1a
Year: p<0.05
Median: 5.1ab
Year: p<0.05
Zone: p<0.05
Global sensory score (0-9)
Median: 7.0b
Year: p>0.05
Median: 7.1ab
Year: p>0.05
Median: 7.1ab
Year: p<0.05
Median: 7.1a
Year: p<0.05
Zone: p<0.05
2009 2010 2011 2012 2013 2014 2015 2016 2017

Figure 3

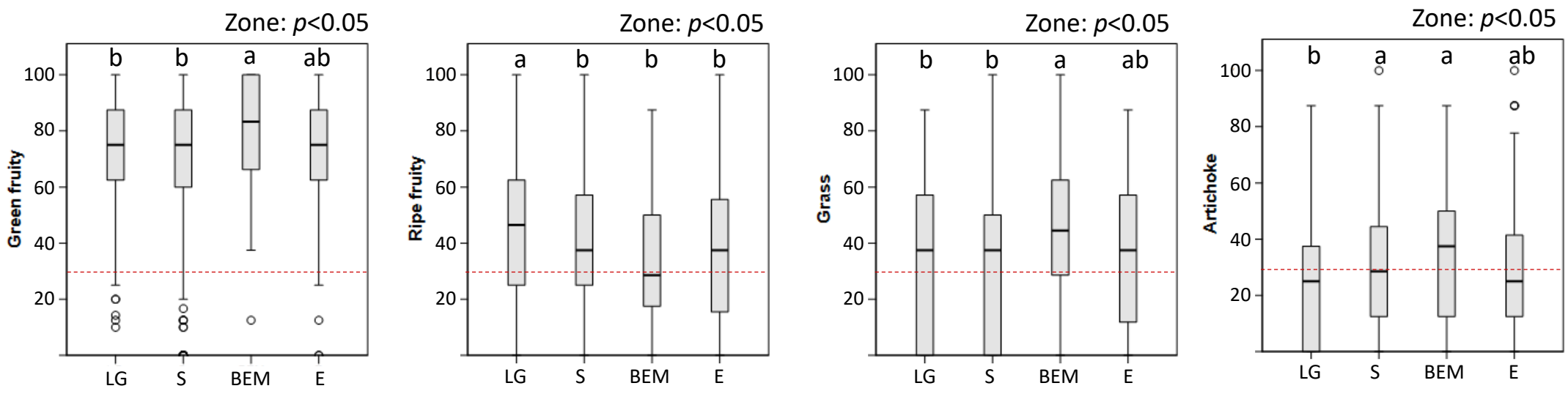

Zone: p<0.05
Green fruity
b b a ab
Zone: p<0.05
Ripe fruity
a b b b
Zone: p<0.05
Grass
b b a ab
Zone: p<0.05
Artichoke
b a a ab
100
80
60
40
20
LG S BEM E

Figure 4

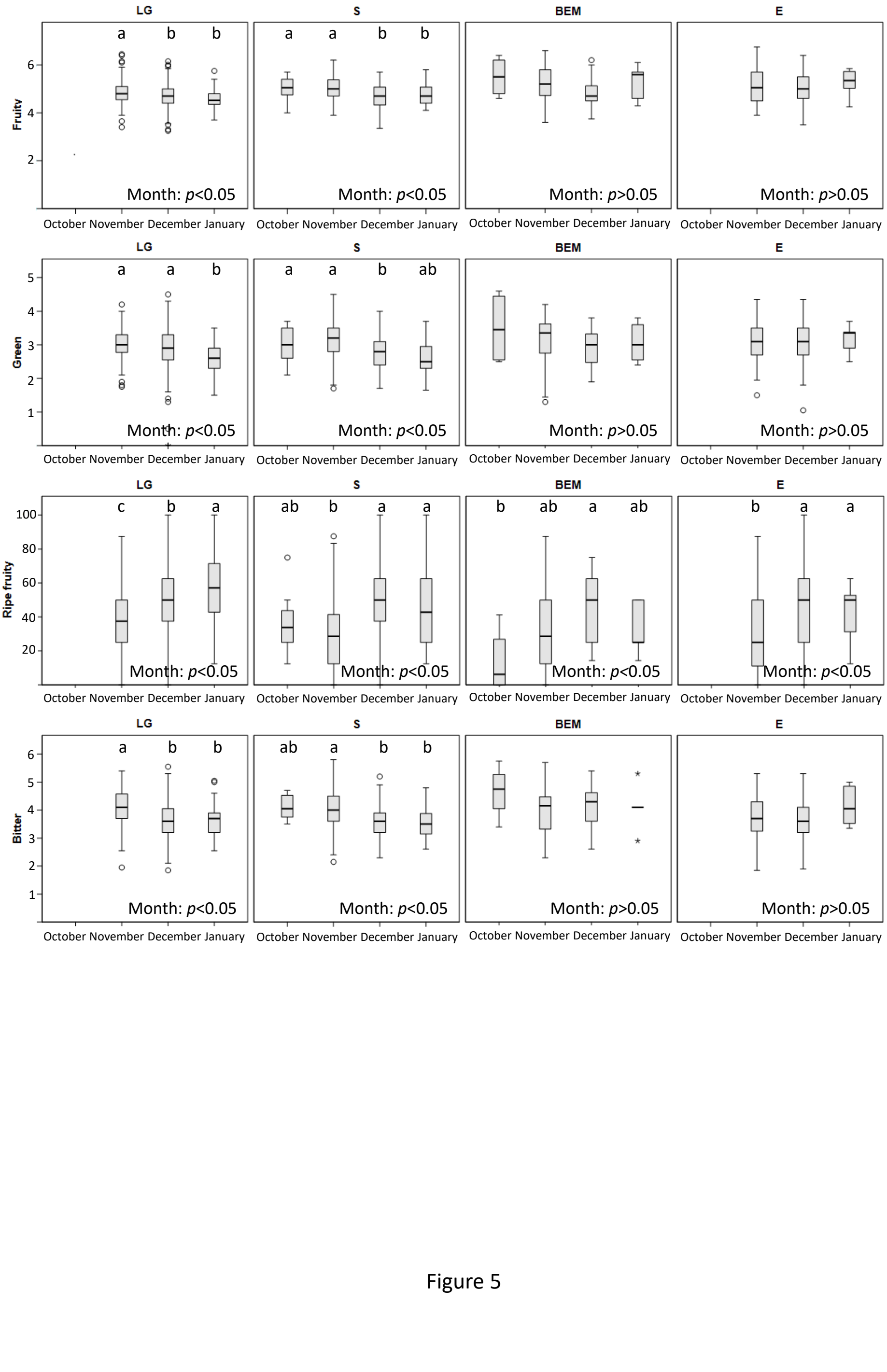

LG
S
BEM
E
Fruity
a b b
a a b b
Month: p<0.05
Month: p<0.05
Month: p>0.05
Month: p>0.05
October November December January
Green
a a b
a a b ab
Month: p<0.05
Month: p<0.05
Month: p>0.05
Month: p>0.05
Ripe fruity
c b a
ab b a a
b ab a ab
b a a
Month: p<0.05
Month: p<0.05
Month: p<0.05
Month: p<0.05
Bitter
a b b
ab a b b
Month: p<0.05
Month: p<0.05
Month: p>0.05
Month: p>0.05

Figure 5

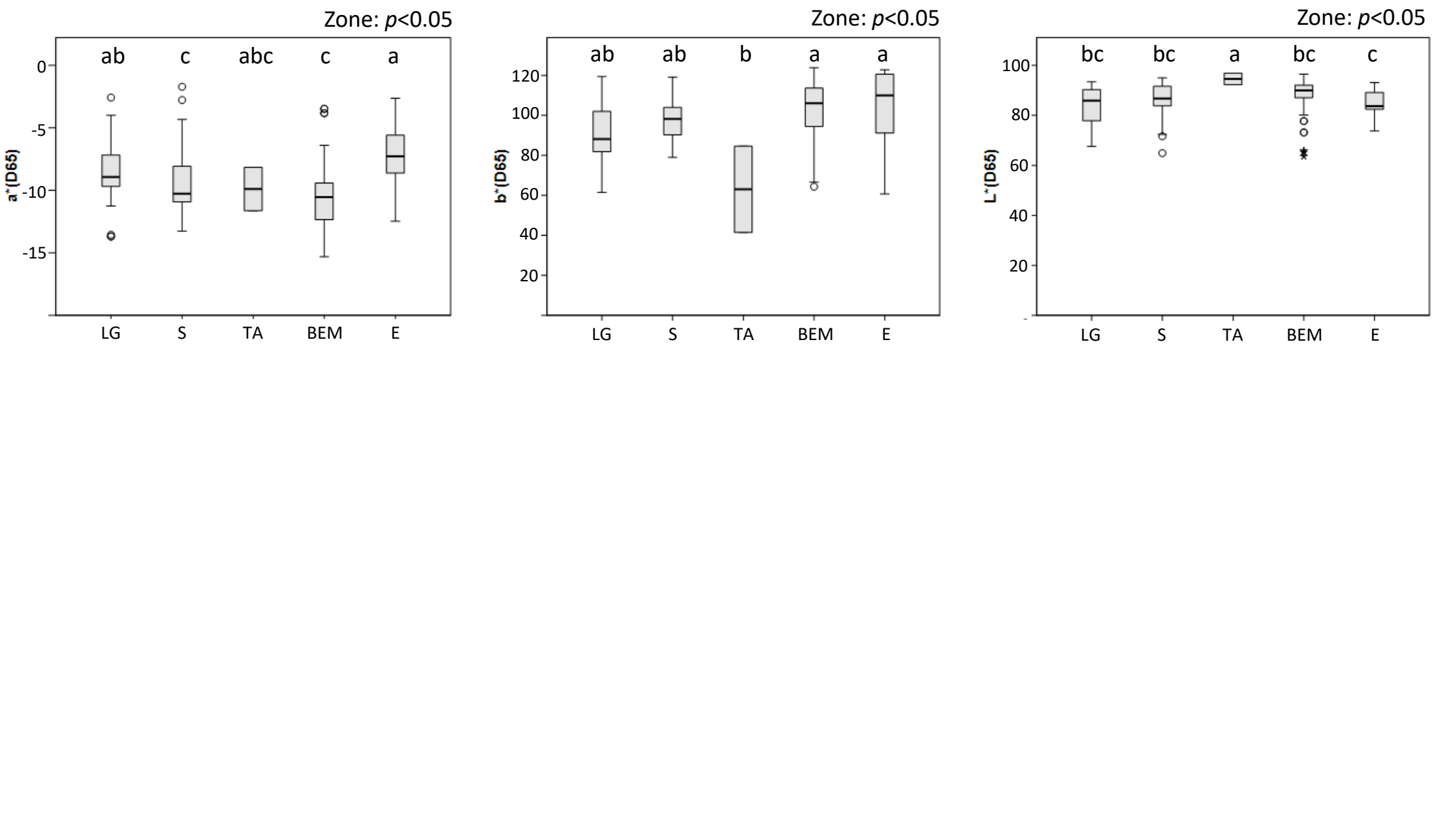

Zone: p<0.05
ab
c
abc
c
a
a*(D65)
0
-5
-10
-15
LG
S
TA
BEM
E
Zone: p<0.05
ab
ab
b
a
a
b*(D65)
120
100
80
60
40
20
LG
S
TA
BEM
E
Zone: p<0.05
bc
bc
a
bc
c
L*(D65)
100
80
60
40
20
LG
S
TA
BEM
E

Figure 6