# Quality classification of the solid biofuels to be considered in the biofuels extended BIOMASUD label

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| **Authors** | Ruth Barro (CIEMAT); Miguel Fernández (CIEMAT); Irene Mediavilla (CIEMAT); Rocio Cortés (CIEMAT), Raquel Bados (CIEMAT); Elena Borjabad (CIEMAT); Thomas Brunner (BIOS), Werner Kanzian (BIOS), Norbert Hajos (BIOS), Ingwald Obernberger (BIOS), Emmanouil Karampinis (CERTH), Panagiotis Grammelis (CERTH), Nikos Nikolopoulos (CERTH), Teresa Almeida (CBE), Cláudia Mendes (CBE), Elsa Cancela (CBE), Neuza Alves (CBE), and Juan Carrasco (CIEMAT). | | |
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## Contents

## Abbreviatures

A: ash content

BD: bulk density

d.b.: dry basis

EU: European Union

ISO: International  Organization for Standarization

ISO/TC 238: ISO Technical Committee 238-Solid biofuels

M: Moisture content

n.a.: not applicable

n.r.: no requirement

NTS: nominal top size

P(X): percentile X%

PSD: particle size distribution

Q: Net calorific value at constant pressure

TSP: total solid particles

UNE: standard produced by the Spanish Association for Standarization (AENOR)

w%: content in percentaje by weight

# 1. Introduction

The main objective of this deliverable is to define fuel quality specifications for commercial and residential use of the following typical Mediterranean solid biofuels: olive tree and vineyard pruning (specifications for pellets and chips), olive stones, and dry fruit shells, specifically: almond, hazelnut, pine nut, pistachio, and walnut shells. The specifications shown in this deliverable should be taken into account as the quality classification limits in an updated and extended BIOMASUD quality label [1] that will be adopted as a result of this Project, which will contribute to the relevance of the BIOMASUD scheme as a tool to promote the use of Mediterranean biofuels for residential heating applications. The specifications should also be taken into consideration to update the current Spanish standards that grade olive stones (UNE 164003:2014 )[2] and dry fruit shells (UNE 164004:2014)[3] to accommodate biofuels coming from the geographical area covered in this project, which comprises a much more extensive Mediterranean area compared to the one initially considered when these national standards were created (SUDOE EU Region). It should be remarked that the current Biomasud label has recently adopted the quality specifications of the cited UNE standards.

To achieve the described objectives the results obtained from the analysis campaign performed in Task 3.2 and contained in D3.2 [4] and the results of combustion tests in WP5 (Task 5.3)[5] and other on purpose combustion tests using these fuels were used. Samples of the considered biofuels were collected in the Mediterranean countries participating in the current project (Croatia, Greece, Italy, Portugal, Slovenia, Spain and Turkey) and their quality assessment was presented in deliverable D.3.2 by BIOS (Austria), CBE (Portugal), CERTH (Greece), and CIEMAT (Spain), the laboratories participating in Task 3.2.

To achieve the objectives, this deliverable deals with the following issues:

- ✓ The extent to which the biofuels coming from the afore-mentioned geographical area comply with the quality classes and/or requirements originally set in the Biomasud quality label for SUDOE EU region (Spain, Portugal, south of France) and more specifically those of the current Spanish UNE 164003:2014 [2] and UNE 164004:2014 [3] standards that contain the specifications to grade olive stones and some types of dry fruit shells, respectively, for commercial and residential fuel use. Presently, the Biomasud quality label has adopted the qualities and limits set in those standards.
- ✓ According to the results of the above section, to revise current UNE 164003:2014 and UNE 164004:2014 standards and update their requirements to accommodate biofuels coming from the afore-mentioned extended geographical area.

- ✓ To define the specifications to grade pistachio and walnut shells for commercial and residential applications, biofuels not covered by the current Spanish UNE standard that grades dry fruit shells [3] and the Biomasud quality certification system [1].
- ✓ To determine the extent to which vineyard and olive tree pruning meet the requirements set in the related international standards ISO 17225-2:2014 [6] and ISO 17225-4:2014 [7] that grade wood pellets and wood chips, respectively.
- ✓ According to the results of last point, to define, if applicable, specifications that can be reflected in future standards to grade pellets and chips made of vineyard and olive tree pruning for commercial and residential applications.

## 2. Methodology

The selected biofuels and the number of samples collected per country were presented in Deliverable D.3.2 (section 2)[4]. In addition, Deliverable D.3.2 also shows the results of their physical and chemical characterization as a function of the country where the samples were collected (D3.2.Annex II), and the quality assessment of all the biofuels studied (D3.2.Sections 5 and 6). The results of D3.2 are the basis for the work developed in Task 3.3 and described in this Deliverable D3.3.

Before revising the existing limits in the current applicable standards, some samples were excluded from the statistical analysis because of not being representative of efficient/appropriate industrial processes for fuel preparation, the use of certain additives and/or the presence of contaminations. The decision was made after a visual inspection of the samples, and after taking into consideration the information compiled during sampling and in view of the results of their physical and chemical characterization. Table 2.1 shows the samples that were excluded from the dataset that was used to define the quality requirements recommendations, as well as the reason for their exclusion. Table 2.2 can be checked for the description of the codes used for each cause of exclusion.

*Table 2.1. Samples excluded from the set of samples used to define the quality requirements and causes of exclusion.*

| Country | Sample | Original reference | Cause of exclusion |
|---|---|---|---|
| **GREECE** | **Olive stones 6** | B20170215BSDOLKER1 | 1 |
| **GREECE** | **Olive stones 7** | B20170215BSDOLKER2 | 1 |
| **GREECE** | **Olive stones 9** | B20170222BSDOLKER1 | 1 |
| **GREECE** | **Olive stones 10** | B20170222BSDOLKER2 | 1 |
| **ITALY** | **Olive stones 1** | 89/17 | 2 |
| **ITALY** | **Olive stones 2** | 90/17 | 1 |
| **ITALY** | **Olive stones 3** | 133/17 | 1 |
| **TURKEY** | **Olive stones 1** | 10984 | 3 |
| **TURKEY** | **Olive stones 2** | 11013 | 3 |
| **TURKEY** | **Olive stones 3** | 11014 | 3 |
| **SPAIN** | **Walnut shells 3** | 1701403 | 4 |

*Table 2.2. Description of causes of exclusion.*

| **Causes of exclusion** | |
|---|---|
| **Code** | **Description** |
| **1** | Inefficient industrial process for stone cleaning<br>Contamination with mineral impurities cannot be ruled out |
| **2** | Inefficient industrial process for pulp separation |
| **3** | Use of additives (possibly salt) |
| **4** | Presence of whole fruits |

The excluded samples are all olive stones samples, with the exception of a sample of walnut shells that consisted of the whole fruits instead of being composed of the shell fraction only.

Obtained results for olive stones suggest that the conventional industrial processes to separate stones from the pulp fraction can easily produce clean olive stones with ash contents well below 2.0 w% (limit set in ISO 17225-2 for wood pellets, class B [6]). Therefore, olive stone samples 6, 7, 9 and 10 from Greece and 2 and 3 from Italy were discarded to define the specifications of graded olive stones for commercial and domestic applications, given that they have been produced without centrifugation methods that result in lower quality final products. Moreover, the elevated contents of some elements such as Si, Ca, Ti , Fe and/or Al, makes it not possible to rule out a contamination of these samples with mineral impurities due to an inadequate management in the factory where they were produced. Pollution with soil particles can be easily avoided and should not be accepted when producing high quality biofuels for commercial and residential applications. The olive stone samples 1, 2 and 3 from Turkey were rejected because their extremely high Cl (0.79-1.2 w%) and Na (0.72-0.89 w%) contents, which reveals that additives (possibly salt) were used during the production of table olives, which strongly worsens the quality of the biofuel. Their presence should therefore not be accepted when producing high quality biofuels.

Concerning dry fruit shells, it is of interest to take into account that the efficiency of the industrial process for separation of shells from grain (pulp) strongly depends on the whole fruit (cover+nut) its characteristics at the time of crushing, particularly its moisture content, which, on the other hand, depends on the type of fruit, the climatological conditions at the time of collection and the management of the fruits during storage, together with some other factors like the immersion or not of the whole fruits in water and the period of immersion. This is a common industrial practice before crushing for softening (separate the cover from the nut) and to separate the imperfect fruits due to its lower density, particularly in case of walnuts. Moreover, it was noticed that some transforming companies mixed the shell fraction that had been successfully removed during the crushing process with the imperfect nuts that, as mentioned, had been separated from the process main flow in a previous step. This common, although avoidable, practice increases the fraction of grain, resulting in products characterized by high oil contents and elements such as nitrogen, sulfur and chlorine that are present in the grain fraction mostly. Nevertheless, in spite of this practice and the high variability found for some parameters such as the oil content, it was decided not to reject any sample of dry fruit shells, given that these samples seem to represent the products coming from real industrial processes. As it was previously mentioned, an exception was a Spanish sample of walnut shells that consisted of whole walnuts entirely.

The rest of the analyzed samples were all considered to define the specifications of the studied biofuels and took part of the statistical analysis that involved means, maximum and minimum values, as well as the 99% (P99), 95% (P95), 90% (P90), 75% (P75), 50% (P50), 25% (P25), and 10% (P10) percentiles for every quality property.

The properties considered were moisture (M), bulk density (BD), net calorific value at constant pressure (Q), ash (A), nitrogen (N), sulphur (S), chlorine (Cl), oil, skin, particle size distribution (PSD) at different mesh sizes, arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb), and zinc (Zn). It was examined whether the selected samples complied with the requirements established for the different quality classes in the existing applicable UNE and ISO quality standards and/or to what extent they did. Moreover, the characteristic ash fusibility temperatures are considered to provide valuable information regarding the ash fusibility behavior of these fuels during combustion. Therefore, it was decided to include this parameter in the specifications for olive stones and shells as an informative property, the same way it is listed in the ISO standards that grade solid biofuels.

As far as the authors know, there is no comprehensive review regarding the effect of oil content on the combustion of olive stones and dry fruit shells. On the one hand, oil-rich fuels pose an advantage in terms of exhibiting increased calorific values. However, on the other hand, it is not clear how strongly the oil content could affect particulate emissions and other emissions during combustion or whether excessive sticky fuels could hinder flow movement in conveyor belts or feeding systems thus affecting the combustion quality. Some countries like Greece limit the oil content on residues from the olive oil processing industry to a maximum value of 2 w% to avoid the direct combustion of olive cake and to ensure that it is further processed by pomace mills. Therefore, combustion tests results of olive stones in Task 5.3 [5], as well as of additional combustion tests of olive stones with different oil content, and almond shells were also taken into consideration in order to address this issue.

Finally, in addition to analytical tests, results of combustion test runs with olive tree and vineyard pruning pellets performed in Task 5.3 [5] were used  to assess the suitability of these fuels to be used in the commercial and residential sectors with the state-of the-art technologies, given that they do not meet important specifications for wood pellets and wood chips of ISO 17225:2014 standards.

Taking into account all the information compiled, the requirements set in the applicable current standards were revised and, when required, new quality specifications were recommended. The following criteria were taken into consideration:

- Percentiles and the individual values obtained from the samples analyzed
- The requirements set in the related Spanish UNE standards for olive stones and some types of fruit shells [2,3 ].
- The requirements set in the ISO standards for wood pellets [6] and wood chips [7].
- The inclusion of samples that come from all the considered countries, trying not to exclude samples that can exhibit different characteristics due to the different pedoclimatic conditions of the areas where they were grown and/or the use of varied agronomic practices that are commonly and frequently used in their countries of origin.
- The existing, conventional, real-life, and appropriate industrial processes followed for the production of the considered biofuels.
- The adoption of requirements that avoid environmental and combustion problems, at least as far as it is reasonably possible with the current existing technologies.
- The homogenization of the requirements for all types of the considered shells regardless of the type of nut, with the exception of bulk density and calorific value.
- The results of the cited combustion tests.

## 3. Results and discussion

This section shows, for each considered type of biofuel, the statistical descriptors (means, percentiles, maximum and minimum values) of the results obtained from the physical and chemical characterization of the analyzed samples, together with the proposed classes and limits for each property, as well as the requirements set in the corresponding applicable standards currently in place; UNE 164003:2014 [2] for olive stones, UNE 164004:2014 [3] for dry fruit shells, ISO 17225-2:2014 [6] for wood pellets and ISO 17225-4:2014 [7] for wood chips. In case of olive stones and dry fruit shells, the specifications set in the international standard ISO 17225-2:2014 [6] to grade wood pellets for commercial and industrial applications were also included for comparison reasons.

The results obtained for the moisture content of the analyzed samples were included in this section even though it should be taken into account that sample collection, storage and transport conditions of samples to the laboratories where the analyses were performed was not made by following a standardized procedure, and therefore the obtained results regarding moisture contents cannot be considered as representative of an optimized procedure for biofuel production.

For trace elements, mean values and percentiles could not be calculated as most of the values fell below the quantification limits reported by the laboratories regarding the methods applied. For this reason, only the minimum and maximum values and the number of analyzed samples are tabulated.

The nominal top size (NTS) included in tables is defined as the aperture size of the sieve through which at least 95 % by mass of the material passes during the determination of particle size distribution of solid fuels, according to ISO 16559:2014 [8].

To set the minimum requirements for the net calorific value, as received, of the considered biofuels, the calorific values obtained in the analyses were taken into consideration and calculated to the maximum moisture content allowed in the different classes.

Red letters highlight when the proposed limit for that particular property differs from that set in the current applicable UNE standards in case of olive stones and dry fruit shells, or in the ISO standards that grade wood pellets and wood chips , in case of pruning.

### 3.1. Pruning samples

As stated in deliverable D.3.2 [4], all pruning samples analyzed in this study were manually collected to prevent, as far as it is reasonably possible, the inclusion of soil impurities, and were later milled prior to characterization. As a consequence, and even though bulk density is listed as a normative property in the ISO related standards, the bulk density of the collected pruning was not determined, for not being representative of a real collection and fuel management process,. It should also be taken into account that, in case pruning were collected by mechanical means, higher ash contents than those found in the considered samples would be expected.

### 3.1.1. Vineyard pruning

Tables 3.1 and 3.2 show the results for all the vineyard pruning samples that were analyzed in Task 3.2 as well as the current limits set in the current ISO 17225-2:2014 [6] and ISO 17225-4:2014 [7] international standards that grade wood pellets and wood chips, respectively, for commercial and residential applications.

*Table 3.1. Statistical results for the main properties of the analyzed vineyard pruning samples and current limits in ISO 17225-2:2014 for wood pellets and ISO 17225-4:2014 for wood chips.*

| | **M** w-% as received | **Q** MJ/kg as received | **A** w-% dry basis | **N** w-% dry basis | **S** w-% dry basis | **Cl** w-% dry basis |
|---|---|---|---|---|---|---|
| MEAN | 36 | 10.38 | 3.4 | 0.74 | 0.05 | 0.02 |
| P99 | 52 | 15.65 | 4.7 | 1.5 | 0.14 | 0.10 |
| P95 | 50 | 15.41 | 4.3 | 1.3 | 0.07 | 0.09 |
| P90 | 50 | 14.56 | 4.1 | 1.1 | 0.06 | 0.05 |
| P75 | 47 | 11.83 | 3.7 | 0.79 | 0.06 | 0.03 |
| P50 | 39 | 9.78 | 3.3 | 0.69 | 0.05 | 0.02 |
| P25 | 29 | 8.13 | 3.1 | 0.60 | 0.04 | 0.01 |
| P10 | 15 | 7.50 | 2.9 | 0.52 | 0.04 | 0.01 |
| MINIMUM | 10 | 7.12 | 2.3 | 0.48 | 0.01 | <0.01 |
| MAXIMUM | 52 | 15.72 | 4.9 | 1.5 | 0.15 | 0.11 |
| n | 112 | 112 | 112 | 112 | 112 | 112 |
| **ISO 17225-2:2014 (wood pellets)** | | | | | | |
| **class A1** | 10 | 16.5 | 0.7 | 0.3 | 0.04 | 0.02 |
| **class A2** | 10 | 16.5 | 1.2 | 0.5 | 0.05 | 0.02 |
| **class B** | 10 | 16.5 | 2.0 | 1.0 | 0.05 | 0.03 |
| **ISO 17225-4:2014 (wood chips)** | | | | | | |
| **class A1** | 10, 25 | n.a. | 1.0 | n.a. | n.a. | n.a. |
| **class A2** | 35 | n.a. | 1.5 | n.a. | n.a. | n.a. |
| **class B1** | n.a. | n.a. | 3.0 | 1.0 | 0.1 | 0.05 |
| **class B2** | n.a. | n.a. | 3.0 | 1.0 | 0.1 | 0.05 |

*n.a.: not applicable*

*Table 3.2. Statistical results for the trace elements of the analyzed vineyard pruning samples and current limits in ISO 17225-2:2014 for wood pellets and ISO 17225-4:2014 for wood chips.*

| Ref. | **As** mg/kg dry basis | **Cd** mg/kg dry basis | **Cr** mg/kg dry basis | **Cu** mg/kg dry basis | **Hg** mg/kg dry basis | **Ni** mg/kg dry basis | **Pb** mg/kg dry basis | **Zn** mg/kg dry basis |
|---|---|---|---|---|---|---|---|---|
| MINIMUM | 0.02 | <0.01 | <0.03 | 3.3 | 0.001 | <0.10 | <0.10 | 10 |
| MAXIMUM | 0.27 | 1.1 | 13 | 65 | 0.017 | 17 | 36 | 260 |
| n | 88 | 112 | 112 | 112 | 112 | 112 | 112 | 112 |
| **ISO 17225-2:2014 (wood pellets for commercial and residential applications)** | | | | | | | | |
| **class A1** | 1 | 0.5 | 10 | 10 | 0.1 | 10 | 10 | 100 |
| **class A2** | 1 | 0.5 | 10 | 10 | 0.1 | 10 | 10 | 100 |
| **class B** | 1 | 0.5 | 10 | 10 | 0.1 | 10 | 10 | 100 |
| **ISO 17225-4:2014 (wood chips for commercial and residential applications)** | | | | | | | | |
| **class A1** | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. |
| **class A2** | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. |
| **class B1** | 1 | 2 | 10 | 10 | 0.1 | 10 | 10 | 100 |
| **class B2** | 1 | 2 | 10 | 10 | 0.1 | 10 | 10 | 100 |

*n.a.: not applicable*

None of the analyzed vineyard pruning samples exhibited ash contents below 2.0 %, the maximum limit allowed for wood pellets, class B, for commercial and residential applications, and only about 20% (22 out of 112 samples) showed ash contents ≤ 3.0 %, the maximum limit allowed for wood chips [7], class B. However, increasing the ash limits for domestic applications in a hypothetical standard for vineyard pruning does not seem to be in principle advisable, due to the high content of K compounds in this biomass, which could result in high fine particulate emissions. The relatively high nitrogen content is another problematic factor of vineyard pruning as a domestic biofuel due to increased NOx emissions to be expected from combustion of this fuel. In fact, combustion tests performed in Task 5.3 [5] with vineyard pruning pellets in small domestic boilers and stoves confirmed the expected much higher particle and NOx emissions than the limits established in EN303-5:2012 for class 5 boilers and the Directive of EcoDesign. In addition to these problematic factors, only one of the analyzed samples exhibited a net calorific value ≥ 16.5 MJ/kg (calculated for a hypothetical moisture content of 10%), the minimum requirement set for wood pellets [6].

All the described facts can be attributed to the intrinsic nature of this type of biomass that mainly consists of twigs with higher bark to wood ratio than other types of wood fuels.

Moreover, as mentioned before, it should be taken into consideration that vineyard pruning collected by mechanical means are expected to exhibit higher ash contents than those reported in Table 3.1, as the samples considered in Task 3.2 were manually collected to avoid the inclusion of mineral impurities from soil, which adds uncertainty on the applicability of this biomass for domestic use.

Also to highlight that most of samples exceeded the limit of Cu established for wood pellets and wood chips in ISO 17225:2014. The presence of this metal is associated to the wide use of Cu-based fungicides as part of the cropping management.

Therefore, the obtained results strongly suggest that this type of biomass might not be an appropriate raw material to produce pellets for domestic use. Vineyard pruning with ash contents below 3.0 w% d.b. could in principle be used as raw material to produce  chips or hog fuel, class B, for commercial and residential applications if the nitrogen and the ruled heavy metals, particularly Cu, do not surpass the limits established in ISO 17522-4:2014. Vineyard pruning ash fraction did not pose significant problems in combustion other that the need to effect the cleaning operation more frequently when compared to wood pellets.

In the described context, the recommendation is to use this type of biomass to preferentially produce chips or pellets for industrial applications. ISO/TC 238 is expected to publish an international standard that grades wood chips for industrial applications in a near future.

#### 3.1.2. Olive tree pruning

Olive tree pruning are, in general, composed of thin tree branches, including the fraction of leaves, that can partially be left on soil after pruning operation, depending on the biomass collection management.

Tables 3.3 and 3.4 show the results for all  olive tree pruning samples that were analyzed in Task 3.2 as well as the proposed limits to grade pellets or chips that could be produced from olive tree pruning for commercial and residential applications and the comparison with ISO standards for wood pellets and wood chips.

*Table 3.3. Statistical results for the main properties of the analyzed olive tree pruning samples, proposed limits for pellets and chips produced from olive tree pruning and current limits in ISO 17225-2:2014 for wood pellets and ISO 17225-4:2014 for wood chips .*

| | **M**<br>w-% as received | **Q**<br>MJ/kg as received | **A**<br>w-% dry basis | **N**<br>w-% dry basis | **S**<br>w-% dry basis | **Cl**<br>w-% dry basis |
|---|---|---|---|---|---|---|
| MEAN | 27 | 12.93 | 4.2 | 0.93 | 0.08 | 0.04 |
| P99 | 46 | 16.23 | 6.3 | 1.6 | 0.15 | 0.08 |
| P95 | 43 | 16.03 | 6.1 | 1.4 | 0.12 | 0.07 |
| P90 | 41 | 15.84 | 5.8 | 1.3 | 0.11 | 0.07 |
| P75 | 36 | 14.71 | 5.0 | 1.2 | 0.10 | 0.05 |
| P50 | 27 | 13.02 | 4.2 | 0.97 | 0.08 | 0.03 |
| P25 | 18 | 11.30 | 3.6 | 0.67 | 0.06 | 0.02 |
| P10 | 12 | 9.90 | 2.7 | 0.50 | 0.04 | 0.02 |
| MINIMUM | 9.1 | 8.80 | 1.7 | 0.19 | 0.02 | <0.01 |
| MAXIMUM | 46 | 16.25 | 6.4 | 1.7 | 0.19 | 0.10 |
| n | 74 | 74 | 74 | 74 | 74 | 74 |
| | | | | | | |
| **Proposed limits (olive tree pruning pellets)** | | | | | | |
| **class P1** | 10 | 16.5 | 0.7 | 0.3 | 0.04 | 0.02 |
| **class P2** | 10 | 16.5 | 1.2 | 0.5 | 0.05 | 0.02 |
| **class P3** | 10 | **15.0** | 2.0 | 1.0 | 0.05 | 0.03 |
| | | | | | | |
| **ISO 17225-2:2014 (wood pellets)** | | | | | | |
| **class A1** | 10 | 16.5 | 0.7 | 0.3 | 0.04 | 0.02 |
| **class A2** | 10 | 16.5 | 1.2 | 0.5 | 0.05 | 0.02 |
| **class B** | 10 | 16.5 | 2.0 | 1.0 | 0.05 | 0.03 |
| | | | | | | |
| **Proposed limits (olive tree pruning chips)** | | | | | | |
| **class A1** | 10, 25 | n.r. | 1.0 | n.r. | n.r. | n.r. |
| **class A2** | 35 | n.r. | 1.5 | n.r. | n.r. | n.r. |
| **class B1** | n.r. | n.r. | 3.0 | 1.0 | 0.1 | 0.05 |
| **class B2** | n.r. | n.r. | 3.0 | 1.0 | 0.1 | 0.05 |
| | | | | | | |
| **ISO 17225-4:2014 (wood chips)** | | | | | | |
| **class A1** | 10, 25 | n.r. | 1.0 | n.r. | n.r. | n.r. |
| **class A2** | 35 | n.r. | 1.5 | n.r. | n.r. | n.r. |
| **class B1** | n.r. | n.r. | 3.0 | 1.0 | 0.1 | 0.05 |
| **class B2** | n.r. | n.r. | 3.0 | 1.0 | 0.1 | 0.05 |

*n.a.: not applicable*

*Table 3.4. Statistical results for the trace elements of the analyzed olive tree pruning samples, proposed limits for pellets and chips produced from olive tree pruning and current limits in ISO 17225-2:2014 for wood pellets and ISO 17225-4:2014 for wood chips.*

| Ref. | As mg/kg dry basis | Cd mg/kg dry basis | Cr mg/kg dry basis | Cu mg/kg dry basis | Hg mg/kg dry basis | Ni mg/kg dry basis | Pb mg/kg dry basis | Zn mg/kg dry basis |
|---|---|---|---|---|---|---|---|---|
| MINIMUM | 0.04 | <0.01 | <0.30 | <1.0 | 0.001 | <1.0 | <0.20 | <2.5 |
| MAXIMUM | 1.3 | 0.86 | 10 | 96 | 0.063 | 24 | 3.2 | 32 |
| n | 54 | 74 | 74 | 74 | 74 | 74 | 74 | 74 |
| **Proposed limits (olive tree pruning pellets)** | | | | | | | | |
| **class A1** | 1 | 0.5 | 10 | 10 | 0.1 | 10 | 10 | 100 |
| **class A2** | 1 | 0.5 | 10 | 10 | 0.1 | 10 | 10 | 100 |
| **class B** | 1 | 0.5 | 10 | 10 | 0.1 | 10 | 10 | 100 |
| **ISO 17225-2:2014 (wood pellets)** | | | | | | | | |
| **class A1** | 1 | 0.5 | 10 | 10 | 0.1 | 10 | 10 | 100 |
| **class A2** | 1 | 0.5 | 10 | 10 | 0.1 | 10 | 10 | 100 |
| **class B** | 1 | 0.5 | 10 | 10 | 0.1 | 10 | 10 | 100 |
| **Proposed limits (olive tree pruning chips)** | | | | | | | | |
| **class A1** | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. |
| **class A2** | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. |
| **class B1** | 1 | 2 | 10 | 10 | 0.1 | 10 | 10 | 100 |
| **class B2** | 1 | 2 | 10 | 10 | 0.1 | 10 | 10 | 100 |
| **ISO 17225-4:2014 (wood chips)** | | | | | | | | |
| **class A1** | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. |
| **class A2** | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. |
| **class B1** | 1 | 2 | 10 | 10 | 0.1 | 10 | 10 | 100 |
| **class B2** | 1 | 2 | 10 | 10 | 0.1 | 10 | 10 | 100 |

*n.a.: not applicable*

Similar comments as for vineyard pruning can be made for olive tree pruning when it includes the leaves fraction:

Most of the analyzed samples are characterized by high ash contents, which is associated to leaves fraction mostly. Only 13% of the analyzed samples showed ash contents ≤3 w% d.b., the maximum limit allowed for domestic wood chips, and only 6% of samples showed ash contents ≤2 w% d.b., the maximum ash content allowed for domestic wood pellets in ISO related standards [6, 7]. Besides, it should be taken into account that olive tree pruning collected by mechanical systems are expected to show higher ash contents than those showed in this report.

Regarding calorific value, only 30% of samples showed a net calorific value above 16.5 MJ/kg (when calculated for a hypothetical moisture content of 10 w%), the requirement set in ISO 17225-2:2014 for wood pellets.

The combustion tests of olive tree pruning pellets including leaves fraction that were performed in the same small boilers and stoves as for the vineyard pruning within Task 5.3 [5], confirmed high levels of NOx emissions, well above those of EcoDesign Directive, as in the case of vineyard pruning. As in the case of vineyard pruning, ash fraction did not produce significant problems in combustion other than an increased need of ash cleaning, but without significant melting related problems.

It should also be highlighted that the copper content could be a limiting factor for the domestic use of biofuels derived from olive tree pruning, according to ISO standards requirements for that element, which, as in the case of vineyard pruning, can be attributed to the extended use of Cu-containing chemicals as fungicides. Only half of the analyzed samples exhibited copper levels below the limits specified for domestic applications (10 mg/kg). Although not confirmed in this study, it might be possible to obtain reduced levels of Cu by an appropriate biomass/fuel management, as it depends on many factors such as the meteorological conditions (e.g. rainy weather conditions) and the time that has passed since fungicide application. The removal of leaves might also be determinant for this purpose, as this element tends to be accumulated in this fraction, as can be seen in next Table 6.

Tables 3.5 and 3.6 show the obtained results for samples that contained a negligible fraction of leaves, mainly consisting of branches (6 out of 74 samples considered).

As can be seen in Table 3.5, samples devoid of leaves exhibited ash contents below 3 w%, N, Cl, and S contents ≤ 0.54 w%, 0.03 w%, and 0.04 w%, respectively, and Cu contents below 10 mg/kg (Table 3.6), within the limits set in ISO standard for wood pellets and wood chips. Moreover, the K content was reduced to about half of the content of the samples with leaves, on average [see D3.2.] [4].

However, results suggest that, even if the fraction of leaves is removed (e.g. by an adequate biomass field management and pretreatment) and only the wood fraction of pruning is used as raw biomass to produce pellets, they would neither meet the specifications set for wood pellets in ISO 17225-2:2014 for commercial and domestic applications, as samples containing only branches did not meet the net calorific value requirement set in relevant ISO standard (≥ 16.5 MJ/kg) [6]).

Combustion tests of olive tree pruning devoid of leaves were not performed, but according to the composition of this fuel compared with high ash content (containing leaves fraction) olive tree pruning pellets, no significant ash related combustion problems can be expected with that fuel.

Therefore, the proposal is to relax the limitation set for the net calorific value of wood pellets, class B, and set it in 15.0 MJ/kg. With the new recommended limit of the net calorific value, olive tree pruning devoid of leaves could be used as raw material to produce wood pellets and/or wood chips for commercial and residential applications. As mentioned, olive tree pruning with a significant fraction of leaves would hardly meet the ash and nitrogen content (as well as Cu and other heavy metals) criteria set for domestic applications and thus their use, as in the case of vineyard pruning, should be to produce wood chips for industrial applications mostly.

*Table 3.5. Statistical results for the main properties of the analyzed olive tree pruning samples devoid of leaves, proposed limits for pellets and chips produced from olive tree prunings and current limits in ISO 17225-2:2014 for wood pellets and ISO 17225-4:2014 for wood chips.*

| | M | Q | A | N | S | Cl |
|---|---|---|---|---|---|---|
| | w-% as received | MJ/kg as received | w-% dry basis | w-% dry basis | w-% dry basis | w-% dry basis |
| MEAN | 22 | 13.48 | 2.0 | 0.39 | 0.03 | 0.02 |
| P99 | 31 | 15.77 | 2.4 | 0.54 | 0.04 | 0.03 |
| P95 | 30 | 15.72 | 2.3 | 0.53 | 0.04 | 0.03 |
| P90 | 29 | 15.64 | 2.3 | 0.52 | 0.04 | 0.03 |
| P75 | 27 | 14.87 | 2.1 | 0.47 | 0.04 | 0.03 |
| P50 | 24 | 12.92 | 1.9 | 0.35 | 0.03 | 0.03 |
| P25 | 16 | 12.44 | 1.8 | 0.30 | 0.02 | 0.01 |
| P10 | 12 | 11.88 | 1.8 | 0.30 | 0.02 | 0.01 |
| MINIMUM | 11 | 11.47 | 1.7 | 0.30 | 0.02 | 0.01 |
| MAXIMUM | 31 | 15.79 | 2.4 | 0.54 | 0.04 | 0.03 |
| n | 6 | 6 | 6 | 6 | 6 | 6 |
| **Proposed limits (olive tree pruning pellets)** | | | | | | |
| **class A1** | 10 | 16.5 | 0.7 | 0.3 | 0.04 | 0.02 |
| **class A2** | 10 | 16.5 | 1.2 | 0.5 | 0.05 | 0.02 |
| **class B** | 10 | 15.0 | 2.0 | 1.0 | 0.05 | 0.03 |
| **ISO 17225-2:2014 (wood pellets)** | | | | | | |
| **class A1** | 10 | 16.5 | 0.7 | 0.3 | 0.04 | 0.02 |
| **class A2** | 10 | 16.5 | 1.2 | 0.5 | 0.05 | 0.02 |
| **class B** | 10 | 16.5 | 2.0 | 1.0 | 0.05 | 0.03 |
| **Proposed limits (olive tree pruning chips)** | | | | | | |
| **class A1** | 10, 25 | n.a. | 1.0 | n.a. | n.a. | n.a. |
| **class A2** | 35 | n.a. | 1.5 | n.a. | n.a. | n.a. |
| **class B1** | n.a. | n.a. | 3.0 | 1.0 | 0.1 | 0.05 |
| **class B2** | n.a. | n.a. | 3.0 | 1.0 | 0.1 | 0.05 |
| **ISO 17225-4:2014 (wood chips)** | | | | | | |
| **class A1** | 10, 25 | n.a. | 1.0 | n.a. | n.a. | n.a. |
| **class A2** | 35 | n.a. | 1.5 | n.a. | n.a. | n.a. |
| **class B1** | n.a. | n.a. | 3.0 | 1.0 | 0.1 | 0.05 |
| **class B2** | n.a. | n.a. | 3.0 | 1.0 | 0.1 | 0.05 |

*Table 3.6. Statistical results for the trace elements of the analyzed olive tree pruning samples devoid of leaves, proposed limits for pellets and chips produced from olive tree pruning and current limits in ISO 17225-2:2014 for wood pellets and ISO 17225-4:2014 for wood chips.*

| Ref. | As<br>mg/kg dry basis | Cd<br>mg/kg dry basis | Cr<br>mg/kg dry basis | Cu<br>mg/kg dry basis | Hg<br>mg/kg dry basis | Ni<br>mg/kg dry basis | Pb<br>mg/kg dry basis | Zn<br>mg/kg dry basis |
|---|---|---|---|---|---|---|---|---|
| MINIMUM | <0.50 | <0.01 | <0.30 | 3.2 | 0.001 | <1.0 | <0.30 | <2.5 |
| MAXIMUM | <0.50 | <0.10 | 2.3 | 9.0 | 0.009 | 2.2 | <1.0 | 14 |
| n | 4 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **Proposed limits (olive tree pruning pellets)** | | | | | | | | |
| **class A1** | 1 | 0.5 | 10 | 10 | 0.1 | 10 | 10 | 100 |
| **class A2** | 1 | 0.5 | 10 | 10 | 0.1 | 10 | 10 | 100 |
| **class B** | 1 | 0.5 | 10 | 10 | 0.1 | 10 | 10 | 100 |
| **ISO 17225-2:2014 (wood pellets)** | | | | | | | | |
| **class A1** | 1 | 0.5 | 10 | 10 | 0.1 | 10 | 10 | 100 |
| **class A2** | 1 | 0.5 | 10 | 10 | 0.1 | 10 | 10 | 100 |
| **class B** | 1 | 0.5 | 10 | 10 | 0.1 | 10 | 10 | 100 |
| **Proposed limits (olive tree pruning chips)** | | | | | | | | |
| **class A1** | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. |
| **class A2** | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. |
| **class B1** | 1 | 2 | 10 | 10 | 0.1 | 10 | 10 | 100 |
| **class B2** | 1 | 2 | 10 | 10 | 0.1 | 10 | 10 | 100 |
| **ISO 17225-4:2014 (wood chips)** | | | | | | | | |
| **class A1** | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. |
| **class A2** | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. |
| **class B1** | 1 | 2 | 10 | 10 | 0.1 | 10 | 10 | 100 |
| **class B2** | 1 | 2 | 10 | 10 | 0.1 | 10 | 10 | 100 |

## 3.2. Olive stones

Tables 3.7 to 3.9 show the results for olive stone samples that were analyzed in Task 3.2 and used to define the quality requirements, as well as the proposed new limits for this type of biomass and the current limits set in UNE 164003:2014. As mentioned in section 2, some olive stone samples were excluded from the set of samples used to define the quality requirements. The excluded samples and the reasons for exclusion were detailed in Tables 2.1 and 2.2.

*Table 3.7. Statistical results for the main properties of the analyzed olive stone samples, proposed limits for olive stones, and current limits in the Spanish standard UNE 164003:2014. The limits set in ISO 17225-2:2014 for wood pellets are also included for comparison reasons.*

| | **M** | **BD** | **Q** | **A** | **N** | **S** | **Cl** |
|---|---|---|---|---|---|---|---|
| | w-% as received | $kg/m^3$ as received | MJ/kg as received | w-% dry basis | w-% dry basis | w-% dry basis | w-% dry basis |
| MEAN | 14 | 710 | 15.94 | 0.67 | 0.21 | 0.02 | 0.03 |
| P99 | 24 | 560 | 17.70 | 1.8 | 0.40 | 0.04 | 0.11 |
| P95 | 22 | 560 | 17.57 | 1.2 | 0.36 | 0.02 | 0.07 |
| P90 | 20 | 550 | 17.38 | 0.90 | 0.24 | 0.02 | 0.06 |
| P75 | 17 | 750 | 16.81 | 0.70 | 0.22 | 0.02 | 0.03 |
| P50 | 14 | 710 | 15.73 | 0.60 | 0.20 | 0.01 | 0.02 |
| P25 | 9.5 | 690 | 15.22 | 0.50 | 0.19 | 0.01 | 0.02 |
| P10 | 7.3 | 620 | 14.78 | 0.40 | 0.14 | 0.01 | 0.01 |
| MINIMUM | 6.3 | 300 | 13.61 | 0.39 | 0.11 | 0.01 | 0.01 |
| MAXIMUM | 25 | 810 | 17.74 | 1.9 | 0.40 | 0.04 | 0.12 |
| n | 38 | 31 | 38 | 38 | 38 | 38 | 38 |
| **Proposed limits (olive stones)** | | | | | | | |
| **class A1** | 12 | 700 | 15.7 | 0.7 | 0.3 | 0.03 | 0.03 |
| **class A2** | 12 | 650 | 15.7 | 1.0 | 0.4 | 0.04 | 0.04 |
| **class B** | 16 | 600 | 14.9 | 1.3 | 0.6 | 0.05 | 0.05 |
| **UNE 164003:2014 (olive stones)** | | | | | | | |
| **class A1** | 12 | 700 | 15.7 | 0.7 | 0.3 | 0.03 | 0.03 |
| **class A2** | 12 | 650 | 15.7 | 1.0 | 0.4 | 0.04 | 0.04 |
| **class B** | 16 | 600 | 14.9 | 1.3 | 0.6 | 0.05 | 0.05 |
| **ISO 17225-2:2014 (wood pellets)** | | | | | | | |
| **class A1** | 10 | 600 | 16.5 | 0.7 | 0.3 | 0.04 | 0.02 |
| **class A2** | 10 | 600 | 16.5 | 1.2 | 0.5 | 0.05 | 0.02 |
| **class B** | 10 | 600 | 16.5 | 2.0 | 1.0 | 0.05 | 0.03 |

*Table 3.8. Statistical results for particle size and the oil and skin contents of the analyzed olive stone samples, proposed limits for olive stones and current limits in the Spanish standard UNE 164003:2014. The limits set in ISO 17225-2:2014 for wood pellets are also included for comparison reasons.*

| | **Oil** | **Skin** | **PSD16** | **PSD8** | **PSD2** | **PSD1** |
|---|---|---|---|---|---|---|
| | w-% dry basis | w-% dry basis | accumulated w-% as received | | | |
| MEAN | 1.1 | 0.62 | 0.00 | 0.04 | 75.31 | 99.02 |
| P99 | 3.0 | 3.2 | 0.00 | 0.92 | 97.56 | 100.00 |
| P95 | 2.6 | 1.3 | 0.00 | 0.00 | 92.35 | 99.99 |
| P90 | 1.9 | 1.2 | 0.00 | 0.00 | 89.11 | 99.94 |
| P75 | 1.5 | 0.80 | 0.00 | 0.00 | 83.14 | 99.83 |
| P50 | 0.90 | 0.39 | 0.00 | 0.00 | 74.51 | 99.46 |
| P25 | 0.49 | 0.11 | 0.00 | 0.00 | 67.71 | 98.81 |
| P10 | 0.11 | 0.04 | 0.00 | 0.00 | 62.70 | 97.10 |
| MINIMUM | 0.03 | 0.01 | 0.00 | 0.00 | 38.01 | 96.10 |
| MAXIMUM | 3.1 | 3.6 | 0.00 | 1.38 | 99.54 | 100.00 |
| n | 36 | 21 | 34 | 34 | 34 | 34 |
| **Proposed limits (olive stones)** | | | | | | |
| **class A1** | 0.6 | **n.r.** | all < 16 mm | **n.r.** | 15 | **n.r.** |
| **class A2** | 1.0 | **n.r.** | all < 16 mm | **n.r.** | 15 | **n.r.** |
| **class B** | **3.0** | **n.r.** | all < 16 mm | **n.r.** | 15 | **n.r.** |
| **UNE 164003:2014 (olive stones)** | | | | | | |
| **class A1** | 0.6 | 1 | all < 16 mm | NTS<8 mm | 15 | 1 |
| **class A2** | 1.0 | 2 | all < 16 mm | NTS<8 mm | 15 | 1 |
| **class B** | 1.4 | 3 | all < 16 mm | NTS<8 mm | 15 | 1 |

*NTS: Nominal top size; n.r.: no requirement*

It should be mentioned that the specifications set for class A can be easily achieved as long as the product consists of clean stones; i.e. those with reduced amounts of pulp and/or other impurities like skin, soil particles or Na-containing additives.

It was decided that there is no need to keep the skin content of olive stones as a normative property because the limits established on other properties such as ash or N already limit the amount of skin that can be present as an impurity. Therefore, it is proposed to skip the skin content out of the normative quality parameters for olive stones in the related UNE standard.

In order to assess the convenience to maintain the oil content as a normative parameter and the influence that it may have on the olive stones fuel quality, combustion tests with olive stones with different oil contents (0.2 % to 3.1 % w% d.b.) were performed in the same boiler and stove that CIEMAT used in Task 5.3 [5]. Nominal and partial (30%) load test runs in the boiler and nominal load tests in stove were performed for each fuel. The emissions (CO, NOx, TSP) obtained in those tests indicated that in boiler tests at nominal load, the CO and TSP emissions were incremented when the oil content exceeded about 1.1 w% d.b., remaining without significant variations for oil contents below that value. In stove test runs all emissions increased as the oil content in the fuel increased. According to the results obtained, it is proposed to keep the oil content as a normative value in Spanish UNE, keeping the existing limits for classes A1 and A2, and increasing the limit of oil content up to 3 w% d.b. for class B. The increment proposed is in consideration that, in view of the results of the combustion tests performed, CO, NOx and particularly TSP are not significantly incremented compared to 2% w d.b. oil content and the limits set in the EcoDesign Directive could be met in big domestic sector boilers utilizing olive stones with 3% oil content by means of appropriate primary and secondary measures.

As can be seen in Table 3.8, the requirements initially set in UNE 164003:2014 regarding the particle size distribution of olive stones have been simplified by removing the limitations set for the 8 (PSD 8)- and 1 (PSD1)- mm sieves. From the experience of the partners participating in the project, a fuel that is able to meet the current proposed requirements on particle size should not pose problems to be used in the combustion installations commonly used in commercial and residential applications.

*Table 3.9. Statistical results for the trace element contents of the analyzed olive stone samples, proposed limits for olive stones, and current limits in the Spanish standard UNE 164003:2014. The limits set in ISO 17225-2:2014 for wood pellets are also included for comparison reasons.*

| | **As** | **Cd** | **Cr** | **Cu** | **Hg** | **Ni** | **Pb** | **Zn** |
|---|---|---|---|---|---|---|---|---|
| | mg/kg dry basis | mg/kg dry basis | mg/kg dry basis | mg/kg dry basis | mg/kg dry basis | mg/kg dry basis | mg/kg dry basis | mg/kg dry basis |
| MINIMUM | <0.01 | <0.01 | <0.30 | <1.0 | <0.001 | 0.13 | <0.02 | <0.60 |
| MAXIMUM | 0.06 | 0.18 | 7.4 | 13 | 0.002 | 5.0 | 15 | 160 |
| n | 28 | 38 | 38 | 38 | 38 | 38 | 38 | 38 |
| **Proposed limits (olive stones)** | | | | | | | | |
| **class A1** | 0.5 | **0.5** | 10 | 15 | 0.01 | 15 | 10 | **100** |
| **class A2** | 0.5 | **0.5** | 10 | 15 | 0.01 | 15 | 10 | **100** |
| **class B** | 0.5 | **0.5** | 10 | 15 | 0.01 | 15 | 10 | **100** |
| **UNE 164003:2014 (olive stones)** | | | | | | | | |
| **class A1** | 0.5 | 1 | 10 | 15 | 0.01 | 15 | 10 | 20 |
| **class A2** | 0.5 | 1 | 10 | 15 | 0.01 | 15 | 10 | 20 |
| **class B** | 0.5 | 1 | 10 | 15 | 0.01 | 15 | 10 | 20 |
| **ISO 17225-2:2014 (wood pellets)** | | | | | | | | |
| **class A1** | 1 | 0.5 | 10 | 10 | 0.1 | 10 | 10 | 100 |
| **class A2** | 1 | 0.5 | 10 | 10 | 0.1 | 10 | 10 | 100 |
| **class B** | 1 | 0.5 | 10 | 10 | 0.1 | 10 | 10 | 100 |

Concerning trace elements (Table 3.9), it was decided to assimilate the limits of Cd and Zn to those corresponding in the ISO standard for wood pellets. However, it was decided to recommend keeping the UNE standard limits for the rest of heavy metals in Table 3.9 given the analytical results obtained and the fact that only one sample slightly surpassed the established limit (and possibly associated to contamination) in the case of Pb.

### 3.3. Dry fruit shells

This section shows the analysis of the results obtained of all dry fruit shell samples considered in Task 3.2, organized by type of shell, together with the proposed quality class limits for these fuels, compared to the current specifications included in UNE 164004:2014 [3] that grades almond and hazelnut shells. Therefore, as foreseen, a review of the current specifications of UNE 164004:2014 to adapt it to the fuels coming from all Mediterranean countries participating in Biomasud Plus project, as well as quality grading of new types of shells, including pistachio and walnut shells, are made.

As mentioned in section 2, the specifications for all types of the considered dry fruit shells were unified in a single table, regardless of the type of nut, and with the exception of bulk density and calorific value. In this way, the classification of dry fruit shells is clearly simplified. However, as commented in Section 2, it is to note that the values of important fuel properties, as it can be the oil and nitrogen contents are in direct relation to the fraction of fruit present in these fuels, which, as already mentioned, depends on the type of fruit, the climatological conditions at the collection time and the management of the fruits prior to crushing. This makes more difficult the production of standarised fuels in the market and, at the end, the use of dry fruit shells for commercial and residential applications, particularly in small combustion equipments. Moreover, it has not been found in the market any small combustion equipment certified or at least declared suitable for dry fruit shells by the manufacturer.

In addition, some tests carried out at nominal and partial (30% nominal load) loads in the boiler used by CIEMAT in Task 5.3 (certified class 5, according to EN303-5:2012)[9] with almond shells have revealed very high CO (up to more than 2600mg/$Nm^3$ for partial load test) and TSP emissions (110-120 mg/kg at nominal and partial loads), even for a high quality and very low oil content (0.13 w% d.b.) fuel. In this situation, it has not been possible to address oil content limits for quality classes of dry fruit shells and, accordingly, the limits set in the existing UNE standard have been maintained. Moreover, the described situation brings out the issue on whether these fuels are suitable to be used in small residential heating devices or not with state of the art technologies. Comprehensive studies with suitable combustion equipments (if available in the market) and utilizing all types of dry fruit shells would be necessary to asses this issue, which is out of the scope of this project.

In this context, the dry fruit shells quality assessment produced in this report was exclusively made by addressing the analytical values of the considered samples.

In order to set out the recommendations on minimum requirements for the net calorific value of each type of shell the net calorific values obtained from the analyzed samples and calculated to the maximum moisture content allowed in the different classes of UNE standard (12 w% for classes A1 and A2, and 16 w% for class B) were considered. In general, and as far as it was reasonably possible, the reference values of UNE 164004:2014 were adopted. However, from the analyzed results, it was seen that hazelnut shells were characterized by higher calorific values than almond shells. Therefore, the limits proposed for hazelnut shells were increased by about 1 MJ/kg with respect to those of the Spanish standard UNE 164004. This standard had set the same requirements for almond and hazelnut shells.

Nevertheless, the authors consider that the proposed requirements for the calorific value for the different types of dry fruit shells can be easily achieved by the corresponding fuels. Relaxed limits are therefore being proposed for this property with the aim of limiting the effect that higher amounts of pulp could have on increasing the calorific value of the analyzed samples. As it was observed, many of the analyzed samples contained a variable and visible fraction of grain (not quantified). Higher fractions of grain than expected could increase the calorific value of the biofuel as well as its oil content.

Taken into account these considerations, two groups of shells were formed based on the calorific value requirements: hazelnut, pine nut, and walnut shells on the one hand, with stricter limits (16, 16, and 15 MJ/kg, as received, for classes A1, A2, and B, respectively), and almond and pistachio shells on the other (with 15, 15, and 14 MJ/kg for classes A1, A2, and B, respectively).

In general, the requirement proposed of bulk density class A1 was assimilated for each fuel and at least as far as it was reasonably possible, to a value close to that obtained for percentile 50 (P50). At the same time and, when possible (as long as an acceptable number of analyzed samples were able to fulfill the limits), it was decided to maintain the original UNE requirements for classes A2 and B. This property depends not only on the intrinsic nature of shell but also on the fuel processing after crushing. That is the reason why homogenizing bulk density requirements for all the considered types of shells was not possible, and therefore specific limits were assigned for each type of shell.

Besides, analogously to olive stones, the requirements initially set in UNE 164003:2014 regarding the particle size distribution of dry fruit shells have been simplified by removing the limitations set for the 16 (PSD16)- and 1 (PSD1)- mm sieves. From the experience of the partners participating in the project, the proposed requirements on particle size distribution are suitable to provide an adequate information of the fuel behavior related to this property.

A number of the analyzed dry shells surpassed the S (pistachio and walnut shells) and Cl (pistachio, walnut, almond and pine nut shells) limits currently specified in UNE 164004:2014. Therefore, in an attempt of homogenizing the S and Cl requirements for all types of shells, the proposed limits for these properties  were relaxed for class B, in case of S, and classes A2 and B, in case of Cl.

As regard to trace elements, the vast majority of the analyzed dry fruit shells complied with the limits originally set in UNE 164004:2014 for the contents of As, Hg, Ni and Pb in almond and hazelnut shells, and, therefore, the requirements for the cited elements were maintained in this proposal. However, the analyzed dry fruit shells showed levels of Cd well below 2 mg/kg, the limit set in UNE 164004:2014 [3], and thus it was decided to define a more restrictive limit for all shells (1 mg/kg) for this element. As commented in section 3.2, the Zn limit was matched to the requirement set in ISO 17225-2:2014 (100 mg/kg [6]), the international standard that grades wood pellets for commercial and residential applications. The relatively high levels of Cr found in some of the analyzed dry shells also highlights the need to relax the requirements for this element, as well as for Ni, since these materials are hard and resilient to grinding and milling, and tend to cause a larger erosion on the metallic parts of the industrial equipment than other fuels, as it was explained in section 2. The Cu limit was also stretched to 20 mg/kg as a consequence of the higher Cu levels found in a significant number of the analyzed samples, which was attributed to the Cu-containing fungicides that are typically used in Mediterranean dry fruit plantations.

### 3.3.1. Almond shells

Tables 3.10 to 3.12 show the results for all almond shell samples that were analyzed in Task 3.2, as well as the proposed new limits for this type of biomass and the current limits set in UNE 164004:2014 for almond and hazelnut shells. Similarly as for other shells, recommended  limits of some parameters have been adjusted in order almond shells can be graded together with other types shells.

*Table 3.10. Statistical results for the main properties of the analyzed almond shell samples, proposed limits for almond shells, and current limits in the Spanish standard UNE 164004:2014 for almond and hazelnut shells. The limits set in ISO 17225-2:2014 for wood pellets are also included.*

| | **M** | **BD** | **Q** | **A** | **N** | **S** | **Cl** |
|---|---|---|---|---|---|---|---|
| | w-% as received | kg/m$^3$ as received | MJ/kg as received | w-% dry basis | w-% dry basis | w-% dry basis | w-% dry basis |
| MEAN | 11 | 420 | 16.05 | 1.6 | 0.36 | 0.01 | 0.02 |
| P99 | 13 | 530 | 16.70 | 3.2 | 1.1 | 0.03 | 0.04 |
| P95 | 13 | 510 | 16.67 | 2.8 | 0.64 | 0.02 | 0.04 |
| P90 | 13 | 500 | 16.53 | 2.5 | 0.61 | 0.02 | 0.04 |
| P75 | 12 | 460 | 16.22 | 1.8 | 0.51 | 0.02 | 0.02 |
| P50 | 11 | 450 | 15.99 | 1.4 | 0.28 | 0.01 | 0.01 |
| P25 | 9.7 | 380 | 15.85 | 1.3 | 0.22 | 0.01 | 0.01 |
| P10 | 9.2 | 320 | 15.79 | 1.1 | 0.20 | 0.01 | 0.01 |
| MINIMUM | 8.1 | 240 | 15.27 | 0.60 | 0.18 | <0.01 | <0.01 |
| MAXIMUM | 13 | 540 | 16.71 | 3.3 | 1.2 | 0.03 | 0.04 |
| n | 25 | 24 | 25 | 25 | 25 | 25 | 25 |
| **Proposed limits (almond shells)** | | | | | | | |
| **class A1** | 12 | **450** | 15.0 | 0.7 | 0.4 | 0.03 | 0.02 |
| **class A2** | 12 | 300 | 15.0 | 1.5 | 0.6 | 0.03 | **0.03** |
| **class B** | 16 | 270 | **14.0** | 2.0 | 0.8 | **0.05** | **0.04** |
| **UNE 164004:2014 (almond and hazelnut shells)** | | | | | | | |
| **class A1** | 12 | 500 | 15.0 | 0.7 | 0.4 | 0.03 | 0.02 |
| **class A2** | 12 | 300 | 15.0 | 1.5 | 0.6 | 0.03 | 0.02 |
| **class B** | 16 | 270 | 14.2 | 2.0 | 0.8 | 0.04 | 0.03 |
| **ISO 17225-2:2014 (wood pellets)** | | | | | | | |
| **class A1** | 10 | 600 | 16.5 | 0.7 | 0.3 | 0.04 | 0.02 |
| **class A2** | 10 | 600 | 16.5 | 1.2 | 0.5 | 0.05 | 0.02 |
| **class B** | 10 | 600 | 16.5 | 2.0 | 1.0 | 0.05 | 0.03 |

In spite of the maximum value showed in Table 3.10 (1.2 %), it should be pointed out that N contents below 0.60 % should be expected in case of most clean almond shells.

*Table 3.11. Statistical results for the particle size and the oil content of the analyzed almond shell samples, proposed limits for almond shells, and current limits in the Spanish standard UNE 164004:2014 for almond and hazelnut shells.*

| | Oil | PSD31.5 | PSD16 | PSD2 | PSD1 |
|---|---|---|---|---|---|
| | w-% dry basis | accumulated w-% as received | | | |
| MEAN | 2.0 | 1.89 | 35.32 | 94.21 | 98.28 |
| P99 | 4.4 | 35.87 | 81.13 | 99.84 | 99.89 |
| P95 | 3.7 | 0.00 | 73.25 | 99.81 | 99.87 |
| P90 | 3.6 | 0.00 | 67.53 | 99.73 | 99.86 |
| P75 | 2.7 | 0.00 | 61.93 | 99.62 | 99.83 |
| P50 | 2.2 | 0.00 | 43.74 | 99.34 | 99.73 |
| P25 | 1.0 | 0.00 | 0.00 | 97.35 | 98.56 |
| P10 | 0.4 | 0.00 | 0.00 | 82.01 | 96.71 |
| MINIMUM | <0.10 | 0.00 | 0.00 | 54.76 | 85.29 |
| MAXIMUM | 4.6 | 47.20 | 83.18 | 99.84 | 99.90 |
| n | 25 | 25 | 25 | 25 | 25 |
| **Proposed limits (almond shells)** | | | | | |
| **class A1** | 0.6 | all < 31.5 mm | **n.r.** | 2 | **n.r.** |
| **class A2** | 1.0 | all < 31.5 mm | **n.r.** | 2 | **n.r.** |
| **class B** | 1.5 | all < 31.5 mm | **n.r.** | 4 | **n.r.** |
| **UNE 164004:2014 (almond and hazelnut shells)** | | | | | |
| **class A1** | 0.6 | all < 31.5 mm | NTS<16 mm | 2 | 1 |
| **class A2** | 1.0 | all < 31.5 mm | NTS<16 mm | 2 | 1 |
| **class B** | 1.5 | all < 31.5 mm | NTS<16 mm | 4 | 3 |

*NTS: Nominal top size; n.r.: no requirement*

*Table 3.12. Statistical results for the trace element contents of the analyzed almond shell samples, proposed limits for almond shells, and current limits in the Spanish standard UNE 164004:2014 for almond and hazelnut shells. The limits set in ISO 17225-2:2014 for wood pellets are also included.*

| | As | Cd | Cr | Cu | Hg | Ni | Pb | Zn |
|---|---|---|---|---|---|---|---|---|
| | mg/kg dry basis | mg/kg dry basis | mg/kg dry basis | mg/kg dry basis | mg/kg dry basis | mg/kg dry basis | mg/kg dry basis | mg/kg dry basis |
| MINIMUM | <0.5 | <0.01 | <0.30 | 0.23 | <0.001 | 0.33 | <0.02 | <1.0 |
| MAXIMUM | <0.5 | 0.50 | 7.1 | 14 | 0.003 | 5.3 | 13 | 9.5 |
| n | 15 | 25 | 25 | 25 | 25 | 25 | 25 | 25 |
| **Proposed limits (almond shells)** | | | | | | | | |
| **class A1** | 0.5 | **1** | **15** | **20** | 0.01 | 15 | 15 | **100** |
| **class A2** | 0.5 | **1** | **15** | **20** | 0.01 | 15 | 15 | **100** |
| **class B** | 0.5 | **1** | **15** | **20** | 0.01 | 15 | 15 | **100** |
| **UNE 164004:2014 (almond and hazelnut shells)** | | | | | | | | |
| **class A1** | 0.5 | 2 | 10 | 15 | 0.01 | 15 | 15 | 20 |
| **class A2** | 0.5 | 2 | 10 | 15 | 0.01 | 15 | 15 | 20 |
| **class B** | 0.5 | 2 | 10 | 15 | 0.01 | 15 | 15 | 20 |
| **ISO 17225-2:2014 (wood pellets)** | | | | | | | | |
| **class A1** | 1 | 0.5 | 10 | 10 | 0.1 | 10 | 10 | 100 |
| **class A2** | 1 | 0.5 | 10 | 10 | 0.1 | 10 | 10 | 100 |
| **class B** | 1 | 0.5 | 10 | 10 | 0.1 | 10 | 10 | 100 |

### 3.3.2. Hazelnut shells

Tables 3.13 to 3.15 show the results for all the hazelnut shell samples that were analyzed in Task 3.2 as well as the proposed new limits for this type of biomass and the current limits set in UNE 164004:2014 for almond and hazelnut shells.

*Table 3.13. Statistical results for the main properties of the analyzed hazelnut shell samples, proposed limits for hazelnut shells, and current limits in the Spanish standard UNE 164004:2014 for almond and hazelnut shells. The limits set in ISO 17225-2:2014 for wood pellets are also included for comparison reasons.*

| | M | BD | Q | A | N | S | Cl |
|---|---|---|---|---|---|---|---|
| | w-% as received | $kg/m^3$ as received | MJ/kg as received | w-% dry basis | w-% dry basis | w-% dry basis | w-% dry basis |
| MEAN | 13 | 320 | 16.54 | 1.2 | 0.28 | 0.02 | 0.02 |
| P99 | 17 | 560 | 17.84 | 1.7 | 0.41 | 0.04 | 0.03 |
| P95 | 16 | 560 | 17.15 | 1.5 | 0.38 | 0.03 | 0.03 |
| P90 | 16 | 550 | 17.06 | 1.4 | 0.35 | 0.03 | 0.03 |
| P75 | 14 | 340 | 16.96 | 1.3 | 0.32 | 0.03 | 0.02 |
| P50 | 13 | 310 | 16.49 | 1.2 | 0.30 | 0.02 | 0.01 |
| P25 | 11 | 300 | 16.21 | 1.1 | 0.25 | 0.02 | 0.01 |
| P10 | 10 | 290 | 15.90 | 1.1 | 0.19 | 0.02 | 0.01 |
| MINIMUM | 9.4 | 280 | 15.51 | 0.99 | 0.19 | 0.02 | 0.01 |
| MAXIMUM | 17 | 420 | 18.10 | 1.8 | 0.4 | 0.04 | 0.03 |
| n | 33 | 33 | 33 | 33 | 33 | 28 | 33 |
| **Proposed limits (hazelnut shells)** | | | | | | | |
| **class A1** | 12 | **300** | **16.0** | 0.7 | 0.4 | 0.03 | 0.02 |
| **class A2** | 12 | 300 | **16.0** | 1.5 | 0.6 | 0.03 | **0.03** |
| **class B** | 16 | 270 | **15.0** | 2.0 | 0.8 | **0.05** | **0.04** |
| **UNE 164004:2014 (almond and hazelnut shells)** | | | | | | | |
| **class A1** | 12 | 500 | 15.0 | 0.7 | 0.4 | 0.03 | 0.02 |
| **class A2** | 12 | 300 | 15.0 | 1.5 | 0.6 | 0.03 | 0.02 |
| **class B** | 16 | 270 | 14.2 | 2.0 | 0.8 | 0.04 | 0.03 |
| **ISO 17225-2:2014 (wood pellets)** | | | | | | | |
| **class A1** | 10 | 600 | 16.5 | 0.7 | 0.3 | 0.04 | 0.02 |
| **class A2** | 10 | 600 | 16.5 | 1.2 | 0.5 | 0.05 | 0.02 |
| **class B** | 10 | 600 | 16.5 | 2.0 | 1.0 | 0.05 | 0.03 |

As can be noticed in Table 3.13, the bulk density requirement set in UNE 164004:2014 for class A1 was so strict that only around 20% of the analyzed hazelnut shells were able to fulfill this limit. The proposal is therefore to update this limit to 300 $kg/m^3$, as received, which is around P50. In this case, the values obtained for P25 and P50 are very close, and therefore the requirement proposed for both classes A1 and A2 is 300 $kg/m^3$.

As previously explained, it should be highlighted that the limits proposed in this report for the calorific value of hazelnut shells are stricter than those specified in the current Spanish standard UNE 164004:2014 for this type of fuel.

*Table 3.14. Statistical results for the particle size and the oil content of the analyzed hazelnut shell samples, proposed limits for hazelnut shells, and current limits in the Spanish standard UNE 164004:2014 for almond and hazelnut shells.*

| | **Oil** | **PSD31.5** | **PSD16** | **PSD2** | **PSD1** |
|---|---|---|---|---|---|
| | w-% dry basis | accumulated w-% as received | | | |
| MEAN | 1.3 | 0.00 | 40.55 | 98.54 | 99.32 |
| P99 | 5.8 | 0.00 | 68.79 | 99.80 | 99.86 |
| P95 | 3.2 | 0.00 | 67.79 | 99.74 | 99.84 |
| P90 | 2.5 | 0.00 | 66.60 | 99.62 | 99.79 |
| P75 | 1.6 | 0.00 | 62.07 | 99.29 | 99.63 |
| P50 | 0.8 | 0.00 | 59.97 | 98.75 | 99.50 |
| P25 | 0.4 | 0.00 | 4.55 | 98.09 | 99.23 |
| P10 | 0.2 | 0.00 | 0.58 | 97.43 | 98.89 |
| MINIMUM | 0.11 | 0.00 | 0.00 | 95.78 | 97.86 |
| MAXIMUM | 6.6 | 0.00 | 69.04 | 99.81 | 99.86 |
| n | 23 | 13 | 13 | 13 | 13 |
| **Proposed limits (hazelnut shells)** | | | | | |
| **class A1** | 0.6 | all < 31.5 mm | **n.r.** | 2 | **n.r.** |
| **class A2** | 1.0 | all < 31.5 mm | **n.r.** | 2 | **n.r.** |
| **class B** | 1.5 | all < 31.5 mm | **n.r.** | 4 | **n.r.** |
| **UNE 164004:2014 (almond and hazelnut shells)** | | | | | |
| **class A1** | 0.6 | all < 31.5 mm | NTS<16 mm | 2 | 1 |
| **class A2** | 1.0 | all < 31.5 mm | NTS<16 mm | 2 | 1 |
| **class B** | 1.5 | all < 31.5 mm | NTS<16 mm | 4 | 3 |

*NTS: Nominal top size; n.r.: no requirement*

*Table 3.15. Statistical results for the trace element contents of the analyzed hazelnut shell samples, proposed limits for hazelnut shells, and current limits in the Spanish standard UNE 164004:2014 for almond and hazelnut shells. The limits set in ISO 17225-2:2014 for wood pellets are also included.*

| | **As** | **Cd** | **Cr** | **Cu** | **Hg** | **Ni** | **Pb** | **Zn** |
|---|---|---|---|---|---|---|---|---|
| | mg/kg dry basis | mg/kg dry basis | mg/kg dry basis | mg/kg dry basis | mg/kg dry basis | mg/kg dry basis | mg/kg dry basis | mg/kg dry basis |
| MINIMUM | <0.01 | <0.01 | <0.30 | 3.5 | <0.001 | 0.43 | 0.01 | <2.5 |
| MAXIMUM | 0.15 | 0.03 | 13 | 22 | 0.003 | 7.7 | 1.1 | 24 |
| n | 28 | 33 | 33 | 33 | 33 | 33 | 33 | 33 |
| **Proposed limits (hazelnut shells)** | | | | | | | | |
| **class A1** | 0.5 | **1** | **15** | **20** | 0.01 | 15 | 15 | **100** |
| **class A2** | 0.5 | **1** | **15** | **20** | 0.01 | 15 | 15 | **100** |
| **class B** | 0.5 | **1** | **15** | **20** | 0.01 | 15 | 15 | **100** |
| **UNE 164004:2014 (almond and hazelnut shells)** | | | | | | | | |
| **class A1** | 0.5 | 2 | 10 | 15 | 0.01 | 15 | 15 | 20 |
| **class A2** | 0.5 | 2 | 10 | 15 | 0.01 | 15 | 15 | 20 |
| **class B** | 0.5 | 2 | 10 | 15 | 0.01 | 15 | 15 | 20 |
| **ISO 17225-2:2014 (wood pellets)** | | | | | | | | |
| **class A1** | 1 | 0.5 | 10 | 10 | 0.1 | 10 | 10 | 100 |
| **class A2** | 1 | 0.5 | 10 | 10 | 0.1 | 10 | 10 | 100 |
| **class B** | 1 | 0.5 | 10 | 10 | 0.1 | 10 | 10 | 100 |

### 3.3.3. Pine nut shells

Tables 3.16 to 3.18 show the results for all the pine nut shell samples analyzed in Task 3.2 as well as the proposed new limits for this type of biomass and the current limits set in UNE 164004:2014.

*Table 3.16. Statistical results for the main properties of the analyzed pine nut shell samples, proposed limits for pine nut shells, and current limits in the Spanish standard UNE 164004:2014 for this type of biomass. The limits set in ISO 17225-2:2014 for wood pellets are also included.*

| | M | BD | Q | A | N | S | Cl |
|---|---|---|---|---|---|---|---|
| | w-% as received | kg/m$^3$ as received | MJ/kg as received | w-% dry basis | w-% dry basis | w-% dry basis | w-% dry basis |
| MEAN | 13 | 530 | 16.55 | 1.6 | 0.27 | 0.03 | 0.03 |
| P99 | 16 | 560 | 17.28 | 2.2 | 0.33 | 0.04 | 0.11 |
| P95 | 15 | 560 | 17.11 | 2.1 | 0.31 | 0.04 | 0.07 |
| P90 | 14 | 550 | 16.96 | 2.0 | 0.30 | 0.04 | 0.04 |
| P75 | 13 | 540 | 16.76 | 1.7 | 0.30 | 0.03 | 0.03 |
| P50 | 13 | 530 | 16.51 | 1.6 | 0.27 | 0.03 | 0.02 |
| P25 | 12 | 520 | 16.34 | 1.4 | 0.24 | 0.02 | 0.02 |
| P10 | 11 | 520 | 16.16 | 1.3 | 0.21 | 0.02 | 0.01 |
| MINIMUM | 9.9 | 480 | 15.83 | 1.2 | 0.21 | 0.02 | <0.01 |
| MAXIMUM | 16 | 560 | 17.32 | 2.2 | 0.33 | 0.04 | 0.12 |
| n | 14 | 10 | 14 | 14 | 14 | 14 | 14 |
| **Proposed limits (pine nut shells)** | | | | | | | |
| **class A1** | 12 | 470 | 16.0 | **0.7** | 0.4 | 0.03 | 0.02 |
| **class A2** | 12 | 470 | 16.0 | **1.5** | **0.6** | 0.03 | **0.03** |
| **class B** | 16 | 450 | **15.0** | 2.0 | 0.8 | 0.05 | **0.04** |
| **UNE 164004:2014 (pine nut shells)** | | | | | | | |
| **class A1** | 12 | 470 | 16.0 | 1.3 | 0.4 | 0.03 | 0.02 |
| **class A2** | 12 | 470 | 16.0 | 1.6 | 0.4 | 0.03 | 0.04 |
| **class B** | 16 | 450 | 15.2 | 2.0 | 0.8 | 0.05 | 0.06 |
| **ISO 17225-2:2014 (wood pellets)** | | | | | | | |
| **class A1** | 10 | 600 | 16.5 | 0.7 | 0.3 | 0.04 | 0.02 |
| **class A2** | 10 | 600 | 16.5 | 1.2 | 0.5 | 0.05 | 0.02 |
| **class B** | 10 | 600 | 16.5 | 2.0 | 1.0 | 0.05 | 0.03 |

All the analyzed samples were able to fulfill the requirements set in UNE 164004:2014 for the bulk density of this type of fuel and therefore no changes regarding the current limits are needed with respect to the mentioned standard.

It must be commented that most of the analyzed samples (12 out of 14) showed Cl levels ≤ 0.03 %. An exception is a Portuguese sample that is likely to be contaminated with salt, exhibiting Cl and Na contents of 0.12 % and 460 mg/kg, respectively.

*Table 3.17. Statistical results for the particle size and the oil content of the analyzed pine nut shell samples, proposed limits for pine nut shells, and current limits in the Spanish standard UNE 164004:2014 for this type of biomass.*

| | **Oil** | **PSD31.5** | **PSD16** | **PSD2** | **PSD1** |
|---|---|---|---|---|---|
| | w-% dry basis | accumulated w-% as received | | | |
| MEAN | 0.6 | 0.00 | 0.06 | 99.27 | 99.77 |
| P99 | 1.4 | 0.00 | 0.44 | 99.96 | 99.99 |
| P95 | 1.2 | 0.00 | 0.32 | 99.95 | 99.97 |
| P90 | 1.1 | 0.00 | 0.18 | 99.91 | 99.96 |
| P75 | 0.8 | 0.00 | 0.00 | 99.67 | 99.91 |
| P50 | 0.5 | 0.00 | 0.00 | 99.54 | 99.80 |
| P25 | 0.4 | 0.00 | 0.00 | 98.85 | 99.57 |
| P10 | 0.2 | 0.00 | 0.00 | 98.75 | 99.57 |
| MINIMUM | 0.1 | 0.00 | 0.00 | 97.59 | 99.52 |
| MAXIMUM | 1.4 | 0.00 | 0.47 | 99.97 | 99.99 |
| n | 14 | 12 | 12 | 12 | 12 |
| **Proposed limits (pine nut shells)** | | | | | |
| **class A1** | 0.6 | all < 31.5 mm | **n.r.** | 2 | **n.r.** |
| **class A2** | 1.0 | all < 31.5 mm | **n.r.** | 2 | **n.r.** |
| **class B** | 1.5 | all < 31.5 mm | **n.r.** | 4 | **n.r.** |
| **UNE 164004:2014 (pine nut shells)** | | | | | |
| **class A1** | 0.6 | all < 31.5 mm | NTS<16 mm | 2 | 1 |
| **class A2** | 1.0 | all < 31.5 mm | NTS<16 mm | 2 | 1 |
| **class B** | 1.5 | all < 31.5 mm | NTS<16 mm | 4 | 2 |

*NTS: Nominal top size; n.r.: no requirement*

*Table 3.18. Statistical results for the trace element contents of the analyzed pine nut shell samples, proposed limits for pine nut shells, and current limits in the Spanish standard UNE 164004:2014 for this type of biomass. The limits set in ISO 17225-2:2014 for wood pellets are also included.*

| | **As** | **Cd** | **Cr** | **Cu** | **Hg** | **Ni** | **Pb** | **Zn** |
|---|---|---|---|---|---|---|---|---|
| | mg/kg dry basis | mg/kg dry basis | mg/kg dry basis | mg/kg dry basis | mg/kg dry basis | mg/kg dry basis | mg/kg dry basis | mg/kg dry basis |
| MINIMUM | <0.50 | <0.01 | <0.30 | 0.45 | 0.002 | <1.0 | <0.60 | 5.3 |
| MAXIMUM | <0.50 | 0.04 | 5.0 | 4.2 | 0.006 | 4.3 | <1.0 | 17 |
| n | 4 | 14 | 14 | 14 | 14 | 14 | 14 | 14 |
| **Proposed limits (pine nut shells)** | | | | | | | | |
| **class A1** | 0.5 | **1** | **15** | **20** | 0.01 | 15 | **15** | **100** |
| **class A2** | 0.5 | **1** | **15** | **20** | 0.01 | 15 | **15** | **100** |
| **class B** | 0.5 | **1** | **15** | **20** | 0.01 | 15 | **15** | **100** |
| **UNE 164004:2014 (pine nut shells)** | | | | | | | | |
| **class A1** | 0.5 | 2 | 10 | 15 | 0.01 | 15 | 10 | 20 |
| **class A2** | 0.5 | 2 | 10 | 15 | 0.01 | 15 | 10 | 20 |
| **class B** | 0.5 | 2 | 10 | 15 | 0.01 | 15 | 10 | 20 |
| **ISO 17225-2:2014 (wood pellets)** | | | | | | | | |
| **class A1** | 1 | 0.5 | 10 | 10 | 0.1 | 10 | 10 | 100 |
| **class A2** | 1 | 0.5 | 10 | 10 | 0.1 | 10 | 10 | 100 |
| **class B** | 1 | 0.5 | 10 | 10 | 0.1 | 10 | 10 | 100 |

### 3.3.4. Pistachio shells

Tables 3.19 to 3.21 show the results for all the pistachio shell samples that were analyzed in Task 3.2 as well as the proposed new limits for this type of biomass and the current limits set in UNE 164004:2014 for almond and hazelnut shells.

*Table 3.19. Statistical results for the main properties of the analyzed pistachio shell samples, proposed limits for pistachio shells, and current limits in the Spanish standard UNE 164004:2014 for almond and hazelnut shells. The limits set in ISO 17225-2:2014 for wood pellets for commercial and residential applications are also included for comparison reasons.*

| | M | BD | Q | A | N | S | Cl |
|---|---|---|---|---|---|---|---|
| | w-% as received | $kg/m^3$ as received | MJ/kg as received | w-% dry basis | w-% dry basis | w-% dry basis | w-% dry basis |
| MEAN | 11 | 320 | 15.52 | 0.7 | 0.32 | 0.02 | 0.02 |
| P99 | 24 | 350 | 16.53 | 3.2 | 0.86 | 0.05 | 0.04 |
| P95 | 23 | 340 | 16.47 | 1.2 | 0.76 | 0.04 | 0.04 |
| P90 | 16 | 330 | 16.44 | 0.8 | 0.60 | 0.04 | 0.03 |
| P75 | 12 | 330 | 16.25 | 0.7 | 0.40 | 0.03 | 0.02 |
| P50 | 10 | 320 | 15.63 | 0.5 | 0.26 | 0.02 | 0.01 |
| P25 | 8.0 | 310 | 15.25 | 0.4 | 0.15 | 0.01 | 0.01 |
| P10 | 7.7 | 290 | 14.71 | 0.3 | 0.12 | 0.01 | <0.01 |
| MINIMUM | 7.5 | 290 | 12.85 | 0.2 | 0.12 | 0.01 | <0.01 |
| MAXIMUM | 24 | 350 | 16.55 | 3.7 | 0.89 | 0.05 | 0.04 |
| n | 19 | 19 | 19 | 19 | 19 | 15 | 19 |
| **Proposed limits (pistachio shells)** | | | | | | | |
| **class A1** | 12 | **300** | 15.0 | 0.7 | 0.4 | 0.03 | 0.02 |
| **class A2** | 12 | 300 | 15.0 | 1.5 | 0.6 | 0.03 | **0.03** |
| **class B** | 16 | 270 | **14.0** | 2.0 | 0.8 | **0.05** | **0.04** |
| **UNE 164004:2014 (almond and hazelnut shells)** | | | | | | | |
| **class A1** | 12 | 500 | 15.0 | 0.7 | 0.4 | 0.03 | 0.02 |
| **class A2** | 12 | 300 | 15.0 | 1.5 | 0.6 | 0.03 | 0.02 |
| **class B** | 16 | 270 | 14.2 | 2.0 | 0.8 | 0.04 | 0.03 |
| **ISO 17225-2:2014 (wood pellets)** | | | | | | | |
| **class A1** | 10 | 600 | 16.5 | 0.7 | 0.3 | 0.04 | 0.02 |
| **class A2** | 10 | 600 | 16.5 | 1.2 | 0.5 | 0.05 | 0.02 |
| **class B** | 10 | 600 | 16.5 | 2.0 | 1.0 | 0.05 | 0.03 |

As pistachio shells were not ruled in UNE 164004:2014 and none of the analyzed samples was able to fulfill the requirements set in this standard for the bulk density of almond and hazelnut shells, it is necessary to propose specific quality requirements for this type of fuel. As the values obtained for the lower percentiles are very close, it is proposed to set a bulk density requirement of 300 $kg/m^3$ for both classes A1 and A2. In this way, none of the samples with a bulk density around this value would be left out.

*Table 3.20. Statistical results for the particle size and the oil content of the analyzed pistachio shell samples, proposed limits for pistachio shells, and current limits in the Spanish standard UNE 164004:2014 for almond and hazelnut shells.*

| | **Oil** | **PSD31.5** | **PSD16** | **PSD2** | **PSD1** |
|---|---|---|---|---|---|
| | w-% dry basis | accumulated w-% as received | | | |
| MEAN | 1.4 | 0.00 | 1.49 | 99.52 | 99.77 |
| P99 | 4.0 | 0.00 | 6.48 | 99.98 | 99.99 |
| P95 | 3.5 | 0.00 | 5.42 | 99.96 | 99.97 |
| P90 | 3.3 | 0.00 | 4.42 | 99.95 | 99.96 |
| P75 | 2.4 | 0.00 | 1.98 | 99.89 | 99.94 |
| P50 | 1.2 | 0.00 | 0.23 | 99.58 | 99.80 |
| P25 | 0.2 | 0.00 | 0.00 | 99.28 | 99.69 |
| P10 | 0.2 | 0.00 | 0.00 | 99.03 | 99.51 |
| MINIMUM | 0.1 | 0.00 | 0.00 | 98.24 | 99.36 |
| MAXIMUM | 4.1 | 0.00 | 6.74 | 99.98 | 99.99 |
| n | 19 | 13 | 13 | 13 | 13 |
| **Proposed limits (pistachio shells)** | | | | | |
| **class A1** | 0.6 | all < 31.5 mm | **n.r.** | 2 | **n.r.** |
| **class A2** | 1.0 | all < 31.5 mm | **n.r.** | 2 | **n.r.** |
| **class B** | 1.5 | all < 31.5 mm | **n.r.** | 4 | **n.r.** |
| **UNE 164004:2014 (almond and hazelnut shells)** | | | | | |
| **class A1** | 0.6 | all < 31.5 mm | NTS<16 mm | 2 | 1 |
| **class A2** | 1.0 | all < 31.5 mm | NTS<16 mm | 2 | 1 |
| **class B** | 1.5 | all < 31.5 mm | NTS<16 mm | 4 | 3 |

*NTS: Nominal top size; n.r.: no requirement*

*Table 3.21. Statistical results for the trace element contents of the analyzed pistachio shell samples, proposed limits for pistachio shells, and current limits in the Spanish standard UNE 164004:2014 for almond and hazelnut shells. The limits set in ISO 17225-2:2014 for wood pellets for commercial and residential applications are also included for comparison reasons.*

| | **As** | **Cd** | **Cr** | **Cu** | **Hg** | **Ni** | **Pb** | **Zn** |
|---|---|---|---|---|---|---|---|---|
| | mg/kg dry basis | mg/kg dry basis | mg/kg dry basis | mg/kg dry basis | mg/kg dry basis | mg/kg dry basis | mg/kg dry basis | mg/kg dry basis |
| MINIMUM | <0.01 | <0.01 | 0.72 | 0.67 | <0.001 | 0.27 | <0.02 | 0.78 |
| MAXIMUM | 0.028 | <0.10 | 13 | 72 | 0.006 | 11 | 4.0 | 67 |
| n | 9 | 19 | 19 | 19 | 19 | 19 | 19 | 19 |
| **Proposed limits (pistachio shells)** | | | | | | | | |
| **class A1** | 0.5 | **1** | **15** | **20** | 0.01 | 15 | 15 | **100** |
| **class A2** | 0.5 | **1** | **15** | **20** | 0.01 | 15 | 15 | **100** |
| **class B** | 0.5 | **1** | **15** | **20** | 0.01 | 15 | 15 | **100** |
| **UNE 164004:2014 (almond and hazelnut shells)** | | | | | | | | |
| **class A1** | 0.5 | 2 | 10 | 15 | 0.01 | 15 | 15 | 20 |
| **class A2** | 0.5 | 2 | 10 | 15 | 0.01 | 15 | 15 | 20 |
| **class B** | 0.5 | 2 | 10 | 15 | 0.01 | 15 | 15 | 20 |
| **ISO 17225-2:2014 (wood pellets)** | | | | | | | | |
| **class A1** | 1 | 0.5 | 10 | 10 | 0.1 | 10 | 10 | 100 |
| **class A2** | 1 | 0.5 | 10 | 10 | 0.1 | 10 | 10 | 100 |
| **class B** | 1 | 0.5 | 10 | 10 | 0.1 | 10 | 10 | 100 |

It should be mentioned that all of analyzed pistachio samples showed Cu levels below 20 mg/kg, with the exception of the three samples that came from Greece (46-72 mg/kg). Although not confirmed, it has been hypothesized that these samples exhibited elevated levels of Cu due the specific wet treatment, which was used to separate the nuts from the shells. A wet treatment of pistachio fruits (exocarp) might have transferred some Cu from fungicide sprayings into shells (endocarp) fraction. In contrast, a dry separation of nuts from the shell fraction would have not altered the Cu content of the involved fractions. In this report, and waiting for a secure explanation of the high Cu content values obtained from the cited Greek fuel samples, those values have not been taken into consideration to rule this element.

### 3.3.5. Walnut shells

Tables 3.22 to 3.24 show the results for all the walnut shell samples that were analyzed in Task 3.2 as well as the proposed new limits for this type of biomass and the current limits set in UNE 164004:2014 for almond and hazelnut shells.

*Table 3.22. Statistical results for the main properties of the analyzed walnut shell samples, proposed limits for walnut shells, and current limits in the Spanish standard UNE 164004:2014 for almond and hazelnut shells. The limits set in ISO 17225-2:2014 for wood pellets are also included.*

| | **M** | **BD** | **Q** | **A** | **N** | **S** | **Cl** |
|---|---|---|---|---|---|---|---|
| | w-% as received | kg/m$^3$ as received | MJ/kg as received | w-% dry basis | w-% dry basis | w-% dry basis | w-% dry basis |
| MEAN | 10 | 240 | 17.21 | 1.2 | 0.42 | 0.02 | 0.04 |
| P99 | 13 | 330 | 19.85 | 1.6 | 1.01 | 0.06 | 0.12 |
| P95 | 12 | 290 | 18.63 | 1.5 | 0.80 | 0.05 | 0.09 |
| P90 | 12 | 260 | 18.15 | 1.5 | 0.80 | 0.04 | 0.07 |
| P75 | 11 | 260 | 17.65 | 1.4 | 0.65 | 0.02 | 0.04 |
| P50 | 10 | 240 | 16.93 | 1.1 | 0.32 | 0.02 | 0.03 |
| P25 | 9.7 | 220 | 16.54 | 1.0 | 0.20 | 0.02 | 0.02 |
| P10 | 8.7 | 210 | 16.51 | 0.9 | 0.14 | 0.01 | 0.02 |
| MINIMUM | 7.6 | 180 | 15.73 | 0.8 | 0.13 | 0.01 | 0.01 |
| MAXIMUM | 14 | 340 | 20.16 | 1.6 | 1.06 | 0.06 | 0.13 |
| n | 21 | 19 | 21 | 21 | 21 | 21 | 21 |
| **Proposed limits (walnut shells)** | | | | | | | |
| **class A1** | 12 | **250** | **16.0** | 0.7 | 0.4 | 0.03 | 0.02 |
| **class A2** | 12 | **200** | **16.0** | 1.5 | 0.6 | 0.03 | **0.03** |
| **class B** | 16 | **200** | **15.0** | 2.0 | 0.8 | **0.05** | **0.04** |
| **UNE 164004:2014 (almond and hazelnut shells)** | | | | | | | |
| **class A1** | 12 | 500 | 15.0 | 0.7 | 0.4 | 0.03 | 0.02 |
| **class A2** | 12 | 300 | 15.0 | 1.5 | 0.6 | 0.03 | 0.02 |
| **class B** | 16 | 270 | 14.2 | 2.0 | 0.8 | 0.04 | 0.03 |
| **ISO 17225-2:2014 (wood pellets)** | | | | | | | |
| **class A1** | 10 | 600 | 16.5 | 0.7 | 0.3 | 0.04 | 0.02 |
| **class A2** | 10 | 600 | 16.5 | 1.2 | 0.5 | 0.05 | 0.02 |
| **class B** | 10 | 600 | 16.5 | 2.0 | 1.0 | 0.05 | 0.03 |

As in case of pistachio, walnut shells are also a new material, not initially included in UNE 164004:2014. Therefore, it was necessary to establish specific requirements for the bulk density of this type of fuel. Again, the requirement for the bulk density of class A1 was set in 250 kg/m$^3$, a value that lies around P50. Regarding classes A2 and B, a requirement of 200 kg/m$^3$ is proposed, a bulk density that should be easily achieved by this type of fuel. As it can be seen in Table 3.22, around 95% of the analyzed samples met this criteria.

All the analyzed samples exhibited Cu contents below 10 mg/kg, excepting for one sample from Turkey with a Cu content of 42 mg/kg.

*Table 3.23. Statistical results for the particle size and the oil content of the analyzed walnut shell samples, proposed limits for walnut shells, and current limits in the Spanish standard UNE 164004:2014 for almond and hazelnut shells.*

| | Oil | PSD31.5 | PSD16 | PSD2 | PSD1 |
|---|---|---|---|---|---|
| | w-% dry basis | accumulated w-% as received | | | |
| MEAN | 3.9 | 2.03 | 69.45 | 99.54 | 99.72 |
| P99 | 11 | 10.83 | 96.53 | 100.00 | 100.00 |
| P95 | 10 | 9.60 | 95.86 | 99.98 | 99.98 |
| P90 | 7.1 | 8.05 | 95.02 | 99.96 | 99.96 |
| P75 | 5.1 | 1.59 | 83.76 | 99.75 | 99.86 |
| P50 | 3.8 | 0.00 | 76.24 | 99.59 | 99.72 |
| P25 | 1.9 | 0.00 | 57.32 | 99.38 | 99.61 |
| P10 | 0.3 | 0.00 | 33.60 | 99.02 | 99.41 |
| MINIMUM | 0.1 | 0.00 | 33.27 | 98.98 | 99.39 |
| MAXIMUM | 11 | 11.14 | 96.70 | 100.00 | 100.00 |
| n | 21 | 11 | 11 | 11 | 11 |
| **Proposed limits (walnut shells)** | | | | | |
| **class A1** | 0.6 | all < 31.5 mm | **n.r.** | 2 | **n.r.** |
| **class A2** | 1.0 | all < 31.5 mm | **n.r.** | 2 | **n.r.** |
| **class B** | 1.5 | all < 31.5 mm | **n.r.** | 4 | **n.r.** |
| **UNE 164004:2014 (almond and hazelnut shells)** | | | | | |
| **class A1** | 0.6 | all < 31.5 mm | NTS<16 mm | 2 | 1 |
| **class A2** | 1.0 | all < 31.5 mm | NTS<16 mm | 2 | 1 |
| **class B** | 1.5 | all < 31.5 mm | NTS<16 mm | 4 | 3 |

*NTS: Nominal top size; n.r.: no requirement*

*Table 3.24. Statistical results for the trace element contents of the analyzed walnut shell samples, proposed limits for walnut shells, and current limits in the Spanish standard UNE 164004:2014 for almond and hazelnut shells.* The limits set in ISO 17225-2:2014 for wood pellets are also included.

| | As | Cd | Cr | Cu | Hg | Ni | Pb | Zn |
|---|---|---|---|---|---|---|---|---|
| | mg/kg dry basis | mg/kg dry basis | mg/kg dry basis | mg/kg dry basis | mg/kg dry basis | mg/kg dry basis | mg/kg dry basis | mg/kg dry basis |
| MINIMUM | <0.01 | <0.01 | 0.36 | 2.8 | <0.001 | 0.28 | <0.02 | 0.99 |
| MAXIMUM | 0.056 | 0.15 | 7.1 | 42 | 0.002 | 4.9 | 0.64 | 12 |
| n | 16 | 21 | 21 | 21 | 21 | 21 | 21 | 21 |
| **Proposed limits (walnut shells)** | | | | | | | | |
| **class A1** | 0.5 | **1** | **15** | **20** | 0.01 | 15 | 15 | **100** |
| **class A2** | 0.5 | **1** | **15** | **20** | 0.01 | 15 | 15 | **100** |
| **class B** | 0.5 | **1** | **15** | **20** | 0.01 | 15 | 15 | **100** |
| **UNE 164004:2014 (almond and hazelnut shells)** | | | | | | | | |
| **class A1** | 0.5 | 2 | 10 | 15 | 0.01 | 15 | 15 | 20 |
| **class A2** | 0.5 | 2 | 10 | 15 | 0.01 | 15 | 15 | 20 |
| **class B** | 0.5 | 2 | 10 | 15 | 0.01 | 15 | 15 | 20 |
| **ISO 17225-2:2014 (wood pellets)** | | | | | | | | |
| **class A1** | 1 | 0.5 | 10 | 10 | 0.1 | 10 | 10 | 100 |
| **class A2** | 1 | 0.5 | 10 | 10 | 0.1 | 10 | 10 | 100 |
| **class B** | 1 | 0.5 | 10 | 10 | 0.1 | 10 | 10 | 100 |

# 4. Specifications of graded biofuels

This section summarizes the specifications proposed to grade vineyard and olive tree pruning, olive stones and dry fruit shells. These specifications could be reflected in future standards and they should be considered to update and extend the existing BIOMASUD label to new solid biofuels.

## 4.1. Pruning samples

### 4.1.1. Vineyard pruning

As exposed in section 3, with the current available information a specific standard or specific limits in ISO that grade prunings from vineyards is not deemed necessary. At present, it is proposed to maintain the current ISO specifications that grade wood pellets [6] and wood chips[7] unchanged for this fuel.

### 4.1.2. Olive tree pruning

Olive tree prunings devoid of leaves could be used to produce wood pellets, class B, for commercial and residential applications, in case the requirement in ISO [6] for the net calorific value of this class was set in 15.0 MJ/kg, as received. The use of this type of biomass in the domestic sector would otherwise be limited to produce wood chips, class B, according to ISO [7]. Olive tree pruning with a significant fraction of leaves would hardly meet the ash criteria set for domestic applications (3.0 w%) and thus their use should be oriented to produce wood chips for industrial applications.

## 4.2. Olive stones

Table 4.1 shows the specifications that are proposed to grade olive stones for commercial and residential applications and that should be reflected in an updated standard and Biomasud label for olive stones.

*Table 4.1. Specification of graded olive stones for commercial and residential applications*

| | Property class, Analysis method | | Unit | A1 | A2 | B |
|---|---|---|---|---|---|---|
| Normative | **Origin and source,** ISO 17225-1 | | | 3.1.2.3 Stone/kernel/fruit fibre<br>3.2.1.2 Stone/kernel fruits/fruit fibre<br>3.2.2.2 Stone/kernel fruits (chemically treated) [a] | 3.1.2.3 Stone/kernel/fruit fibre<br>3.2.1.2 Stone/kernel fruits/fruit fibre<br>3.2.2.2 Stone/kernel fruits (chemically treated) [a] | 3.1.2.3 Stone/kernel/fruit fibre<br>3.2.1.2 Stone/kernel fruits/fruit fibre<br>3.2.2.2 Stone/kernel fruits (chemically treated) [a] |
| | **Particle size [b],** ISO 17827 | Fines, F < 2mm | w-% as received | < 15 | < 15 | < 15 |
| | **Oil,** EEC2568/91 | | w-% dry | < 0.6 | < 1.0 | < 3.0 |
| | **Moisture, M,** ISO 18134-1, ISO 18134-2 | | w-% as received, wet basis | M12 ≤ 12 | M12 ≤ 12 | M16 ≤ 16 |
| | **Ash, A,** ISO 18122 | | w-% dry | A0.7 ≤ 0.7 | A1.0 ≤ 1.0 | A1.3 ≤ 1.3 |
| | **Net calorific value, Q,** ISO 18125 | | MJ/kg as received | Q15.7 ≥ 15.7 | Q15.7 ≥ 15.7 | Q14.9 ≥ 14.9 |
| | **Bulk density, BD** ISO 17828 | | $kg/m^3$ as received | BD700 ≥ 700 | BD650 ≥ 650 | BD600 ≥ 600 |
| | **Nitrogen, N,** ISO 16948 | | w-% dry | N0.3 ≤ 0.3 | N0.4 ≤ 0.4 | N0.6 ≤ 0.6 |
| | **Sulfur, S,** ISO 16994 | | w-% dry | S0.03 ≤ 0.03 | S0.04 ≤ 0.04 | S0.05 ≤ 0.05 |
| | **Chlorine, Cl,** ISO 16994 | | w-% dry | Cl0.03 ≤ 0.03 | Cl0.04 ≤ 0.04 | Cl0.05 ≤ 0.05 |
| | **Arsenic, As**, ISO 16968 | | mg/kg dry | ≤ 0.5 | ≤ 0.5 | ≤ 0.5 |
| | **Cadmium, Cd,** ISO 16968 | | mg/kg dry | ≤ 0.5 | ≤ 0.5 | ≤ 0.5 |
| | **Chromium, Cr,** ISO 16968 | | mg/kg dry | ≤ 10 | ≤ 10 | ≤ 10 |
| | **Copper, Cu,** ISO 16968 | | mg/kg dry | ≤ 15 | ≤ 15 | ≤ 15 |
| | **Lead, Pb,** ISO 16968 | | mg/kg dry | ≤ 10 | ≤ 10 | ≤ 10 |
| | **Mercury, Hg,** ISO 16968 | | mg/kg dry | ≤ 0.01 | ≤ 0.01 | ≤ 0.01 |
| | **Nickel, Ni,** ISO 16968 | | mg/kg dry | ≤ 15 | ≤ 15 | ≤ 15 |
| | **Zinc, Zn,** ISO 16968 | | mg/kg dry | ≤ 100 | ≤ 100 | ≤ 100 |
| Informative | **Informative: Ash melting behaviour,** CEN/TS 15370-1 | | $^0C$ | Should be stated | Should be stated | Should be stated |
| | [a] Olive stones can come from oil mills or oil extractors. In case it comes from oil extractors, it may have suffered a chemical treatment with hexane or other solvents, which are subsequently recovered, fro the extraction process of the residual oil. This extraction process and the solvents used must be stated. Olive stones treated with chemical additives, such as salt or soda, are excluded from this standard. | | | | | |
| | [b] 100 w-% of sample must pass through the round hole sieve size of 16 mm | | | | | |

## 4.3. Dry fruit shells

Table 4.2 shows the specifications that are proposed to grade dry fruit shells for commercial and residential applications. Table 4.3 sets the particular specifications (calorific value and bulk density) that are proposed to grade dry fruit shells as a function of the type of fruit shell. These specifications should be reflected in an updated standard and Biomasud label for dry fruit shells.

*Table 4.2. Specification of graded dry fruit shells for commercial and residential applications*

| | **Property class,** Analysis method | | Unit | A1 | A2 | B |
|---|---|---|---|---|---|---|
| Normative | **Origin and source,** ISO 17225-1 | | | 3.1.3.2 Shells/husks | 3.1.3.2 Shells/husks | 3.1.3.2 Shells/husks |
| | **Particle size** [a], ISO 17827 | Fines, F < 2mm | w-% as received | < 2.0 | < 2.0 | < 4.0 |
| | **Oil,** EEC2568/91 | | w-% dry | < 0.6 | < 1.0 | < 1.5 |
| | **Moisture, M,** ISO 18134-1, ISO 18134-2 | | w-% as received, wet basis | M12 ≤ 12 | M12 ≤ 12 | M16 ≤ 16 |
| | **Ash, A,** ISO 18122 | | w-% dry | A0.7 ≤ 0.7 | A1.6 ≤ 1.6 | A2.0 ≤ 2.0 |
| | **Net calorific value, Q,** ISO 18125 | | MJ/kg as received | To be selected from Table 4.6 | | |
| | **Bulk density, BD** ISO 17828 | | $kg/m^3$ as received | To be selected from Table 4.6 | | |
| | **Nitrogen, N,** ISO 16948 | | w-% dry | N0.4 ≤ 0.4 | N0.6 ≤ 0.6 | N0.8 ≤ 0.8 |
| | **Sulfur, S,** ISO 16994 | | w-% dry | S0.03 ≤ 0.03 | S0.03 ≤ 0.03 | S0.05 ≤ 0.05 |
| | **Chlorine, Cl,** ISO 16994 | | w-% dry | Cl0.02 ≤ 0.02 | Cl0.03 ≤ 0.03 | Cl0.04 ≤ 0.04 |
| | **Arsenic, As,** ISO 16968 | | mg/kg dry | ≤ 0.5 | ≤ 0.5 | ≤ 0.5 |
| | **Cadmium, Cd,** ISO 16968 | | mg/kg dry | ≤ 1.0 | ≤ 1.0 | ≤ 1.0 |
| | **Chromium, Cr,** ISO 16968 | | mg/kg dry | ≤ 15 | ≤ 15 | ≤ 15 |
| | **Copper, Cu,** ISO 16968 | | mg/kg dry | ≤ 20 | ≤ 20 | ≤ 20 |
| | **Lead, Pb,** ISO 16968 | | mg/kg dry | ≤ 15 | ≤ 15 | ≤ 15 |
| | **Mercury, Hg,** ISO 16968 | | mg/kg dry | ≤ 0.01 | ≤ 0.01 | ≤ 0.01 |
| | **Nickel, Ni,** ISO 16968 | | mg/kg dry | ≤ 15 | ≤ 15 | ≤ 15 |
| | **Zinc, Zn,** ISO 16968 | | mg/kg dry | ≤ 100 | ≤ 100 | ≤ 100 |
| Informative | **Informative: Ash melting behaviour,** CEN/TS 15370-1 | | $^0C$ | Should be stated | Should be stated | Should be stated |

*Table 4.3. Particular specifications depending on the type of dry fruit shell.*

| | Property class, Analysis method | Unit | A1 | A2 | B |
|---|---|---|---|---|---|
| **Almond shells** | | | | | |
| Normative | **Net calorific value, Q,** ISO 18125 | MJ/kg as received | Q15.0 ≥ 15.0 | Q15.0 ≥ 15.0 | Q14.0 ≥ 14.0 |
| | **Bulk density, BD** ISO 17828 | kg/m$^3$ as received | BD450 ≥ 450 | BD300 ≥ 300 | BD270 ≥ 270 |
| **Hazelnut shells** | | | | | |
| Normative | **Net calorific value, Q,** ISO 18125 | MJ/kg as received | Q16.0 ≥ 16.0 | Q16.0 ≥ 16.0 | Q15.0 ≥ 15.0 |
| | **Bulk density, BD** ISO 17828 | kg/m$^3$ as received | BD300 ≥ 300 | BD300 ≥ 300 | BD270 ≥ 270 |
| **Pine nut shells** | | | | | |
| Normative | **Net calorific value, Q,** ISO 18125 | MJ/kg as received | Q16.0 ≥ 16.0 | Q16.0 ≥ 16.0 | Q15.0 ≥ 15.0 |
| | **Bulk density, BD** ISO 17828 | kg/m$^3$ as received | BD470 ≥ 470 | BD470 ≥ 470 | BD450 ≥ 450 |
| **Pistachio shells** | | | | | |
| Normative | **Net calorific value, Q,** ISO 18125 | MJ/kg as received | Q15.0 ≥ 15.0 | Q15.0 ≥ 15.0 | Q14.0 ≥ 14.0 |
| | **Bulk density, BD** ISO 17828 | kg/m$^3$ as received | BD300 ≥ 300 | BD300 ≥ 300 | BD270 ≥ 270 |
| **Walnut shells** | | | | | |
| Normative | **Net calorific value, Q,** ISO 18125 | MJ/kg as received | Q16.0 ≥ 16.0 | Q16.0 ≥ 16.0 | Q15.0 ≥ 15.0 |
| | **Bulk density, BD** ISO 17828 | kg/m$^3$ as received | BD250 ≥ 250 | BD200 ≥ 200 | BD200 ≥ 200 |

## 5. Conclusions

On the basis of the results obtained from the biomass and biofuels analysis campaign performed in Task 3.2 that included more than 300 samples coming from Croatia, Greece, Italy, Portugal, Slovenia, Spain, and Turkey, and those from testing of these fuels in state of the art domestic combustion equipments ([5] and additional tests), this report shows the proposed specifications to grade solid biofuels (pellets, chips) for residential and commercial use that can be produced from the following typical Mediterranean biomasses: olive tree and vineyard pruning, olive stones, and dry fruit shells: almond, hazelnut, pine nut, pistachio, and walnut shells.

Concerning olive stones, the quality classes and limits for this fuel in Spanish standard (UNE 164003:2014) have been kept with exception of limits for Cd and Zn that have been modified to adapt them to the considered samples sets and to the limits of ISO 17225-2, for wood pellets. Moreover, it has been confirmed the oil content as a useful and necessary normative parameter to establish quality classes and it has been proposed to relax the limit of oil content for class B olive stones of UNE standard up to 3 w% d.b. Contrarily, determination of skin content is proposed to be skipped from the UNE standard, as it is related to oil content and in principle does not seem to provide any additional information about fuel behavior. The analysis of granulometry has been simplified to two particle sizes only.

With respect to the Spanish standard that grades dry fruit shells (UNE 164004:2014), an important achievement is the inclusion of new types of fruit shells, namely walnut and pistachio shells, and the unification of most requirements for the normative quality properties in a single table, regardless of the type of shell considered, with the exception of calorific value and bulk density, quality properties that depend on the intrinsic nature of the material and the fuel management and preparation process. It is also relevant to mention the relaxed limits proposed in the UNE standard for some normative minor elements in fruit shells, namely chromium and cupper, which is deemed necessary, possibly in connection to the higher abrasion produced on the metallic parts of the mills by the these materials compared to other biomasses, and the use of copper as a component of the pesticides utilized in the cultivation of fruit trees. However, the doubts about the convenience or not to consider oil content as a normative parameter to grade the dry fruit shells and the eventual quality grading still remains. Moreover, the adequacy or not of these fuels to be used in small domestic state of the art heating systems is an issue identified in the project that will require further more comprehensive combustion test studies, out of the scope of the project.

This deliverable also shows the need to relax the limit imposed of the net calorific value of wood pellets, class B, in the relevant ISO standard and set this requirement in 15.0 MJ/kg (instead of 16.5 MJ/kg), as received, or to create a specification for olive tree pruning. In this way, olive tree pruning devoid of leaves could be used to produce wood pellets for commercial and residential applications. The use of this type of biomass in the domestic sector would otherwise be limited to produce domestic wood chips, class B. For similar reasons commented for vineyard prunings below, the use of olive tree pruning with a significant fraction of leaves should be oriented to produce wood chips for industrial applications.

With the current available information, a specific standard or specific limits to grade the quality of vineyard pruning to be used in the commercial and residential sector is not deemed necessary because, on one hand, the analytical results for this biomass indicate that the possibilities of vineyard pruning to comply with ISO 17225 2:2014 (wood pellets) and ISO 17225 4:2014 (wood chips) class limits are very limited, if any, and, on the other hand, the combustion test runs performed with vineyard pruning pellets in small boilers and stoves revealed high emissions levels which, in principle (particularly NOx), do not seem can be reasonability reduced in these heating devices with cost efficient measures. In turn, this type of biomass could be used to produce wood chips for industrial applications. ISO/TC 238 is expected to publish an international standard that grades wood chips for industrial applications in a near future.

As a general conclusion, and despite the still not well defined situation in regard to the suitability of dry fruit shells as fuels in the commercial and residential sector, the objectives initially planned in Task 3.3 have been met within the foreseen scope in the project grant agreement.

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