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Reviewed Article:

Lighting the Dark in The Palaeolithic: Examining Variation in Light between Different Wood Species Using a Randomised Firewood Collection Strategy

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Light produced by fire was a crucial survival tool for Palaeolithic hunter-gatherers, enabling the occupation of deep caves and the extension of daylight hours. Previous research using standardised experimental protocols identified variations in the illuminance properties of

different wood species, which could be utilised for various tasks as part of fuel selection strategies. However, these standardised experiments, which control for the size and state of the wood and hearth design, do not accurately reflect actual firewood collection and fuel management strategies employed by prehistoric hominins. This study uses a randomised wood collection strategy, without controls on the size or state of the wood and a flat hearth design to test whether illuminance properties of different wood species observed in previous studies can be replicated. The results indicate that lux (light) measurements, ranked from highest to lowest, are consistent with those found in standardised experiments. Significant differences were, however, noted in the overall measure of light properties, with some species yielding much lower values than previously observed. This demonstrates that variations in the size and state of the wood (decayed, dry, or semi-decayed) can influence the levels of outgoing light. By employing a firewood collection strategy more representative of prehistoric hunter-gatherers, these findings more accurately reflect the levels of light experienced from hearths using different types of wood and fuels and provide new data that can be used in computational models examining sources of light in deep caves.

> This work provides more realistic data in terms of how light could have been experienced and utilised in both open air, caves, and rock shelters, preserving the trace remains of hearths such as charcoals for species-level identification.

Introduction

The study of fire and lighting systems in the Palaeolithic has gained increased attention over recent years due to its profound impact on the daily lives and survival strategies of prehistoric humans (James, 1989; Hoare, 2020; Kedar, *et al.*, 2023). Artificial light, primarily produced through controlled use of fire, played a crucial role in various aspects of Palaeolithic life, including social activities, extension of daylight hours, habitation of deep caves and the creation of cave art (Medina-Alcaide, *et al.*, 2021; Wisher and Needham. 2023). The ability to produce and manage sources of light, such as torches, lamps, and fireplaces, not only enabled humans to extend their activities beyond the daylight hours but also allowed access into the depths of deep cave systems, thereby influencing spatial behaviour and cultural practices.

There are numerous experimental pyroarchaeology studies which collectively highlight how light could have been used in enclosed spaces to illuminate cave activities and the production of art in the Palaeolithic. Medina-Alcaide, *et al.* (2021) demonstrate that different lighting systems, such as wooden torches, portable fat lamps, and fireplaces, had distinct properties and uses, with torches providing broad illumination for exploration and lamps and fireplaces offering steady light for stationary activities. Kedar, *et al.* (2022) used computer simulations to analyse smoke dispersal from fires at Larazet cave and found that hearths were positioned optimally in areas of low smoke density to maximise light and heat properties whilst minimising the effect of smoke on human health. Wisher and Needham (2023) used virtual reality to simulate dynamic firelight, revealing how the interplay of light and shadow influenced the perception and creation of cave art. Medina-Alcaide (2024) employed a multiproxy approach to analyse combustion residues, providing insights into the types of fuels used, the intensity and duration of cave visits, and the spatial distribution of lighting activities. Together, these studies highlight the complex role of light in Palaeolithic life, from the practical navigation of deep caves, the position of fires for light to reduce exposure to smoke and artistic expression.

Other experimental archaeology studies of light in the Palaeolithic have focused on the production of actualistic data from hearths using different types of fuels in open air and semi-open shelters. Hoare (2020) and Hoare, *et al*. (2023) employed an experimental approach to quantify the outgoing illuminance and radiative heat properties, along with fuel emissions of different wood species used as firewood in the Palaeolithic. Data from both studies demonstrate that significant variability in illuminance from different wood species exists. These studies are valuable as they use standardised experimental protocols (e.g., shape of the fire, dimensions and state of the wood and moisture content) to quantify lux measurements, enabling comparison between different wood species and other types of fuel, such as fresh bone and animal dung. They are also limited as this standardisation does not accurately reflect the actual firewood collection strategies employed by prehistoric and contemporary hunter-gatherers (Théry-Parisot, 2002; Henry and Théry-Parisot, 2014; Henry, *et al*., 2018; Robledo, *et al*., 2025).

Robledo *et al*. (2025) introduced a more realistic approach to the study of radiative heat properties and smoke emissions of *Pinus sylvestris* in prehistoric populations using a flat hearth design and less standardisation. This method involved collecting firewood in various states and dimensions to ensure a data set more representative of firewood collection in the Palaeolithic. By analysing the heat properties and fuel emissions of randomly collected firewood samples, Robledo, *et al*. (2025) aimed to provide a more accurate and comprehensive understanding of fireplace positions and wellbeing in the Palaeolithic. Their findings highlight the importance of considering the variability in wood properties used in fires and collection strategies when examining prehistoric fuel collection criteria.

The remains of fires and charcoal from hearths in caves, rock shelters or open-air sites represent the most abundant resources found at Palaeolithic sites from which to investigate uses of light relative to fuel selection criteria (Albert, *et al*., 2003; Cabanes, *et al*., 2007; Vidal-Matutano. 2017; deLumley, *et al*., 2018). This research paper aims to build on these previous studies by quantifying the light properties of different wood species from open-air fires using a randomised wood collection strategy, to enhance our understanding of Palaeolithic lighting practices and contribute to the broader field of archaeological research on human-environment interactions.

Methods

A series of experiments were conducted using open-air hearths to quantify the luminescence properties of various wood species, employing a randomised firewood collection strategy. This approach is relevant to studying firewood selection criteria at both mobile and home-based sites. The primary aim of this study was to test the accuracy of luminescence properties of different wood species, as quantified in previous experiments (e.g., Hoare, 2020; Hoare, *et al*., 2023), by comparing the results of a consistent standardised experimental protocol (pyramid stacking design, wood diameter, length, and moisture content) against a randomised collection strategy. Following Robledo, *et al*. (2025), the randomised strategy and flat hearth design are considered more representative of firewood collection practices and fire use among prehistoric hunter-gatherers.

All experiments were conducted by the author in an open-air setting, using seven wood species: *Betula pendula, Fraxinus excelsior, Picea abies, Larix decidua, Fagus sylvatica, Pinus sylvestris, and Quercus robur.* These woods were selected based on previous experiments by Hoare (2020). The experiments combined the protocol from Hoare (2020) and Robledo, *et al*. (2025). Terminology describing light properties follows Vandevelde, *et al*. (2024).

To simulate known Palaeolithic fire structures, the experiments utilised a flat hearth design on soil without any surrounding rocks. The hearths were approximately 1 meter in diameter. The fires were active for around 2 hours (120 minutes), during which measurements of hearth temperature, lux properties, and environmental factors (e.g., wind chill) were monitored. After 2 hours, the fires were extinguished. To examine the light properties as experienced by Palaeolithic peoples during specific activities, half of the firewood was added at the start of the experiment, and additional fuel was fed into the fire to sustain the flames realistically. The firewood collection for each species was randomised, with no records kept regarding the state of the wood (dry, decayed, or wet), size, or length, to simulate a more accurate collection strategy like those in the Palaeolithic.

Illuminance (lux measurements)

The measurements were taken an ISO-TECH ILM-01 handheld lux metre. Measurements were taken every 10 min at the same distance of 1 m from the fire as Hoare (2020). The measurements were started 20 min after the fire was started and continued at 10-minute intervals for the duration of the experiment. Experiments were conducted overnight to remove any possible interference from daylight on the lux metre, and the fires were started each night when the lux metre recorded 0 in all directions from the fire.

To control for the potential effects of external variables on the results, ambient temperature, wind speed and humidity measurements were taken every 30 min using a handheld Kestrel 2000 anemometer so these measurements could then be correlated with the temperature and lux data. Temperatures of the fire were recorded using a K-type thermocouple and automated data logger every 5 mins for the duration of the experiments.

Results

The results of the experiments are shown in Tables 1 and 2. In Figure 1a-1g the light properties of the experiments are shown as graphs and compared to previous experiments of Hoare (2020). All the data is available in the tables.

Experiment	Experiment - code	Date	Taxon	Start	Duration (mins)	Type of experiment	Max. Temp.	Average Temp.	Max. Lux.	Average Lux	Lux Standardised experiments
1	P1	13/02/2025	*P. sylvestris*	18:00	120.00	Open Air	814°	590°	24	20.3	20.3
2	B2	14/02/2025	*B. pendula*	18:00	120.00	Open Air	804°	543°	53.4	45.6	60
3	Q3	15/02/2025	*Q. robur*	18:00	120.00	Open Air	930°	614°	6.6	5.7	6.1
4	FR4	16/02/2025	*F. excelsior*	18:00	120.00	Open Air	888°	695°	57	51	68
5	FA5	17/02/2025	*F. sylvatica*	18:00	120.00	Open Air	820°	602°	32.2	26.7	35
6	L6	18/02/2025	*L. decidua*	18:00	120.00	Open Air	891°	650°	29.7	25.5	28.1
7	PIC7	19/02/2025	*P. abies*	18:00	120.00	Open Air	901°	639°	24.7	22.8	26

TABLE 1. SUMMARY OF ALL THE EXPERIMENTAL DATA FOR EACH FIRE INCLUDING MAXIMUM AND AVERAGE TEMP OF THE FIRES IN ̊C AND MAXIMUM AND AVERAGE LUX MEASUREMENTS. THE FINAL COLUMN DENOTES AVERAGE PEAK LUX VALUES FROM HOARE, 2020.

Experiment	**P1**			
Duration (hh:mm)	00:00	00:30	01:00	01:20
Outdoor Temperature (°C)	13.8	13.3	13.1	13.1
Outdoor Humidity (%)	73	75	75	73
Relative Pressure (hPa)	1013	1013	1013	1013.3
Wind Speed (km/h)	0	0	0	0
Windchill (°C)	13.6	13.3	13.1	13.1
24 Hour Rainfall (mm)	0	0	0	0
Experiment	**B2**			
Duration (hh:mm)	00:00	00:30	01:00	01:20

Outdoor Temperature (°C)	12.9	12.8	12.8	12.9
Outdoor Humidity (%)	75	76	76	77
Relative Pressure (hPa)	1012.9	1012.1	1012.4	1012.4
Wind Speed (km/h)	0	0	0	0
Windchill (°C)	13.1	12.7	12.7	12.2
24 Hour Rainfall (mm)	0	0	0	0
Experiment	**Q3**			
Duration (hh:mm)	00:00	00:30	01:00	01:20
Outdoor Temperature (°C)	11.8	11.8	11.8	11.8
Outdoor Humidity (%)	80	80	81	80
Relative Pressure (hPa)	1011	1011.1	1011.1	1011.3
Wind Speed (km/h)	0	0	0	0
Windchill (°C)	12.3	12.3	12.7	12.3
24 Hour Rainfall (mm)	0	0	0	0
Experiment	**FR4**			
Duration (hh:mm)	00:00	00:30	01:00	01:20
Outdoor Temperature (°C)	12.1	12.4	12.4	12.3
Outdoor Humidity (%)	71	70	70	70
Relative Pressure (hPa)	1012.9	1013	1013.1	1013.1
Wind Speed (km/h)	0	0	0	0
Windchill (°C)	14.7	14.4	14.4	14.3
24 Hour Rainfall (mm)	0	0	0	0
Experiment	**FA5**			
Duration (hh:mm)	00:00	00:30	01:00	01:20
Outdoor Temperature (°C)	11.8	11.8	11.8	11.7
Outdoor Humidity (%)	81	80	81	81
Relative Pressure (hPa)	1010.9	1010	1010	1010.2
Wind Speed (km/h)	0	0	0	0
Windchill (°C)	12.6	12.7	12.7	12.6
24 Hour Rainfall (mm)	0	0	0	0
Experiment	**L6**			
Duration (hh:mm)	00:00	00:30	01:00	01:20

Outdoor Temperature (°C)	11.6	11.8	11.8	11.9
Outdoor Humidity (%)	72	74	74	73
Relative Pressure (hPa)	1011	1011.3	1011.3	1011.4
Wind Speed (km/h)	0	0	0	0
Windchill (°C)	12.1	12.3	12.3	12.2
24 Hour Rainfall (mm)	0	0	0	0
Experiment	**PIC7**			
Duration (hh:mm)	00:00	00:30	01:00	01:20
Outdoor Temperature (°C)	11.3	11.3	11.4	11.4
Outdoor Humidity (%)	75	76	76	76
Relative Pressure (hPa)	1012.9	1012.6	1012.6	1012.7
Wind Speed (km/h)	0	0	0	0
Windchill (°C)	11.9	11.9	12	12
24 Hour Rainfall (mm)	0	0	0	0

TABLE 2. SUMMARY OF ALL THE ENVIRONMENTAL MONITORING DATA CAPTURED DURING EACH EXPERIMENT INCLUDING: OUTDOOR AMBIENT TEMPERATURE AND HUMIDITY, WINDSPEED, WINDCHILL AND 24 HOUR RAINFALL.

Experiment P1

The fire was ignited at 6.00 pm and the measurements were recorded for 120 mins. There was no rainfall, and the wind speed was 0. The maximum temperature of the fire was 814°C, with an average of 590°C. The highest lux measurement was 24, with an average of 20.3 for the full 120 mins. Peak values recorded in Hoare (2020) were also 20.3.

Experiment B2

The fire was ignited at 6.00 pm and the measurements were recorded for 120 mins. There was no rainfall, and the windspeed was 0. The maximum temperature of the fire was 804°C, with an average of 543°C. The highest lux measurement was 53.4, with an average of 45.6 for the full 120 mins. Peak values recorded in Hoare (2020) were 60.

Experiment Q3

The fire was ignited at 6.00 pm and the measurements were recorded for 120 mins. There was no rainfall, and the windspeed was 0. The maximum temperature of the fire was 930°C, with an average of 614°C. The highest lux measurement was 6.6, with an average of 5.7 for the full 120 mins. Peak values recorded in Hoare (2020) were 6.1.

Experiment FR4

The fire was ignited at 6.00 pm and the measurements were recorded for 120 min. There was no rainfall, and the wind speed was 0. The maximum temperature of the fire was 888°C, with an average of 695°C. The highest lux measurement was 57, with an average of 51 for the full 120 min. Peak values recorded in Hoare (2020) were 68.

Experiment FA5

The fire was ignited at 6.00 pm and the measurements were recorded for 120 min. There was no rainfall, and the wind speed was 0. The maximum temperature of the fire was 820°C, with an average of 602°C. The highest lux measurement was 32.2 with an average of 26.7 for the full 120 min. Peak values recorded in Hoare (2020) were 35.

Experiment L6

The fire was ignited at 6.00 pm and the measurements were recorded for 120 min. There was no rainfall, and the wind speed was 0. The maximum temperature of the fire was 891°C, with an average of 650°C. The highest lux measurement was 29.7 with an average of 25.5 for the full 120 min. Peak values recorded in Hoare (2020) were 28.1.

Experiment PIC7

The fire was ignited at 6.00 pm and the measurements were recorded for 120 min. There was no rainfall, and the wind speed was 0. The maximum temperature of the fire was 901°C, with an average of 639°C. The highest lux measurement was 24.7 with an average of 22.8 for the full 120 min. Peak values recorded in Hoare (2020) were 26.

Discussion

The results of this study quantified the outgoing light properties of seven experimental fires, each using a different wood species and employing a randomised firewood collection strategy (no controls on the size, state or moisture content of the wood). The study also used a flat hearth design rather than a pyramid stacking design. Analyses of the hearth temperatures were also quantified in tandem with lux measurements. The aim was to examine whether the variation in illuminance observed between individual wood species during standardised experiments with set protocols (concerning the size, state and moisture content of the firewood, e.g., Hoare (2020) could be replicated using a firewood collection strategy and hearth design more representative of prehistoric hunter-gatherers.

The wood species producing the highest lux measurements in this study were ash (*Fraxinus)* and birch (*Betula*)*,* with average values of 51 and 45.6. The wood species producing the lowest lux measurements was oak (*Quercus*)*,* with average values of 5.7. The other species fall in an intermediate category with values of *Fagus* (26.7), *Larix* (25.5), *Picea* (22.8) and *Pinus* (20.3). In terms of highest to lowest, these results are similar to those produced in previous studies using standardised protocols. However, some important differences are observed between the two data sets, which have ramifications for the experience of light from open-air hearths for prehistoric hunter-gatherers. For most of the wood species examined in this new study, lux measurements were lower than those produced during standardised experiments. For example, average values for both *Betula* and *Fraxinus* are 14.4 and 15 lower in this study, whereas *Picea* is 3.2 lower. The only result which was similar to the previous study was for *Pinus*. Our results demonstrate that the size, state and moisture content of wood can influence the illuminance of fires.

Standardised experiments are an important starting point for any experimental pyroarchaeological project; however, should always be correlated with data that is representative of a specific activity in situations where factors have been identified as significant in potentially influencing results. In this regard, Robledo, *et al*. (2025), noted the importance of examining how variation between different wood states could influence radiative heat output and smoke emission. These authors demonstrate how both temperature and smoke emissions from experimental fires, using the wood of *P. sylvestris*, can vary according to the state of the firewood, whether decayed or semi-decayed. Our results also demonstrate how variation in both the state of the firewood and diameter size can influence illuminance of different wood species relevant to the study of firewood collection strategies in the Palaeolithic. This work provides more realistic data in terms of how light could have been experienced and utilised in both open air, caves, and rock shelters, preserving the trace remains of hearths such as charcoals for species-level identification.

Conclusion

Variation has been demonstrated to exist in the combustion properties of different wood species (light, heat and smoke), which can be harnessed by prehistoric hunter-gatherers for different purposes. Previous studies had demonstrated that illuminance of wood used for fuels in the Palaeolithic varied according to species, with outgoing light ranked from highest to lowest (*Betula, Fraxinus, Fagus, Larix, Picea, Pinus* and *Quercus*). The experimental design did not, however, represent firewood collection strategies of prehistoric hunter-gatherers. The results of this study, generated using a randomised wood collection strategy and hearth design of Palaeolithic origin, support the findings of the previous studies in terms of highest to lowest outgoing light properties for each species. However, in most cases, the actual light properties were lower and, in some cases, e.g. *Betula* and *Fraxinus*, significantly so. The results show that variation in the size and state of the wood, along with hearth design, can reduce outgoing light from fires. These results are important and reflect the need to supplement standardised experiments with actualistic data, especially for those produced in laboratory settings. The results also provide further data which can be used in computational models of fire use for light in caves. These new results are more relevant to the use of light from fires and fuel management strategies in the Palaeolithic.

Keywords fire

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Gallery Image

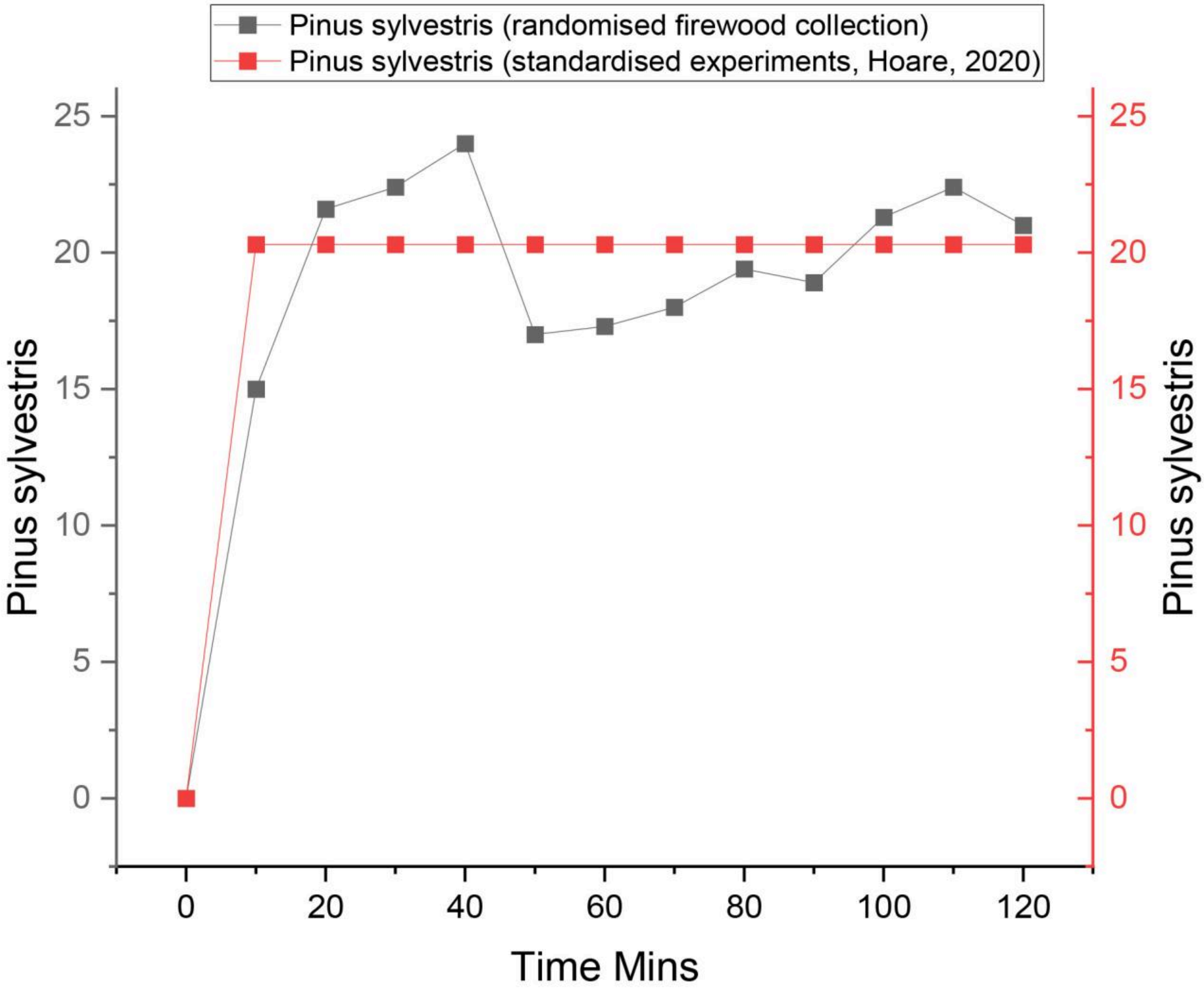

FIG 1A. SHOW THE LIGHT PROPERTIES OF EXPERIMENTS CONDUCTED IN THIS STUDY FOR EACH WOOD SPECIES - P. SYLVESTRIS - USING A RANDOM FIREWOOD COLLECTION STRATEGY AS COMPARED TO THE LIGHT PROPERTIES USING STANDARDISED EXPERIMENTAL PROTOCOLS IN HOARE, 2020.

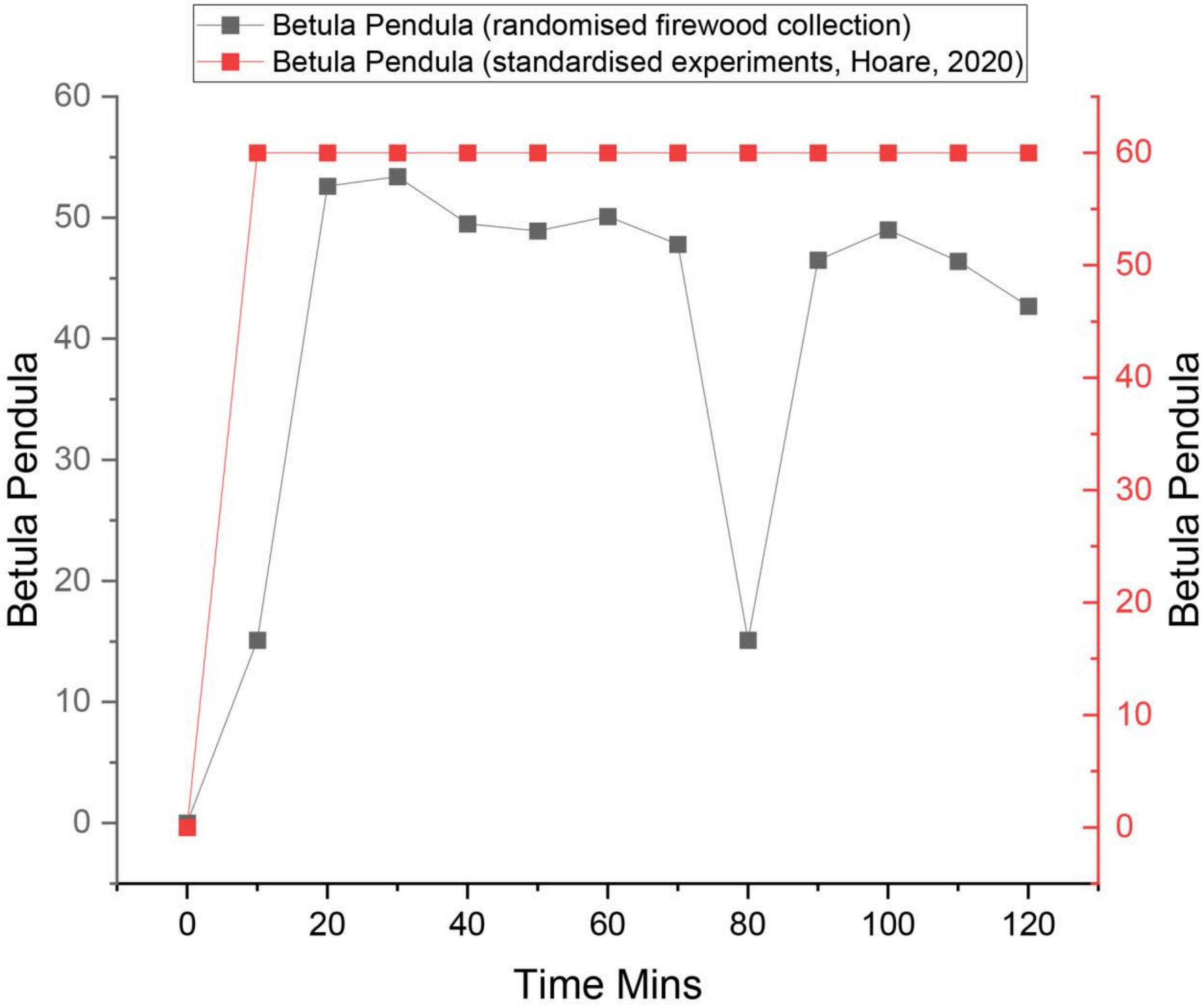

FIG 1B. SHOW THE LIGHT PROPERTIES OF EXPERIMENTS CONDUCTED IN THIS STUDY FOR EACH WOOD SPECIES - B. PENDULA - USING A RANDOM FIREWOOD COLLECTION STRATEGY AS COMPARED TO THE LIGHT PROPERTIES USING STANDARDISED EXPERIMENTAL PROTOCOLS IN HOARE, 2020.

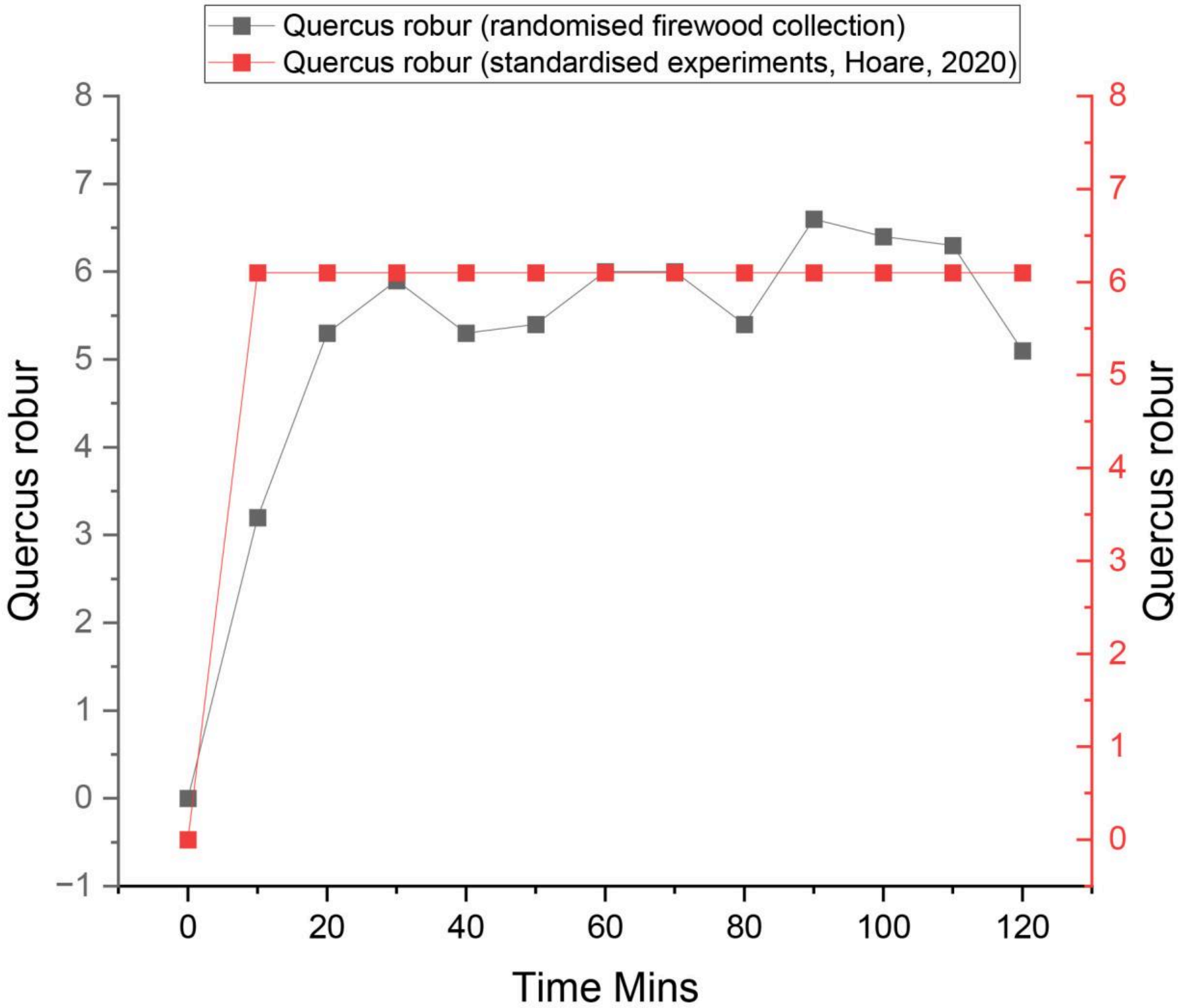

FIG 1C. SHOW THE LIGHT PROPERTIES OF EXPERIMENTS CONDUCTED IN THIS STUDY FOR EACH WOOD SPECIES - Q. ROBUR - USING A RANDOM FIREWOOD COLLECTION STRATEGY AS COMPARED TO THE LIGHT PROPERTIES USING STANDARDISED EXPERIMENTAL PROTOCOLS IN HOARE, 2020.

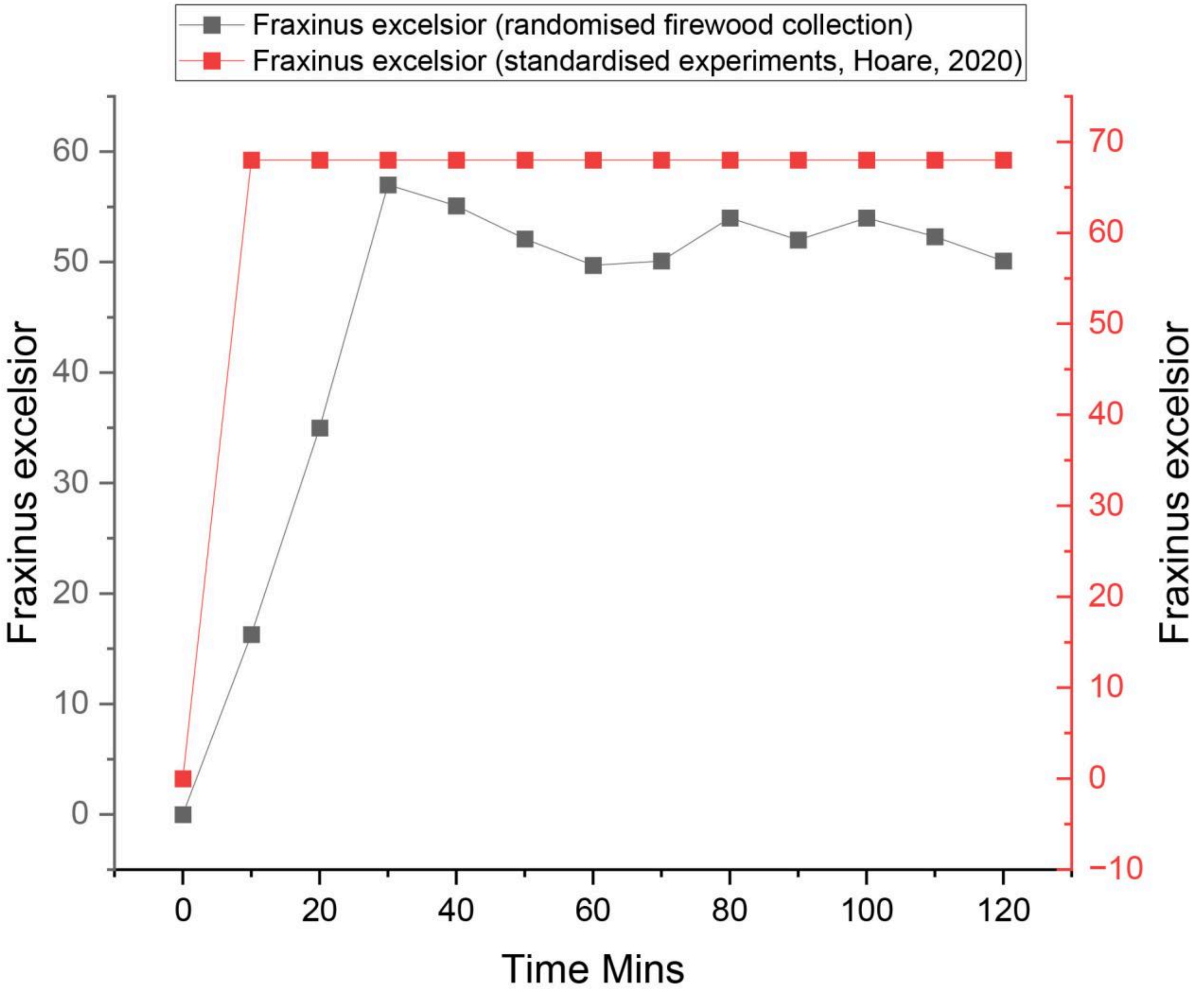

FIG 1D. SHOW THE LIGHT PROPERTIES OF EXPERIMENTS CONDUCTED IN THIS STUDY FOR EACH WOOD SPECIES - F. EXCELSIOR - USING A RANDOM FIREWOOD COLLECTION STRATEGY AS COMPARED TO THE LIGHT PROPERTIES USING STANDARDISED EXPERIMENTAL PROTOCOLS IN HOARE, 2020.

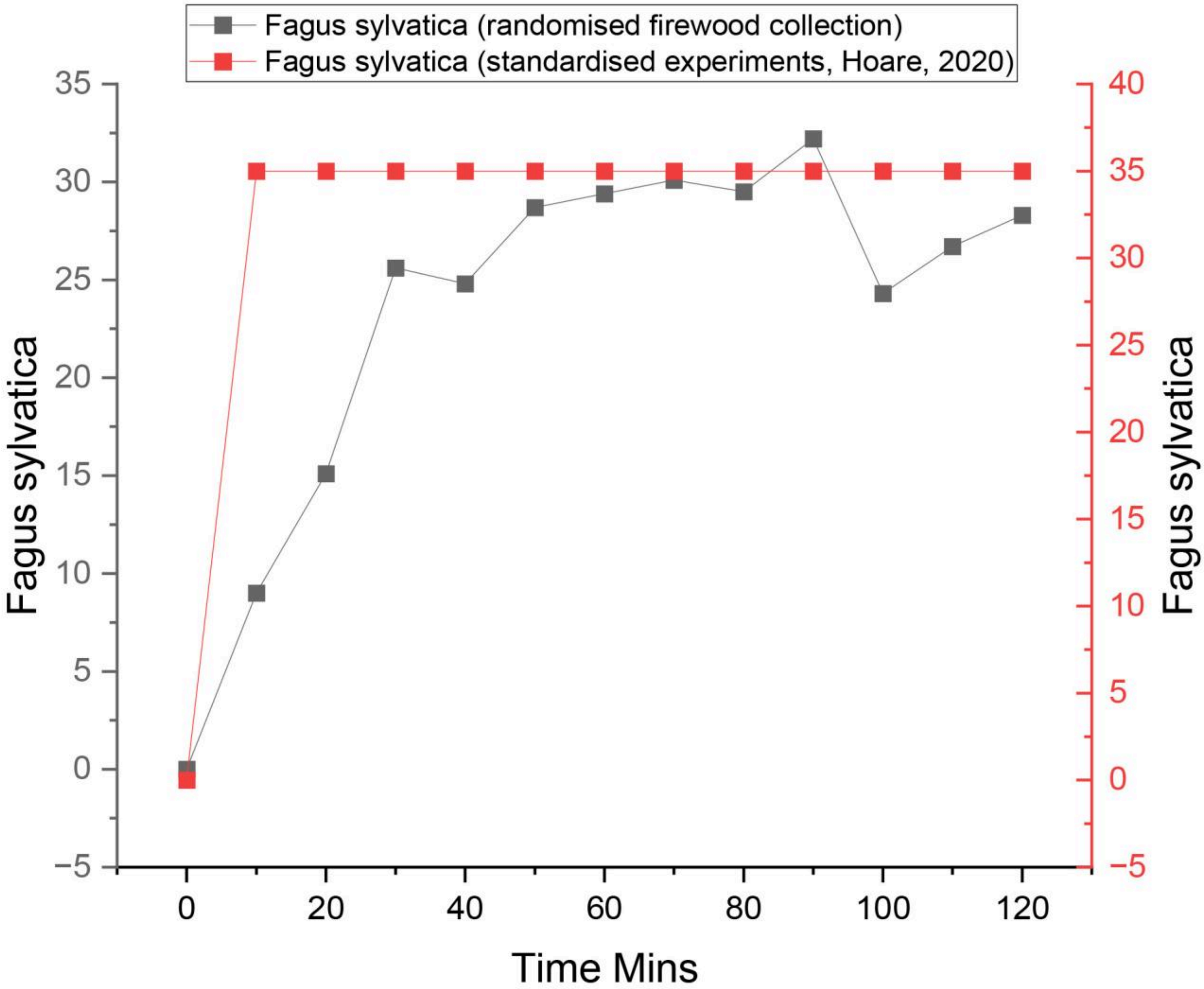

FIG 1E. SHOW THE LIGHT PROPERTIES OF EXPERIMENTS CONDUCTED IN THIS STUDY FOR EACH WOOD SPECIES - F. SYLVATICA - USING A RANDOM FIREWOOD COLLECTION STRATEGY AS COMPARED TO THE LIGHT PROPERTIES USING STANDARDISED EXPERIMENTAL PROTOCOLS IN HOARE, 2020.

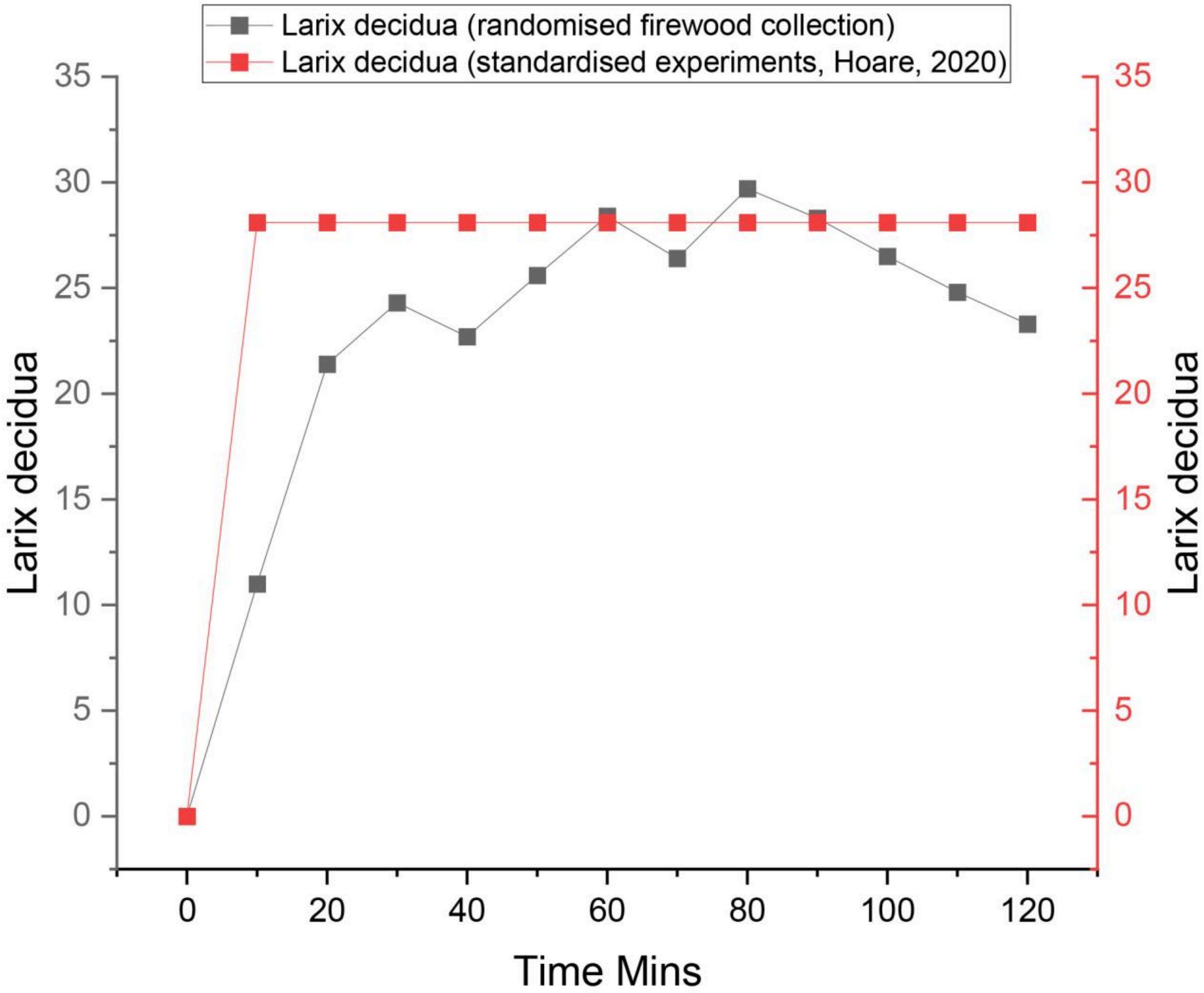

FIG 1F. SHOW THE LIGHT PROPERTIES OF EXPERIMENTS CONDUCTED IN THIS STUDY FOR EACH WOOD SPECIES - L. DECIDUA - USING A RANDOM FIREWOOD COLLECTION STRATEGY AS COMPARED TO THE LIGHT PROPERTIES USING STANDARDISED EXPERIMENTAL PROTOCOLS IN HOARE, 2020.

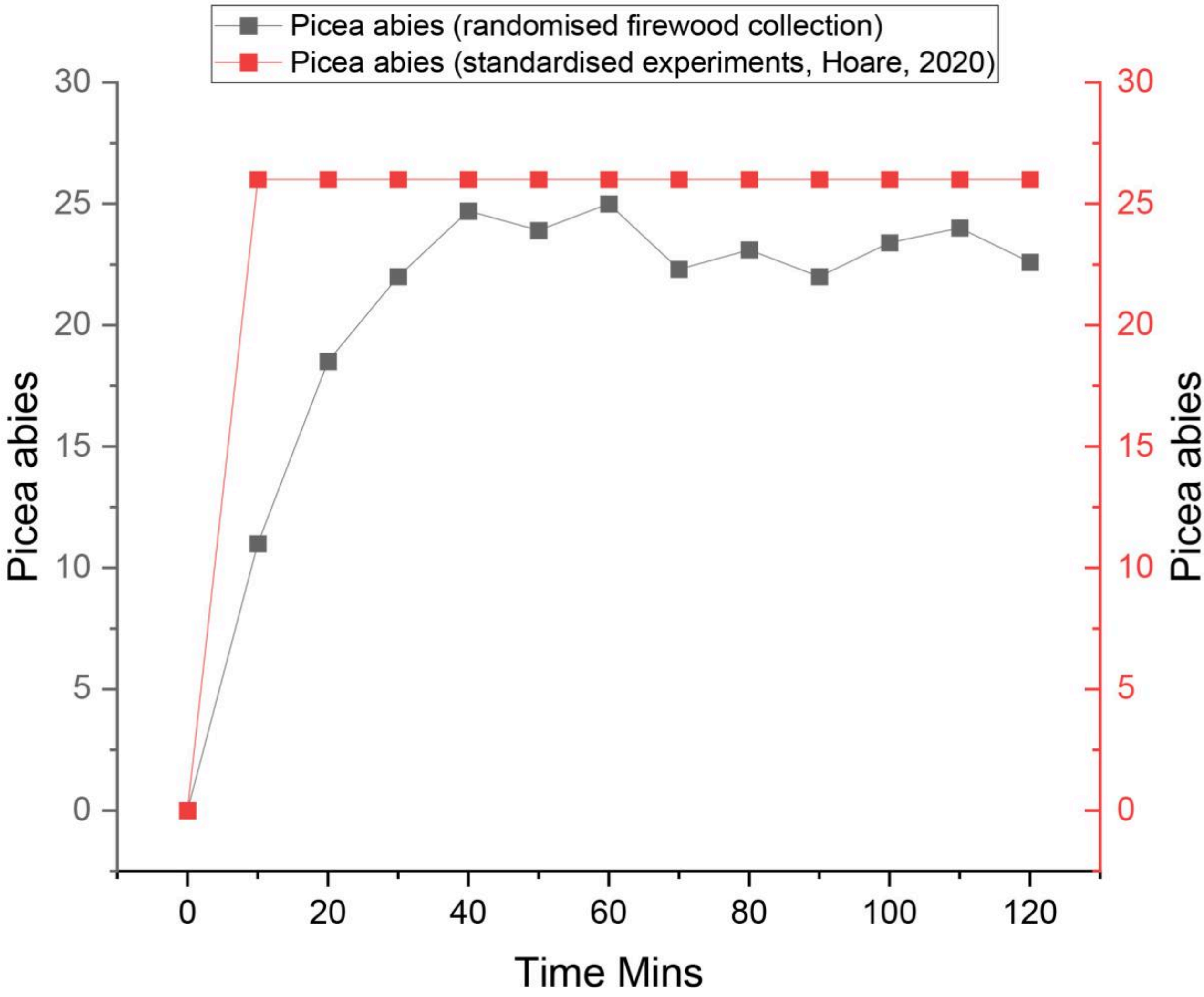

FIG 1G. SHOW THE LIGHT PROPERTIES OF EXPERIMENTS CONDUCTED IN THIS STUDY FOR EACH WOOD SPECIES - P. ABIES - USING A RANDOM FIREWOOD COLLECTION STRATEGY AS COMPARED TO THE LIGHT PROPERTIES USING STANDARDISED EXPERIMENTAL PROTOCOLS IN HOARE, 2020.