1.3 WEATHER SEASONALITY AND PATTERN OF THERMOCHEMICAL PROPERTIES IN VEGETATION LIVING IN THE MEDITERRANEAN BASIN

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1. INTRODUCTION

Wildland fires represent a serious threat to forests and wooded areas of Mediterranean Basin, in particular Spain, Portugal and Italy (European Communities 2002). Many factors affect wildland fire occurrence. The impact of vegetation variables includes land cover, type, humidity status, and availability of fuel.

Evergreen sclerophyll shrubland is a prominent feature of Mediterranean Basin. Mediterranean shrub species are also an important component of the understorey vegetation that constitutes the surface fuels primarily responsible for the ignition and the spread of wildland fires in Mediterranean forests. Moreover, it represents the principal type of vegetation in the wildland urban interface, especially in tourist resort areas. In Mediterranean shrublands, the main component of the available fuel to fire is represented by live fuel (Sun *et al.* 2006). Prediction of fire behavior in Mediterranean shrubland is difficult because of the high specific and structural heterogeneity and complexity that characterize this type of vegetation. Therefore classification of Mediterranean shrubs according to their expected flammability can represent an important component of fuel hazard assessment (Dimitrakopoulos 2001).

The term flammability is widely used in fire literature to indicate the ability of a particular fuel to ignite and sustain fire. Several studies (Anderson 1970; Mak 1988; Hogenbirk and Sarrazin-Delay 1995) defined flammability as a combination of three components:

- ignitability, the time until ignition occurs;
- sustainability, the ability of the fire to continue burning;
- combustibility, how quickly a fuel is consumed by fire.

Standard widely accepted methods for vegetation flammability measurements have not been identified. Different plants characteristics and different methodologies have been used to define flammability and the relative fire hazard of the vegetation (Weise *et al.* 2005). Etlinger and Beall (2004) and Weise *et al.* (2005) provided a summary of the different approaches for evaluating vegetation flammability, reporting that the methodologies to estimate the fire behavior in living vegetation differ according to spatial observation scales (from leaf material to ecosystem). Several authors determined time to ignition, live fine fuel moisture content and heat content for estimating flammability of plants (Trabaud 1976; Valette 1990; Hernando Lara *et al.* 1994; Dimitrakopoulos and Papaioannou 2001; Castro *et al.* 2003; Behem *et al.* 2004; Chuvieco *et al.* 2004; Engstrom *et al.* 2004; Núñez-Regueira *et al*. 2004).

In this work, heat content, time to ignition (*ID time*), and moisture content (*LFMC*) of live fine fuel for ten dominant species (*Arbutus unedo* L., *Cistus salvifolius* L., *Cistus monspeliensis* L., *Erica scoparia* L., *Helichrysum italicum* Roth., *Juniperus phoenicea* L., *Lavandula stoechas* L., *Phillyrea angustifolia* L., *Pistacia lentiscus* L., and *Rosmarinus officinalis* L.) growing in two areas located in North Sardinia, Italy, were measured.

The main objectives of this work were (i) to describe seasonal variations of time to ignition, live fuel moisture content, and heat content; (ii) to evaluate relationships between moisture content and time to ignition, and (iii) to evaluate the influence of seasonal weather variations and phenology on seasonal patterns of flammability characteristics. The general goal is to identify differences among species in terms of flammability.

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2. MATERIALS AND METHODS

The study was carried out in two Mediterranean type ecosystems. The first was in a coastal area and the second in an inland hilly site, both dominated by evergreen and semi-deciduous small shrub species.

The first site is located in North-Western Sardinia, Italy, within a nature reserve (40° 36' N, 8° 09' E, 30 m a.s.l.) covering approximately 1200 ha. The climate is semi-arid with a remarkable water deficit from May through September (mean annual rainfall 600 mm, mean annual temperature 16 °C). The vegetation was mainly characterized by the presence of *Cistus monspeliensis* L., *Helichrysum italicum* Roth., *Juniperus phoenicea* L., *Phillyrea angustifolia* L., *Pistacia lentiscus* L., and *Rosmarinus officinalis* L.

The second site is located in a forest area in North-Eastern Sardinia, Italy (40° 42' N; 9° 24' E, 700 m a.s.l.), mainly covered by evergreen and semi-deciduous small shrubs. Rainfall events are concentrated in autumn and winter seasons with a water deficit from June through September (mean annual rainfall 996 mm, mean annual temperature 12.9 °C). The vegetation cover mainly includes *Arbutus unedo* L., *Cistus salvifolius* L., *Erica scoparia* L., and *Lavandula stoechas* L.

ID time, *LFMC* and heat content values of terminal portion of twigs (live fine fuel) were measured on the above-mentioned dominant species in the coastal and inland sites. Measurements were taken every one or two months, from October 2003 to October 2004, in the coastal site, and from April to November 2005 in the inland site. In addition, *LFMC* values were also measured weekly in both sites from March to December 2005.

To determine *LFMC*, three samples of each species were weighed, dried and reweighed. *LFMC* was expressed as percentage of dry weight according to the following equation:

$$LFMC = \left[\left(FW - DW\right)/DW\right]100$$

where *FW* indicates the fresh weight of the plant material and *DW* indicates the dry weight after oven drying for 48 h at 102 °C.

Ignitability test was performed using a standard epiradiator of 500 W constant nominal power according to the methodology described by Valette (1990). At each sampling, 45 samples for each species were tested.

Heat content for each species was measured by an oxygen bomb calorimeter (model 1425 Semimicro, Parr Instrument Company, Moline, IL, USA). The analyses were performed using 0.2 g of dried and ground vegetal samples.

During the whole period of experimentation, meteorological variables were recorded by an automated weather station located in the study sites, and the soil moisture content at 0.2 m depth was monitored by TDR probes (model CS 615, Campbell Scientific Inc., Logan, UT, USA). Phenological stages were also observed on sampling dates.

A regression analysis was performed to describe the relations between *ID time* and *LFMC* values by species. Spearman's rank correlation analysis was performed to test the significance of relationships between:

- *LFMC* and soil moisture content, and
- *LFMC* and the mean value of daily maximum air temperature calculated over 10 days before sampling.

A one-way ANOVA with heat content values as dependent variable, and date of sampling as independent factor, was performed to test the effect of season. In addition, a one-way ANOVA with heat content values as dependent variable, and species as independent factor, was performed to identify potential significant differences of heat content among species. Duncan's multiple range test was used to test significant differences between means.

3. RESULTS AND DISCUSSION

Significant positive relations between *LFMC* and *ID time* were observed for all species. Moisture content variability accounted for most of the variance in *ID time* values (Table 1). These results confirm findings that other authors reported about the relationship between *LFMC* and ignitability in Mediterranean species (Hernando Lara *et al*. 1994; Dimitrakopoulos and Papaioannou 2001).

Different ranges and seasonal trends of *LFMC* and *ID time* values were observed for the studied species. *Cistus m., Rosmarinus, Helichrysum* (coastal site) and *Cistus s.* and *Lavandula* (inland site) showed the highest seasonal variability on *LFMC* and *ID time* (Figures 1 and 2).

Table 1 – Regression coefficients (α and β) and coefficient of determination (R^2) of simple linear regression for time to ignition (*ID time*) versus live fine fuel moisture content (*LFMC*) by species. Level of statistical significance (p) is also indicated.

	Regression model *ID time* = α + β *LFMC*			
Species	α	β	R^2	p
Pistacia	-1.78	0.20	0.94	***
Cistus s.	4.13	0.11	0.92	***
Helichrysum	3.41	0.12	0.90	***
Rosmarinus	5.61	0.13	0.85	***
Lavandula	4.85	0.09	0.76	**
Cistus m.	8.70	0.09	0.73	**
Phillyrea	-1.52	0.17	0.72	**
Juniperus	2.68	0.23	0.67	*
Erica	4.82	0.12	0.66	*
Arbutus	4.31	0.09	0.64	*

* p ≤ 0.05; **p ≤0.01; ***p ≤0.001

The lower *LFMC* and *ID time* values were recorded in summer, whereas an increase of values was observed in autumn when rainfall occurred. *Juniperus*, *Phillyrea* and *Pistacia* (coastal site) and *Arbutus* and *Erica* (inland site) showed a narrow range of *LFMC* and *ID time* values throughout the observation period with a relatively small decrease in late summer. In late spring, when the plants were in resprouting or flowering phases, most of species showed an increase of *LFMC* and *ID time* values.

These behaviors are related to both life cycle of plants and seasonal changes of meteorological conditions (Table 2).

According to our results, the species examined could be classified in two groups: (i) *Cistus m., Rosmarinus, Helichrysum* (coastal site) and *Cistus s.* and *Lavandula* (inland site) with *LFMC*, and consequently *ID time* values, strongly sensitive to seasonal changes of meteorological conditions; (ii) *Juniperus*, *Phillyrea* and *Pistacia* (coastal site) and *Arbutus* and *Erica* (inland site) with both *LFMC* and *ID time* values that seemed little affected by meteorological conditions when compared with the other group of species.

The experimental data reveal the different functional types of species. In living fuels the moisture content of foliage and small twigs is governed by the ratio between water uptake rate through the roots and water loss rate by transpiration (Piñol *et al*. 1998; Castro *et al*. 2003). The species more sensitive to seasonal variability avoid water stress either by adjustment of the growing period or limiting water loss by reducing their transpiring surface (Correia *et al*. 1992; Munné-Bosch *et al*. 1999; Gratani and Varone 2004).

Table 2 – Statistical significance of correlation between (i) live fuel moisture content (*LFMC*) and mean value of daily maximum temperature calculated over ten days before sampling (T_{max}), and (ii) *LFMC* and soil moisture content (*SM*).

Species	T_{max}	*SM*
Cistus m.	***	***
Rosmarinus	***	***
Cistus s.	***	***
Helichrysum	***	***
Lavandula	***	***
Juniperus	***	***
Erica	*	**
Phillyrea	*	***
Pistacia	n.s.	**
Arbutus	n.s.	n.s.

Significance levels: n.s. at p > 0.05; * at p ≤0.05; ** at p ≤0.01; *** at p ≤0.001

Juniperus, *Phillyrea* and *Pistacia* (coastal site) and *Arbutus* and *Erica* (inland site) are evergreen deep-rooted sclerophillous species, tolerant to water stress and affected by drought conditions only when they are particularly severe (Kummerow 1981; Correia *et al*. 1992; Manes *et al*. 2002; Alessio *et al*. 2004).

The first group of species shows a real seasonal variation of ignitability risk throughout the year. They reached *ID time* values smaller than 17 s in summer, when *LFMC* values were lower than 70-80%. In winter and spring, when *LFMC* values were equal or higher than 200%, the ignitability risk decreased.

The second group of species showed a range of *LFMC* an *ID time* values narrower than the first group. Nevertheless, *Erica* and *Phillyrea* showed *LFMC* values close to or lower than 100% and *ID time* values lower than 17 s over all year. Therefore, for these species the fire potential related to the fuel status can be considered high and almost constant during most of the year.

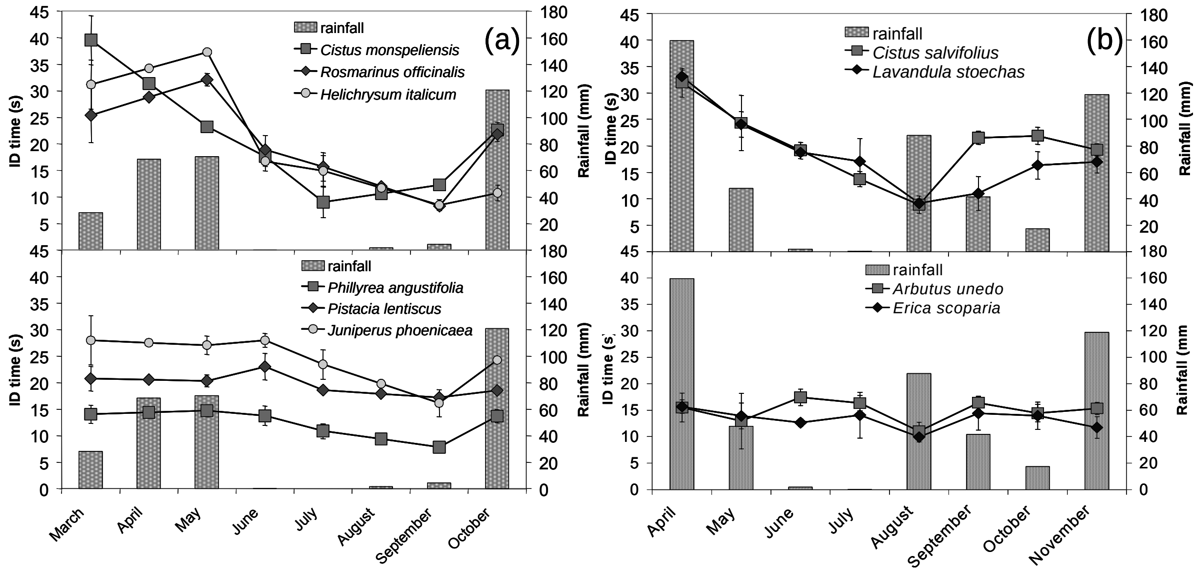

Figure 1. Average values and standard deviation of time to ignition (*ID time*) by species observed in coastal (a) and inland (b) sites. Rainfalls totals cumulated between sampling dates are also shown.

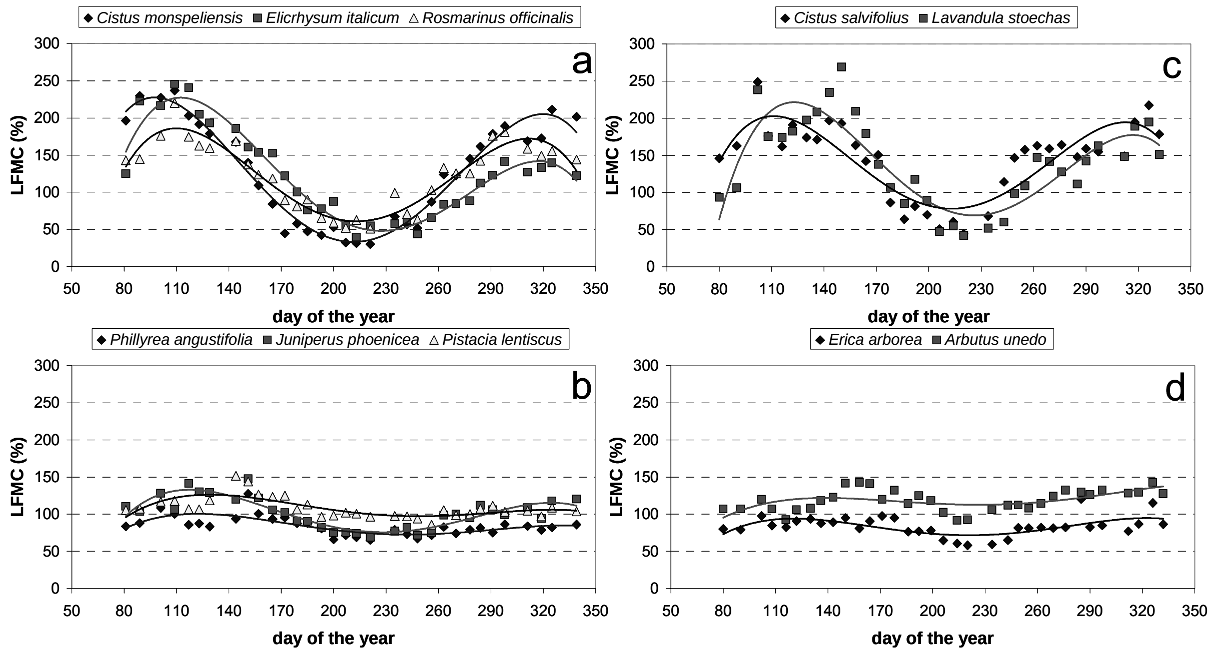

Figure 2. Average values of live fuel moisture content (*LFMC*) observed by site (a and b, coastal; c and d, inland) and species. Solid lines indicate the seasonal pattern of the experimental data by species.

Heat content values are presented in Tables 3 and 4. They ranged from 18.6 to 22.8 kJ g^{-1} for the coastal species, and from 18.0 to 22.6 kJ g^{-1} for the inland species. The studied species did not show any clear seasonal pattern of heat content.

Heat content values observed in spring, summer, and autumn were also compared. Statistical analysis showed that the mean heat content values varied significantly by species (Tables 3 and 4). In the coastal site, *Rosmarinus officinalis* showed values of heat content significantly higher than those observed on the other species during the experiment. In the

Table 3 - Mean seasonal values of heat content observed during the experimental period on coastal species.

Species	heat content kJ g^{-1}					
	Autumn		Spring		Summer	
Elichrysum	19.7	a	19.5	a	19.8	abc
Cistus m.	19.7	a	19.7	a	18.6	a
Pistacia	19.8	a	20.6	ab	19.2	ab
Phillyrea	20.3	a	21.7	b	20.8	bc
Juniperus	21.0	a	21.5	bc	21.1	c
Rosmarinus	22.5	b	22.8	c	22.6	d

Values in each column followed by the same letter are not significantly different at p≤ 0.01 according to Duncan' s test.

Table 4 - Mean seasonal values of heat content observed during the experimental period on inland species.

Species	Heat content kJ g^{-1}					
	Autumn		Spring		Summer	
Cistus s,	18.2	a	18.0	a	18.0	a
Lavandula	19.9	b	18.7	b	19.6	b
Arbutus	21.4	c	19.9	c	20.1	b
Erica	22.6	c	22.1	d	22.3	c

Values in each column followed by the same letter are not significantly different at p≤ 0.01 according to Duncan' s test.

inland site, *Erica scoparia* showed values of heat content significantly higher than those observed on the other species, whereas *Cistus salvifolius* showed the lowest values. The heat content values of the remaining species were between these two extremes.

4. CONCLUSIONS

Experimental data shown in this work (*ID time*, *LFMC*, and heat content) are strictly related to all components of flammability (ignitability, sustainability, and combustibility).

The role of moisture content variation in determining live fine fuel ignitability in Mediterranean vegetation was shown. Strong relationships between *LFMC* and *ID time* were observed for all species. However, based on our results, factors affecting flammability are species-specific.

The seasonal changes of meteorological variables clearly affected *LFMC* and consequently *ID time*.

Two groups of species were identified taking into account seasonal variability of *LFMC* and *ID time*: (i) species characterized by a narrow range of *LFMC* values and high ignitability risk all over the year, and (ii) species with a large seasonal variability of *LFMC* and *ID time* (both high in winter and low in summer).

In addition, some species with low *ID time* values in summer (i.e., high ignitability risk) showed low heat content values throughout the year, as observed on *Cistus spp.*

Seasonal pattern of meteorological variables does not seem to affect the total amount of heat released when a unit quantity of fuel is oxidized completely (i.e., heat content in kJ g^{-1} of dry weight). The heat content is more affected by chemical properties of each species (Shafizadeh *et al.* 1977; Etlinger and Beall 2004). Although it is not an absolute measure of the total energy released by plant materials during combustion, the heat content is useful to compare species thermal properties.

However, it must be noted that the release of energy is mainly affected by structural characteristics of plants and fuel load, and also, to a certain extent, by environmental conditions (Pyne *et al.* 1996; Behm *et al.* 2004; Weise *et al.* 2005). The fine fuel load typical of each species largely affects the total energy content of each individual (Etlinger and Beall 2004).

In conclusion, we can say that weather variability affects greatly both *LFMC* and *ID time* while the total energy release, which plays an important role in determining fire danger, is mainly influenced by each specific fuel load.

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6. REFERENCES

Alessio G.A., de Lillis M., Brugnoli E., Lauteri M., 2004: Water source and water use efficiency in Mediterranean coastal dune vegetation. *Plant Biology* **6** (3), 350-357.

Anderson H.E., 1970: Forest fuel ignitability. *Fire Technol.* **6**, 312-319.

Behm A.L., Duryea M.L., Long A.J., Zipperer W.C., 2004: Flammability of native understory species in pine flatwood and hammock ecosystems and implications for the wildland-urban interface. *Int.J. Wildland Fire* **13**, 355-365.

Castro F..X., Tudela A., Sebastià M.T., 2003: Modeling moisture content in shrubs to predict fire risk in Catalonia (Spain). *Agric. For. Meteorol.*, **116**, 49-59.

Chuvieco E., Aguado I., Dimitrakopoulos A.P., 2004: Conversion of fuel moisture content values to ignition potential for integrated fire danger assessment. *Can J Forest Res* **34**, 2284-2293.

Correia O.A., Martins A.C., Catarino F.M., 1992: Comparative phenology and seasonal foliar nitrogen variation in mediterranean species of Portugal. *Ecologia Mediterranea*, **XVIII**, 7-18.

Dimitrakopoulos A.P., 2001: A statistical classification of Mediterranean species based on their flammability components. *Int.J. Wildland Fire* **10**, 113-118.

Dimitrakopoulos A.P., Papaioannou K.K., 2001: Flammability Assessment of Mediterranean Forest Fuels. *Fire Technol.*, **37**, 143-152.

Engstrom J.D., Butler J.K., Smith S.G., Baxter L.L., Fletcher T.H., Weise D.R. 2004: Ignition behavior of live California chaparral leaves. *Combust Sci Technol* **176**, 1577-1591.

Etlinger M.G., Beall F.C., 2004: Development of a laboratory protocol for fire performance of landscape plants. *Int.J. Wildland Fire* **13**, 479-488.

European Communities, 2002: Forest Fires in Europe: 2001 fire campaign. SPI.02.72 Office for Official Publication of the Communities: Luxembourgh

Gratani L., Varone L., 2004: Leaf key traits of *Erica arborea* L., *Erica multiflora* L. and *Rosmarinus officinalis* L. co-occurring in the Mediterranean maquis. *Flora,* **199**, 58-69.

Hernando Lara C., Moro C., Valette J.-C., 1994: Flammability parameters and calorific values of *Erica arborea* and *Arbutus unedo*. *Proc 2nd Int. Conf. Forest Fire Research* vol. II pp 481-489. Coimbra Nov. 1994.

Hogenbirk J.C., Sarrazin-Delay C.L., 1995: Using fuel characteristics to estimate plant ignitability for fire hazard reduction. Water, Air Soil Poll, **82**, 161-170.

Kummerow J., 1981: Structure of roots and root systems. In *Ecosystems of the world 11, Mediterranean–type shrublands*. Di Castri F., Goodal D.W., and Specht R.L. (Eds). Elsevier Amsterdam 269-288.

Mak E.H., 1988: Measuring foliar flammability with the limited oxygen method. *Forest Sci.* **17** (4), 253-259.

Manes F., Capogna F., Puppi G., Vitale M. 2002: Ecophysiological characterization of *Phillyrea angustifolia* L. and response of resprouts to different fire disturbance intensities. In *Fire and Biological processes,* pp 115-130- edited by Trabaud L and Prodon R. Backhuys Publishers

Munné-Bosch S., Nogués S., Alegre L. 1999: Diurnal variations of photosynthesis and dew absorption by leaves in two evergreen shrubs growing in Mediterranean field conditions. *New Phytol*., **144**, 1069-119.

Núñez-Regueira L., Rodríguez-Añon J.A., Proupín-Castiñeioras J., 2004: Using calorimetry for determining the risk indices to prevent and fight forest fires. *Thermochim Acta* **422**, 81-87.

Piñol J., Filella I., Ogaya R., Peñuelas J., 1998: Ground-based spectroradiometric estimation of live fine fuel moisture of Mediterranean plants. *Agric For. Meteor.*, **90**, 173-186.

Pyne S.J., Andrews P.L., Laven R.D., 1996: Introduction to Wildland Fire. John Wiley & Sons, inc. 2nd edition

Shafizadeh F., Chin P., De PPs, Groot W.F., 1977: Effective heat content of green forest fuels. *Forest Sci.* **23**, 81-89.

Sun L., Zhou X., Mahalingam S., Weise D., 2006: Comparison of burning characteristics of live and dead chaparral fuels. *Combust Flame* **14**4, 349-359.

Trabaud L., 1976: Inflammabilité et combustibilité des principales espèces des garrigues de la région méditerranéennes. *Oecolog Plantar*, **11** (2), 117-136.

Valette J.C., 1990: Inflammabilités des espèces forestières Méditerranéennes – Consequences sur la combustibilité des formations forestières. *Revue forestiére francaise*, **42**, 76-92.

Weise D.R., White R.H., Beall F., Etlinger M., 2005: Seasonal changes in selected combustion characteristics of ornamental vegetation. *Int.J. Wildland Fire* **14**, 321-328.