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Food choice in birds – Colour Preference

A Dissertation submitted as part of the requirement for BSc
Biological Sciences

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Abstract

Effective feeding and foraging are pivotal in survival, with animals requiring adequate energy and nutritional intake. This drives specific feeding behaviour (such as food choice, energy expenditure and feeding time allocation) to maximise net energy intake, explained as the optimal foraging theory. These behaviours are recognised to vary with dynamic factors, including season, food type, and even colour. Literature has observed an innate preference for red coloured food in numerous species. Birds, being of particular focus, have shown this innate colour preference but food preference between species and season varied . This is significant, as most UK homes provide supplementary food for wild birds, without proper understanding of feeding behaviours and preferences, as well as the ecological repercussions it can bring. Therefore, this study aims to demonstrate observable food preferences in UK garden birds using colour, to better educate a growing market.

Two fat balls (one dyed red, the other undyed) were made, hung and observed through both autumn and winter, recording feeding times and species of visiting birds. These observations showed the dyed food source to experience more feeding than the undyed feeder, across both seasons. This preference was consistent with most visiting species. Furthermore, feeding duration was recognised to vary significantly with season, as was colour selection. Both duration, and undyed feeding increased in the winter, potentially explained by the need to increase energy and fat intake. Brown (undyed) food, such as nuts and seeds, are linked to fat and energy density, with red associated with ripeness and sweetness. This may explain the seasonal differences, and feeding preferences seen in this study. Additionally, feeding duration and behaviour differed significantly between species.

These results demonstrate the extent at which foraging preferences and behaviours can vary between species and season. Therefore, when selecting supplementary food type, location and accessibility, it is crucial to acknowledge the results of this study and ensure varied feeding behaviours are accounted for. It’s this recognition and understanding that will maintain ecological health and diversity, a topic which has become increasingly worrisome.

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1 Introduction

The binomial (scientific) name of mentioned species will be used throughout this study, sourced from Britannica.com.

1.1 Importance of selective foraging

Organisms require adequate nutritional intake for growth, reproduction and survival (Birnie-Gauvin et al., 2017). Essential dietary components such as proteins, carbohydrates and vitamins are significant in all fundamental physiological processes (including muscle synthesis (Burd et al., 2019), gestation, glucose production (Ahnen et al., 2020), bone and blood production (Weaver and Hill, 2014)). Therefore, maintaining a sufficient, balanced diet is the key to surviving and thriving.

Nutritional composition of available food differs from source to source depending on climatic and environmental factors (Schőnfeldt and Pretorius, 2011), providing varied nutritional accessibility. Berries and fruits, for example, provide a rich source of sugars, fibre, vitamins and antioxidant phytochemicals (Cosme et al., 2022), while meats, eggs and nuts are rich in protein and fats (Lonnie et al., 2018). And due to special and physiological variety, nutritional requirements in nature are not uniform. The simplest example of this is the comparison of solely carnivorous and herbivorous diets.

While ensuring nutritional intake is adequate, an excess or imbalance can be just as detrimental as a deficit (Oz, 2017). Many organisms show a primary intake of protein, over other nutrients (Raubenheimer et al., 2009), resulting in an imbalance, and health issues such as insulin resistance, increased blood pressure and reduced cardiovascular health, and reproductive difficulties (Yajnik, 2002).

Therefore, it is beneficial for organisms to determine food quality and composition, before consumption. Selective foraging is used by organisms to optimally select ‘food’ based on the highest supply of energy, with the least time and energy expended, as well as specific nutritional demands (Dudová et al., 2019), explained by the optimal foraging theory.

The optimal foraging theory assumes organisms maximise energy gain through ecological behaviour (Watanabe et al., 2014), considering factors concerning time allocation, dietary selection (Beumer et al., 2020), and foraging strategy (Owen-Smith et al., 2010). Deviation from this optimum can decrease reproductive fitness and chance of survival (Beumer et al., 2020; Owen-Smith et al., 2010). The theory assumes these behavioural factors are finetuned in a way that net energy intake could not be further maximised (Pyke and Starr, 2021). And these behaviours can be substantial (migrating for abundant food sources) (Lohmann, 2018), or slight, such as mastication duration (van Casteren et al., 2022; Owen-Smith, 2010).

Optimal foraging behaviour has been observed across all species and trophic levels. However, it is important to understand how organisms recognise and decide on what food constitutes metabolically "beneficial" for them. This is primarily built on experience, learning which food sources provide the most benefits and least consequences (Moore et al., 2005).

Research conducted by Hejcmanova et al. (2019) showed how dietary experience was present in bovids, more specifically, *Taurotragus derbianus*. *T, derbianus* appeared to prefer plants with high cellulose contents, actively avoiding plants with high hemicellulose, nitrogen, calcium and magnesium, due to association with poor digestibility (Hejcmanova et al., 2019). As a result, the bovid can avoid disadvantageous food.

Dietary preference and experience have also been shown in rodents. Brechbuhl et al. (2020) described a favourability in mice, for food with previous positive experience, and/or food that had no potential predatorial threat (Brechbuhl et al., 2020). This allows mice to recognise what food is reliable and safe for ingestion, and when it should be chosen, based on predator presence, and fear (Brechbuhl et al., 2020). Furthermore, Gallant et al. (2004) showed the dietary and functional selectivity of beavers, with preference in both size and species of tree (Gallant et al., 2004) for feeding, and constructing habitats.

Likewise, this selectivity is evident in fungi feeding collembolan arthropods. Jorgensen et al. (2005) highlighted the dietary selection of *Protaphorura armata* in soil, with preference for a specific handful of fungal species (Bracht Jorgensen et al., 2005), despite the high fungal diversity observed in the surrounding environment. Collembolan arthropods have also shown a preference for metabolising fungal hyphae, over senescent hyphae (Moore et al., 1987). This preference would provide a more energy-rich food source for the collembolan, increasing net energy intake.

Optimal foraging is also recognised at a microscopic level. Yawata et al. (2020) explored marine bacteria (*Vibrio ordalii*) actively switching between an attached and planktonic state, in order to access and forage higher nutrient particles (Yawata et al., 2020). This active choice benefits the marine bacteria, increasing survivability with access to a greater supply of nutrients.

Optimal foraging is a significant factor in organism and species survival and reproduction, and proves to be effective across all branches of life. Understanding, and exploring, this theory is significant when analysing ecological behaviour (Ydenberg and Prins, 2012).

1.2 Selective foraging in birds

Foraging in birds is heavily influenced by predation, often sacrificing optimal nutrition to ensure safety (Bonter et al., 2013). This includes decisions on feeding location and type (Bonter et al., 2013). Wild bird diets vary significantly depending on location and species. The largest order, passerines, eat a mix of nuts, seeds, fruits and insects (Nyffeler et al., 2018). Nuts and seeds are both fat, protein, carbohydrate and nutrient rich food sources (Balakrishna et al., 2022), with peanuts, for example, being energy and fat-dense making them beneficial in colder, wet climates (Molokwu et al., 2011). While, as previously mentioned, fruits provide a reliable source of sugars and vitamins (Cosme et al., 2022). Additionally, insects provide a further source of protein, often supplying greater volumes than plant protein sources (Kim et al., 2019).

Fats are of particular significance in all bird species, acting as energy-dense fuel, providing significant energy required for flight (Gugliemo, 2010). Fat density is particularly high in migratory birds, present as a reliable store, nullifying the need to stop and ‘refuel’, while flying great distances (Gugliemo, 2010). Furthermore, bird species show a preference for fat-rich foods in winter months, with increased foraging as temperatures decreased (Renner et al., 2012). Opting for fat-rich foods improves survivability (Plummer et al., 2018), growth and overall metabolic and immune health (Martinez del Rio and Williams, 2016), all of which are crucial in surviving periods of scarcity (winter).

However, excessive, or unbalanced, levels of fat intake have shown to have adverse effects on health, growth, and particularly reproduction (Plummer et al., 2018). Additionally, increased fat stores decrease flight mobility and duration, while increasing flight energy cost, all of which increases risk of predation and lowers survivability (Gugliemo, 2018). Therefore, foraging fats in moderation, allows for balanced nutrient intake and maintenance of good health, further emphasising the role of selective foraging in nature.

Studies continue to show evidence of clear food preferences in bird species, with seasonal changes, and digestibility being a significant contributor. The use of sunflower seeds, peanuts and millet was consistent across the reviewed papers. Molokwu et al. (2011) investigated the significance of content and digestibility of seed types, with the basis that birds concern processing times over nutritional and chemical composition (Diaz, 1996). Data showed an initial preference for peanuts (compared to millet), particularly in lower temperatures (Molokwu et al., 2011). This selectivity could be accredited to the higher fat content and density of peanuts (Bonku and Yu, 2020), with millet being a much better source of carbohydrates (Molokwu et al., 2011). However, this density was eventually selected against, with the wild birds opting for the high digestibility of the millet (Molokwu et al., 2011).

Another instance of this was seen in research conducted by Tryjanowski et al. (2018). Bird species had a clear preference for sunflower seeds, despite having equal access to millet, animal fat and dry fruits (Trykanowski et al., 2018). This preference could be accredited to nutrition, with sunflower seeds providing more fats, essential vitamins and calories (McCulloch, 2018). Furthermore, Tryjanowksi et al. (2018) highlighted the importance of recognising food size as a factor. Smaller food meant birds did not have to eat at the feeder, which is recognised to reduce perceived predation, and increase food consumption (Visscher et al., 2018).

Therefore, based on the findings of these studies, it can be said selective foraging is evident in birds, with nutrition not solely responsible for food selectivity.

With selective and optimal foraging being a crucial component of survival, it is beneficial for organisms to be well equipped for it. ‘Nutritional wisdom’ and specific adaptations, such as enhanced olfaction, have shown to influence, and improve, dietary choices (Kershaw and Mattes, 2018; Brunstrom and Schatzker, 2022). Evidence shows organisms to use both physical and chemical characteristics, combined with reinforcement (such as flavours, digestibility and toxicity) to determine the nutrition of food (Provenza et al., 2015). This is regularly observed in canines, with the use of enhanced smell to determine, and detect, viable food sources, as well as food safety (Petel et al., 2018; Kokocinska-Kusiak et al., 2021).

Colour is of particular focus, affecting perception of food, and, therefore, preference (Clydesdale, 1993).

1.3 The role of colour in food choice

Colour, in nature, aids in survival of species (Dresp-Langley and Reeves, 2018), facilitating processes such as sexual selection, predator deterrence, communication (Caro, 2005), and foraging (Cole and Endler, 2015). Many organisms have advanced, dynamic colour mechanisms, features and perception, crucial in signalling (Ligon and McGraw, 2013). For example, intense red colouration in *Mandrillus* displays dominance and sexual preference (Renoult et al., 2011); similar association was seen in the *Chamaeleonidae* family, with colour intensity and range portraying dominance (Ligon and McGraw, 2013). Moreover, many species use colour for predator deterrence/ camouflage. *Algais io*, for example, utilises colour for mimicry, displaying predator-like eyespots, which proves to be an effective deterrent (Vallin et al., 2005). Organisms also employ colours to create camouflage, with species such as *Pantheras tigris* and *Cicindela campestris* able to 'blend' into their environment and avoid detection from both predators and prey (Yamamoto and Sota, 2020).

However, this is dependent on how other organisms perceive colour. Colour vision is determined by opsin presence within retinal cone cells (Schichida and Matsuyama, 2009). Humans, and most primates, have 3 cone cell opsins, correlating to the colours in which we perceive (red, green and blue) (Schichida and Matsuyama, 2009), but opsin frequency varies highly in the animal kingdom (Jacobs, 2009). Many mammals lack a third opsin, with the inability to process red light (620-750nm wavelength), making them dichromatic (Troscianko et al., 2017).

Birds possess 4 colour processing cones, allowing tetrachromatic vision (Kram et al., 2010), and the perception of near ultraviolet wavelengths (Cuthill et al., 2000). Additionally, birds are adapted for strong colour discrimination, with coloured oil droplets and double cones, resulting in spectral filtering, allowing for vision of longer wavelength light (Olsson et al., 2015; Stavenga and Wilts, 2014; Silvasti et al., 2021). This allows bird species to have precise vision, particularly at distance, to aid in flight, distance perception, and foraging (Stavenga and Wilts, 2014).

Colour assists in determining food sustainability (Cole and Endler, 2015), flavour (Spence, 2015) and nutrition (Dresp-Langley and Reeves, 2018; Fadilah et al., 2012), with most organisms utilising an innate and learned colour preference when foraging (Munoz-Galicia et al., 2021). Studies have shown species of butterfly, fish (Roy et al., 2019) and trichromatic primates (Fornale et al., 2012) to have an innate preference for red food. Muñoz-Galicia et al. (2021) demonstrated this innate preference in *Leptophobia aripa. L. aripa* visited red flowers first, and more frequently, compared to other colours (yellow, white and pink) (Munoz-Galicia et al., 2021), without a learnt association of reward.

This may be due to the nutritional associations of red: sweetness and higher sugar contents (Spence, 2019). Fruit-producing plants utilise this, using pigments (chlorophyll, carotenoids and anthocyanins) to attract frugivores which then disperse seeds (Schaefer et al., 2007). As fruit ripens, anthocyanin content increases, bringing with it the 'ripe' colours (red, black, purple) (Hwang et al., 2019). Additionally, sugar content (sucrose, fructose and glucose) increases, providing greater energy content and palatability (Pablo-Rodriguez et al., 2015; Phillips et al., 2021), both of which affect nutritional perception, and increase consumption (Ibba et al., 2021). This proves beneficial for both plant and forager, allowing for reproduction, and a reliable source of glucose.

It is theorised that red perception (trichromatic and tetrachromatic vision) evolved for the purpose of distinguishing red fruits from greenery and recognising fruit/leaf ripeness (Gerl and Morris, 2008). Therefore, those who perceive red, stand a greater chance at accessing energy-rich food.

As previously mentioned, most bird species possess tetrachromatic vision, and the ability to see red (Kram et al., 2010). And with this, has come the evident preference for red, either innate or learnt.

Recent work by Teichmann et al. (2020) found both an innate and learned preference for red coloured foods in *Cyanistes caeruleus* and *Parus major*. Juvenile *C. caeruleus* and *P. major* showed an immediate selection for red almond flakes, even when presented with orange, green and purple choices (Teichmann et al., 2020).

Additionally, Duan et al. (2014) showed juvenile frugivorous bird species (*Pycnonotus jocosus, P. aurigaster, P. melanicterus* and *Megalaima asiatica*) to innately favour red (and black) fruits, over other colours, particularly green. This could be a result of ripeness perception, with the favoured colours corresponding to ripe fruits found in the frugivores natural environment (Duan et al., 2014).

However, this innate preference in juveniles seems to recede with negative reinforcement, as seen in further work by Teichmann et al. (2020). Sampled species were presented with both red and green unpalatable almonds, and soon came to associate both negatively (consuming less red than green). The sample showed no clear preference for red, until red almonds were associated with a positive stimulus (palatability) (Teichmann et al., 2020). This trend was also seen in work completed by Schaefer and Schmidt (2004), with in-experienced, juvenile *Sylvia atricapilla* innately preferring red, and wild-caught adults selecting red when provided with positive stimulus (Schaefer, 2004). Colour association and avoidance is visible in wild birds with Stevens and Ruxton (2011) showing this. Results showed birds to have a learned association with conspicuous colours and avoidance (Stevens and Ruxton, 2011). Insects, and some plant species, utilise this factor, creating contrasting colours and patterns to deter predators (Stevens and Ruxton, 2011; McLellan et al., 2021).

This study aims to build on these previous findings, while also building a greater understanding on the influence of colour in food choices in UK (United Kingdom) garden birds.

Wild bird feeding has become standard in most UK homes, bringing with it an increased bird diversity (Plummer et al., 2019), and richness (Fuller et al., 2007). Both food and feeder selection is important in maximising bird foraging, with colour being a key factor (Rothery et al., 2017). Therefore, understanding this, and variation in special preference, is environmentally beneficial, promoting a healthier ecosystem (Tanalago et al., 2015).

1.4 Aims and objectives

This study aims to investigate the influence of colour in food choices by birds, while also examining the effect of species and season. The study will focus specifically on the influence of the colour red (620-750nm). Research will be built upon the previous findings showing preferences for specific colours, while also filling the gap in knowledge on special and seasonal variation. This study will achieve this by completing the following objectives:

- Monitor feeding duration of bird species on provided food sources.
- Explore how feeding activity varies throughout the day.
- Compare feeding characteristics of the dyed and undyed feeder.
- Identify species of feeding birds.
- Conduct a repeat experiment in winter months.
- Compare the relationship between species and season.

It is hypothesised that the coloured (red) feeder will receive more visits from all bird species. Additionally, the dyed feeder will record greater total feeding time, and feeding duration. This will be consistent across the initial (summer) and latter (winter) experiment. However, food choice will not vary significantly between species.

2 Methods and Materials

2.1 Study area

Primary research was conducted in a residential back garden in North Somerset. All edges of the garden were neighboured by other residential gardens, divided by hedges. The garden was primarily grass, apart from a small patio area closer to the house where the research equipment was arranged. This study area was selected due to regular bird activity, as well as being a pre-established source of food for the bird species. The patio was chosen to assemble the feeding station as it provided equal conditions for both feeders, accounting for coverage, hedge vicinity, wind and sunlight, and level grounding. Additionally, the distance from the house (2m) allowed for easier observations, while also reducing perceived risk for the birds.

Although the exact garden size was not measured, it is estimated to be 25m x 15m.

2.2 Materials

The feeding station was created using a pre-existing feeding pole, with 2 symmetrical diverging hooks in which feeders can be hung. While the exact name of the feeding pole was not noted, similar can be found at most garden centres, hardware stores and online retailers. The pole measured roughly 2m, with feeders hanging at roughly 5 ft above the ground.

Identical fat ball feeders were purchased from Hillier Garden centre, ensuring the food within would be accessible for most UK garden bird species. Green feeders were selected based on work conducted by Rothery at al. (2017).

Fat balls were created using the recipe at gardenersworld.com. Pre-mixed bird seed (Peckish complete) and lard were mixed in a pan at a rough ratio of 1:2 (2 cups of seed mix, 150g lard). This was heated until the lard had melted and covered the seed mix. Half of the heated lard-seed mix was decanted into a yoghurt pot, while the other half was coloured with 250µL red colouring (Waitrose Essentials). Once stirred, the remaining fat mix was emptied into a yoghurt pot, with both cooled overnight in the freezer.

Oykos yoghurt pots were used to achieve a spherical shape, but this was not necessary.

Images of the setup and fat balls used can be found in the appendices.

2.3 Procedure

Before the data was recorded, both feeders were filled with uncoloured fat balls and left for a week. This meant the bird species could habituate the new feeding location and food source. No data was recorded for this week.

Beyond this, both feeders were emptied and filled with coloured and uncoloured fat balls respectively. The choice of which feeder held the coloured ball was random. The feeders were re-hung, and observations began at 8am, and continued until 11am. This was completed from the 26th September- 2nd October, as birds begin to prepare for winter months.

Data was recorded concerning the time of arrival of bird/birds, feeding duration on coloured/uncoloured feeder and bird species. Weather data was also noted using reports from BBC and the Met Office. This entailed temperature, wind speeds, precipitation and cloud coverage. Species identification was done primarily on personal knowledge but was supplemented with the RSPB bird identifier and UK bird books. Arrival time was logged using a world clock website, and duration noted using a combination of stopwatch and counting (recorded to the nearest second). The fat balls were left in the feeders overnight, despite not recording data.

This procedure was repeated from 11th -15th December, to allow comparison of trends in different seasons. The same materials were used to guarantee a fair test.

2.4 Data analysis

Initial data was recorded on paper but transferred to a spreadsheet for analysis and presentation. Variables were compared, and tested, for statistical significance. Once assumptions had been met, comparison and relationship tests were used.

Investigating the total and average feeding duration of the coloured and uncoloured feeders, an unpaired *t* test was used. This allowed for recognition of significance between coloured and uncoloured feeders. All tests were done twice to compare autumn and winter data.

When analysing special difference in feeding time, an ANOVA test was completed to determine if feeding times were significant between seasons. Beyond this unpaired *t* tests were conducted to explore food preferences between species, and how this varied seasonally. Furthermore, percentages were calculated to portray the proportion of dyed to undyed feeding.

An ANOVA test was also completed to compare the relationship feeder feeding duration, and species. This allowed for the investigation of species as a determining factor of feeding duration. Additionally, a two-way ANOVA was completed to assess the relationship between feeder feeding duration, season, species and time of day.

Additionally, graphs, charts and tables were constructed to best present the recorded data and show relationships between variables. These figures were made in excel.

2.5 Recommendations

The data recorded was limited by the procedure. Due to the nature of the observations, it was difficult to identify and record maturity of the foraging bird. As a result, a strong variable was ignored that may potentially influence the data. As mentioned in work by Teichmann et al. (2020) and Duan et al. (2014), maturity has been seen to influence a bird’s food preference, focusing particularly on the role of colour. In the future, the use of video footage, or more observers would prevent this problem and allow for maturity determination.

Additionally, the data was limited by the comparison of two single wavelengths. Similar studies compare the red stimulus to other colours of varying wavelengths, creating a greater comparison and conclusion on the influence of red in food choice. This could have been overcome with a larger research team and more equipment, or further research experiments. However, this was avoided to maintain the repeatable and simple nature of the experiment, making recreation of the method simple.

Another limitation of the method was the lack of investigation of feeder position as a variable. With the dyed food remaining in the same location across all observation days, the position may have an influence on the preference of birds. Although both feeders experienced almost identical environments, one may be perceived as safer by the visiting birds species, therefore, showing a preference for it. This limitation was mainly due to time restraints, and further observations in both autumn and winter would rectify this.

3 Results

This study aimed to investigate the influence of UV exposure (colour red) on food choices in UK garden birds. The procedure used allowed for data collection concerning feeding times, species observed feeding, time of day of recorded foraging and weather conditions. The use of statistical tests, analysis and presentation displayed trends and statistical differences suggesting an accepted hypothesis.

Off the data recorded, 6 bird species visited frequently: *Erithacus rubecula*, *Passer domesticus*, *Carduelis carduelis*, *Parus major*, *Prunella modularis* and *Sitta europaea*. Additional species were identified and recorded but did not frequent enough to produce substantial data: *Corvus monedula*, *Troglodytes troglodytes* and *Pica pica*.

An ANOVA test revealed species to make a significant difference concerning the dyed food feeding duration in the autumn months (p=0.0419), but this was not seen in winter, or when investigating undyed food.

The role of season was important to understand, and a chi-squared test revealed a significance in the relationship between dyed/undyed food and season (p=0.0334). Additionally, unpaired t-tests showed significant differences in feeding durations for some bird species, particularly concerning undyed food.

The influence of weather was also relevant. While the relationship between weather and feeding times was not collected to aid in reaching a conclusion, its influence on the data recorded is valuable to understand. Weather parameters were created (good, medium and poor) using wind speeds and precipitation. Many weather documenting websites recognise rainfall above 1mm/h as moderate. Additionally, the Beaufort wind scale states that winds above 20km/h class as a moderate breeze. Therefore, 4 weather parameters were created using these guidelines, which are highlighted below.

- A: <15km/h winds, <1mm/h precipitation (low wind, low rainfall)
- B: ≥15km/h winds, <1mm/h precipitation (high wind, low rainfall)
- C: <15km/h winds, ≥1mm/h precipitation (low wind, high rainfall)
- D: ≥15km/h winds, ≥1mm/h precipitation (high wind, high rainfall)

3.1 Dyed vs Undyed feeding

Results concerning colour showed a preference for dyed food, to undyed. Table 1 highlights how total feeding times and average durations changed with variables.

Table 1. Comparison of feeding times of all observed foraging birds. The average feeding duration is the mean for all 7 autumn days, and 5 winter days respectively. The total shows the sum of all feeding birds on the dyed and undyed feeders, across the experiment days.

	Dyed (total, seconds)	Dyed (average duration, seconds)	Undyed (total, seconds)	Undyed (average duration, seconds)
Autumn	985	3.91	388	2.83
Winter	771	4.65	367	3.9

Bird species fed on red feeders for a greater total time in both autumn (985s) and winter (771s), when compared to undyed feeders. When testing for significant differences of feeding duration, birds feeding in the autumn experiment fed significantly longer on the red-dyed feeder (p= 0.0024). This significance was not seen in the winter experiment.

Comparing feeding durations of the dyed feeder in autumn and winter, no significant difference was seen, but it still showed a strong relationship (p= 0.0579). An additional unpaired t-test showed a significant difference of feeding duration on the undyed feeder in autumn and winter (p=0.0314). This, with the previously mentioned chi-squared test value (p= 0.0344), shows a relationship between feeder colour and season.

Figure 1 explored the influence of time of day on the number of visits the respective feeders received. The figure shows very little change in frequency of visiting birds as time progressed.

In the autumn, the red feeder received, on average, 42 visits/30mins. This was the highest, followed by 22.83 visits/30mins (undyed feeder, autumn). The winter feeders, on average, received the lowest average visits per 30 minutes (red=22.67, undyed=15.67). While no significant correlation was noted for any variables, a slight decrease was seen in visits to either feeder throughout the day.

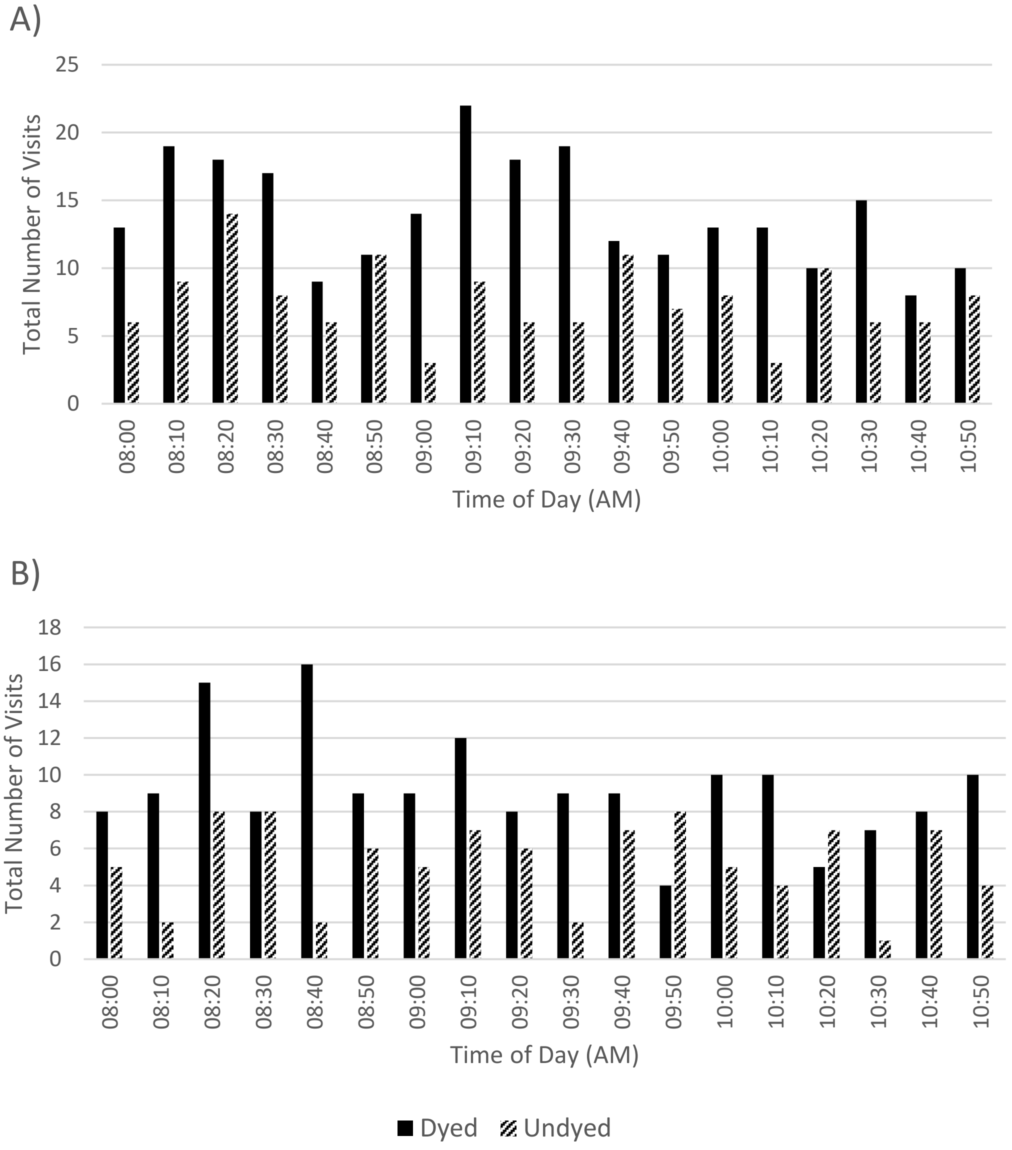

Figure 1. Charts showing the total number of visits per 10 min interval for both feeders. The intervals began at the times shown on the x axis, and would end before the next interval (e.g. 8:00-8:09:59). Graph A represents the dyed and undyed feeder in the autumn, while graph B shows the data collected in the winter. The data represents all species. A visit was recognised as a bird perching on the feeder, even if it was only momentarily. The graph shows very little variation in bird visits as time changes.

Similarly, figure 2 portrays how the average feeding duration changes with time. While no correlation is visibly clear, it shows feeding durations to be more consistent throughout the day in winter months. The data also showed that all 4 variables had the highest average feeding duration before 9am, decreasing beyond this. A two-way ANOVA showed no significant difference when concerning the feeding duration on the feeders and time of day (p= 0.4121).

Very little time of day effect was seen in the collected results, with no significant influence seen.

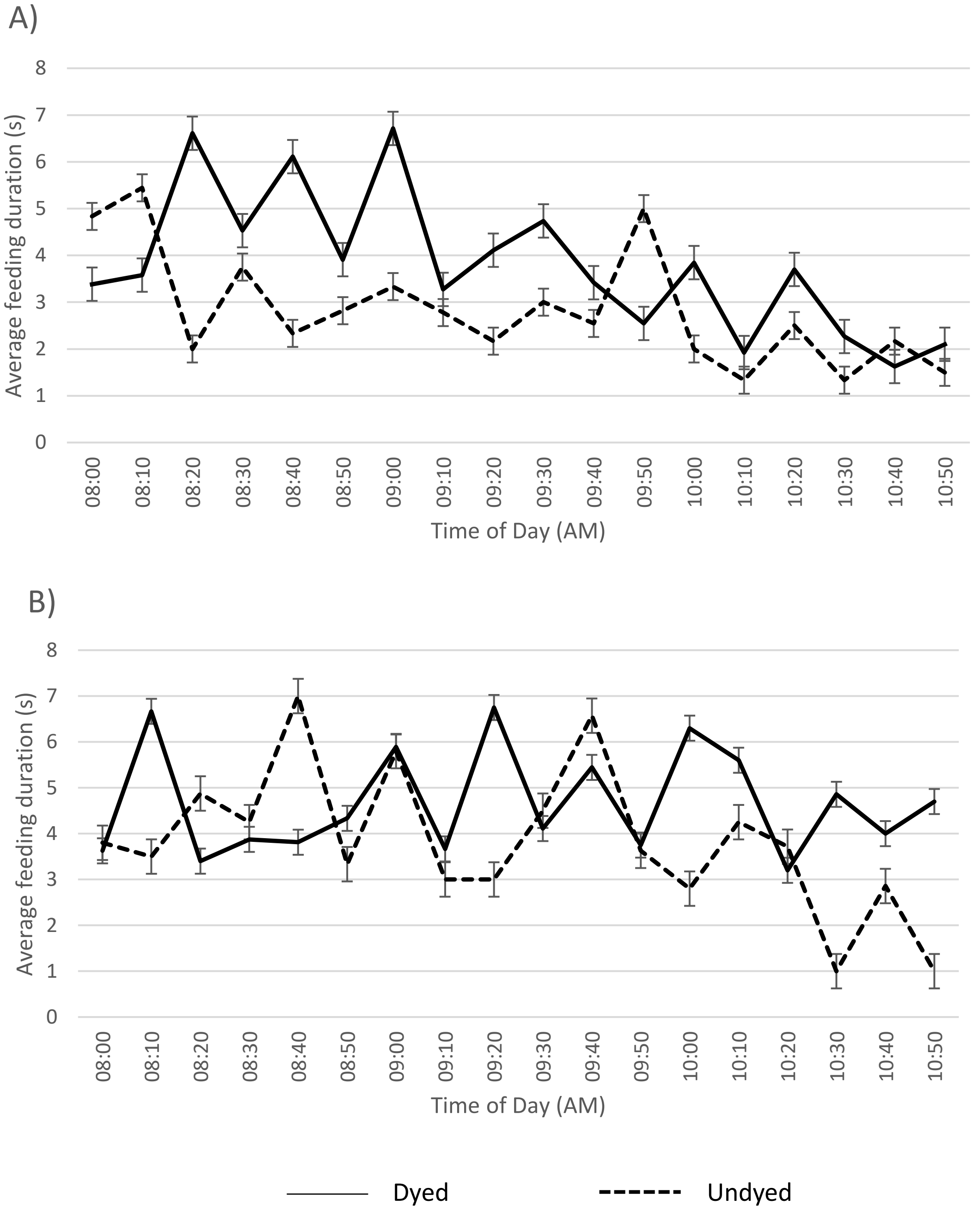

Figure 2. Line graphs comparing average feeding durations between 8-11am. Graph A represents the autumn experiment, and B represents winter. The mean feeding time was calculated for each condition, using data of all bird species. The ten minute intervals ran for 9 minutes and 59 seconds (e.g 08:00:00-08:09:59). The error bars represent standard error (at 95% confidence). Both graphs show a decline in average feeding durations as time passed.

3.2 Influence of bird species on food selection

3.2.1 Influence of species variation in autumn months

Data collected showed a preference for the red feeder across all species. Figure 3 shows the comparison of feeding times in the autumn months. Unpaired *t*-tests revealed a significant difference in feeding duration (dyed vs undyed) for *P. modularis* (*p*= 0.0186), but no significance for other species. Across the 7 autumn days, *P. modularis* recorded the second highest percentage of total dyed:undyed feeding (80.3%), with *P. major* having the highest (84.13%). The dyed v undyed feeding proportions of all bird species are shown in Figure 4. Species showed to have a significant effect on feeding duration, on the dyed feeder, in autumn months, via an ANOVA test (*p*=0.0419). However, no significant difference was observed for the undyed feeder (*p*=0.875).

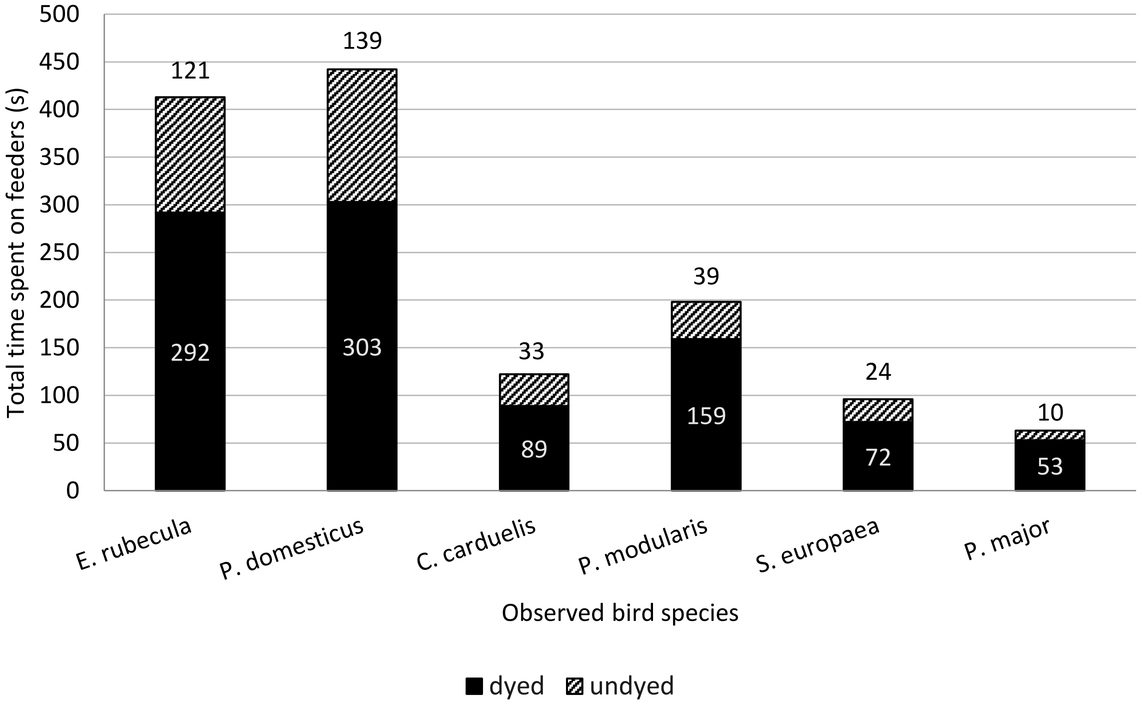

Figure 3. A bar chart comparing total feeding time on respective feeders of the 6 commonly observed species in the autumn experiment. The total is a sum of all feeding times over the 7 experiment days, showing an overall preference for the dyed food in all species.

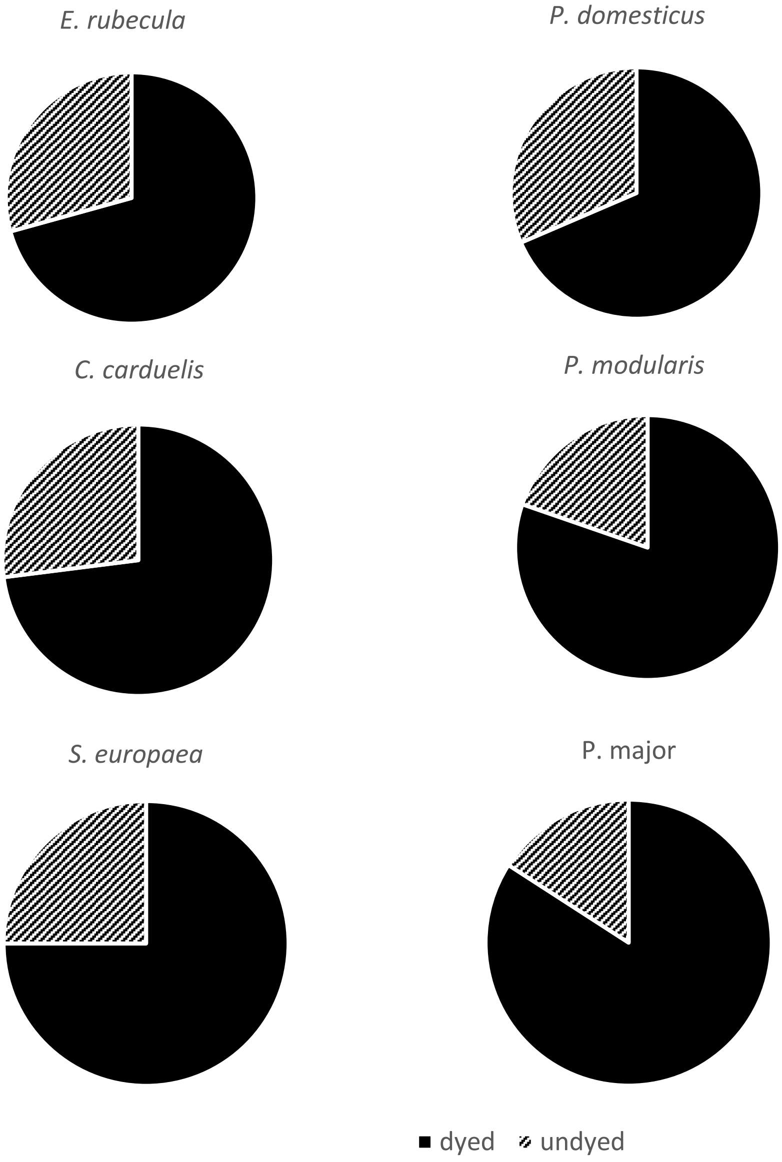

Figure 4. Pie charts showing the percentages of dyed and undyed feeding in the autumn experiment. Percentages were found using the sum of all feeding across the 7 experiment days, calculating proportions of the total. All 6 species had a higher percentage of total feeding time on the dyed feeder.

Figure 5 displays results concerning how feeding time changed with time of day for the 6 commonly observed species. *E. rubecula* and *P. domesticus* recorded the highest total feeding times/10minutes, with 42 seconds/10mins (at 9:30am) and 45 seconds/10mins (at 8:30am) respectively on the dyed feeder. All feeding times were seen to decrease as time progressed, with all species peaking in feeding time before 10am. Additionally, the majority of time intervals (58%) saw a higher total feeding time for the dyed feeder, than undyed. However, only 10% had a greater total feeding time on the undyed feeder compared to the dyed.

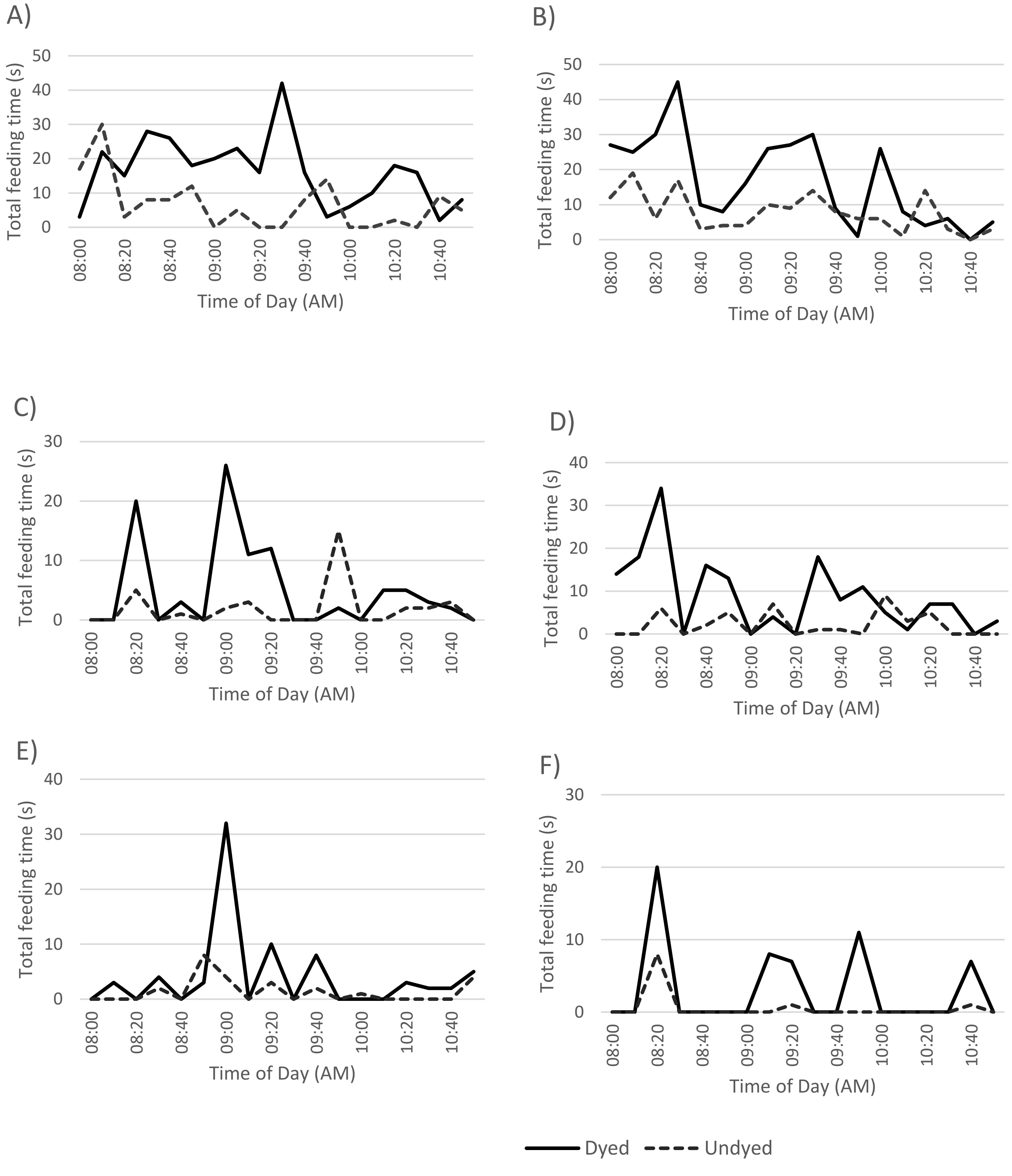

Figure 5. Line graphs displaying total feeding times in the ten minute intervals of the 6 commonly observed species. The total feeding time represents the sum of feeding time on the respective feeder in the 7 days of the autumn experiment. The ten minute intervals ran for 9 minutes and 59 seconds (e.g 08:00:00-08:09:59). Feeding times decrease throughout the day. (A= E. rubecula, B=P. domesticus, C= C. carduelis, D=P. modularis, E= S. europaea, F= P. major)

3.2.2 Influence of species variation in winter months

The winter experiment showed a preference for the dyed feeder across all bird species, excluding *P. major* which showed no preference for either feeder. The total feeding times for the observed species is shown in Figure 6. No significant difference was observed for feeding duration for any species, nor did species make a significant difference on feeding duration for either feeder, tested via ANOVA (Dyed: *p*=0.232, Undyed: *p*=0.289). *P. modularis* recorded the highest percentage of dyed feeding vs undyed (91.01%), with *P. major* showing a ratio of 1:1. These proportions are highlighted in Figure 7.

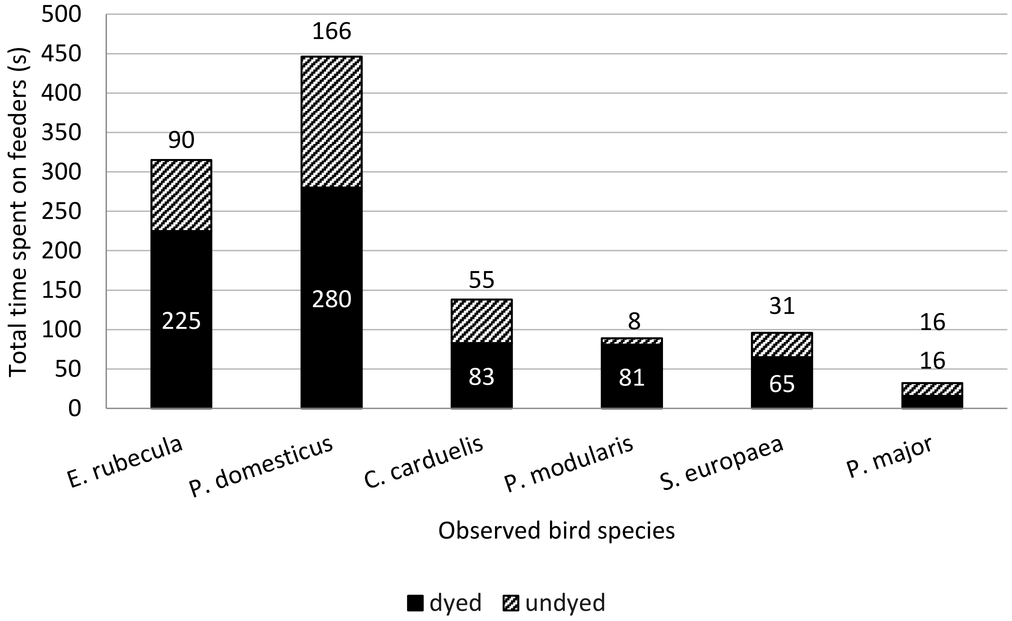

Figure 6. Bar chart highlighting the total feeding times of the 6 commonly observed species in the 5 winter days. The total is a sum of total dyed and undyed feeding, while also showing the total of feeding across both feeders. A preference for the dyed feeder is visible.

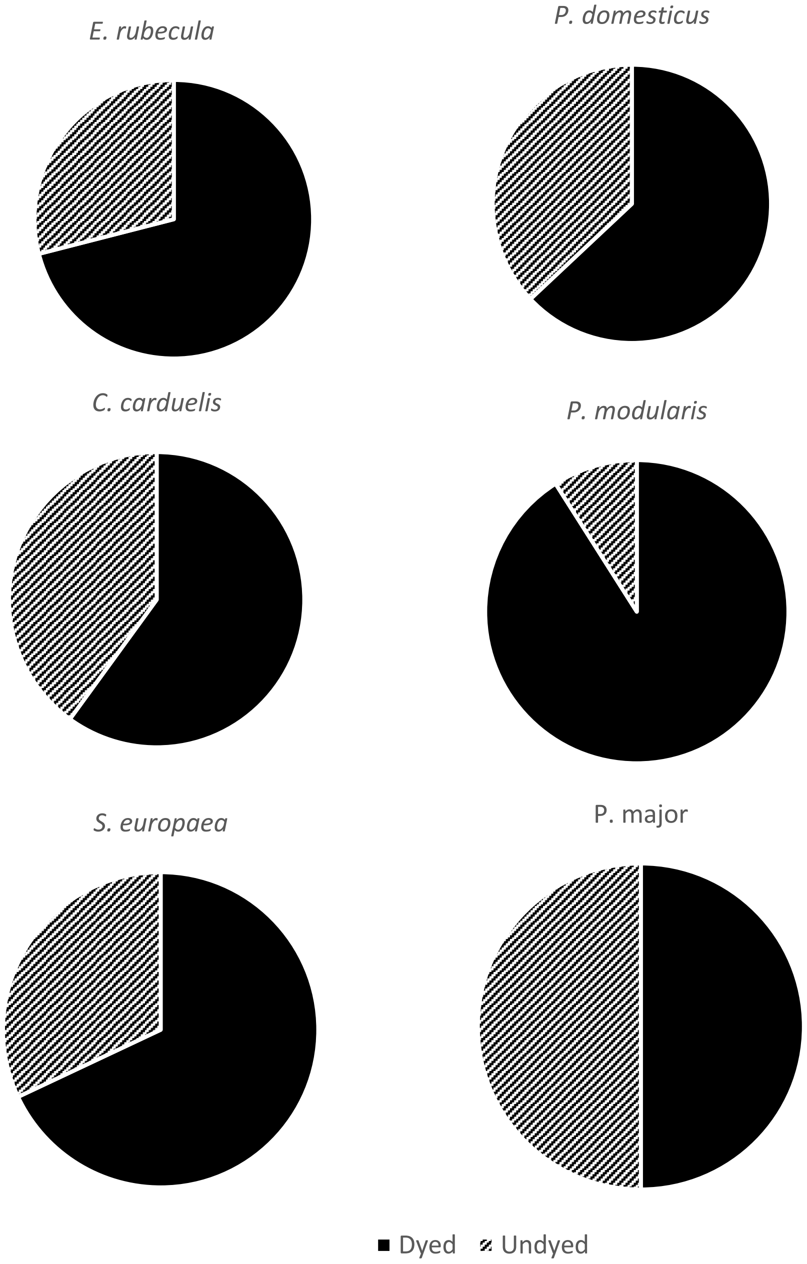

Figure 7. Pie charts showing the proportions of dyed and undyed feeding of the 6 commonly observed species in the winter experiment. Percentages were calculated using the sum of feeding on individual feeders, compared to the sum of feeding on both feeders. This includes all 5 days of experiment. The majority preferred the dyed feeder.

Figure 7 shows the change in total feeding time throughout the day. No real trend was observed for any of the 6 species, with peak feeding time spread across throughout the morning. 48% of the time intervals showed greater total feeding on the dyed feeder, with 21% showing an undyed preference.

Therefore, 31% of time intervals had no preference, as a result of no feeding activity. *E. rubecula* and *P. domesticus* recorded the highest total feeding time /10mins on the dyed feeder. *E. rubecula* recorded 31 seconds at 10:10am, with *P. domesticus* feeding for 34 seconds at 8:40am.

The highest total feeding times on both were recorded by *E. rubecula* (38s at 8:30am) and *P, domesticus* (50s at 8:20am, 38s at 8:40am).

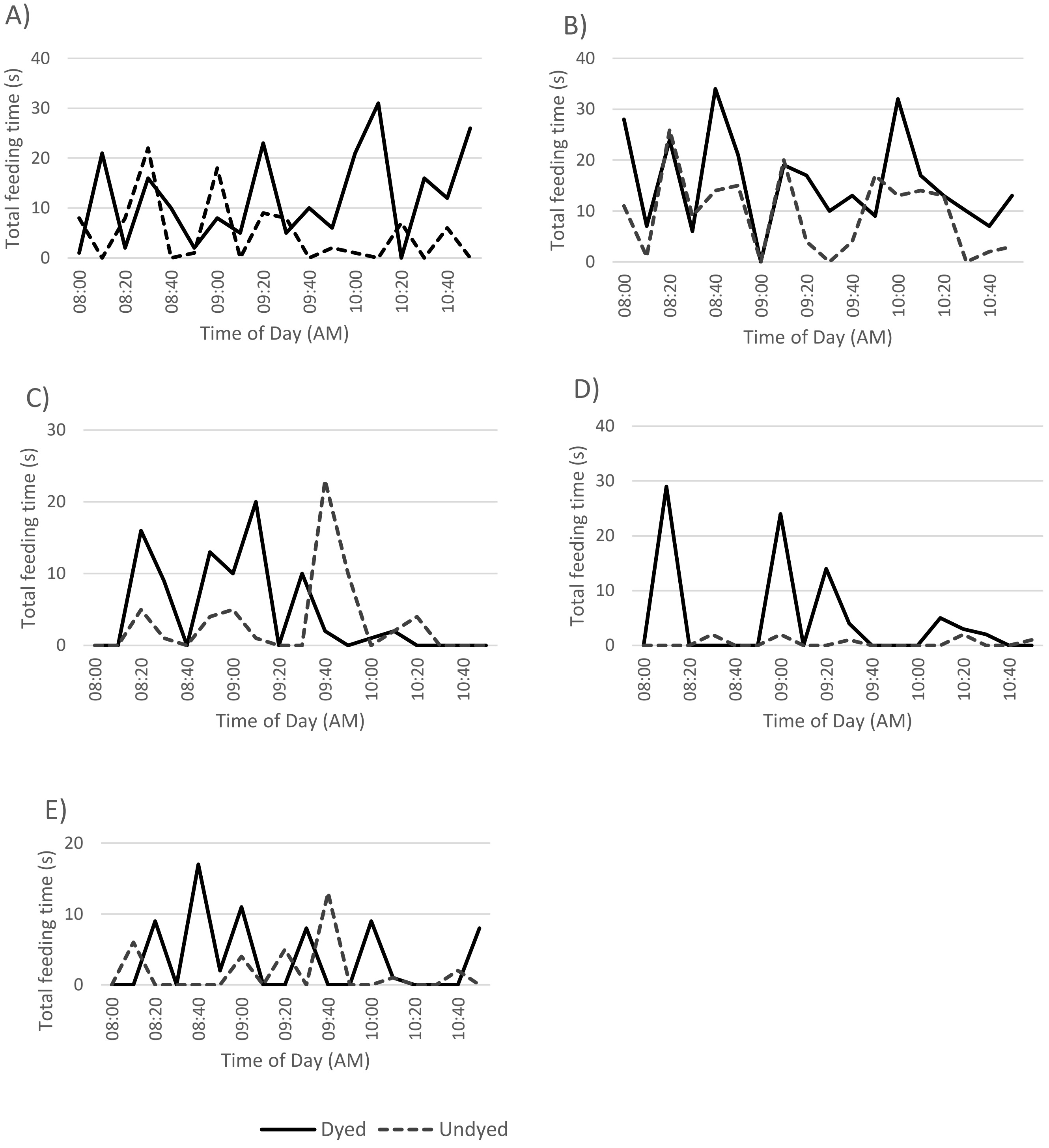

Figure 8. A series of line graphs showing the feeding times of 10 minute intervals throughout the 5 days of the winter experiment. The total feeding time is the sum of all recorded feeding on respective feeders by species within the time interval. The ten minute intervals ran for 9 minutes and 59 seconds (e.g 08:00:00-08:09:59). Insufficient data was recorded to form a graph for P. major. The graphs show very little correlation between feeding time, species and time of day. (A= E. rubecula, B=P. domesticus, C= C. carduelis, D=P. modularis, E= S. europaea).

3.2.3 Influence of species variation between seasons

Comparison of species feeder preference between seasons showed very little significant difference. *E. rubecula* feeding on the undyed showed a significant difference in feeding duration between seasons (*p*=0.0247), but no significance for the dyed feeder. No other species showed significant difference between seasons, but for the most part, bird species fed for longer on the feeders in winter compared to autumn. Figure 9 highlights this.

Table 2 highlights the *p* values of the unpaired *t* tests conducted comparing feeding duration between seasons. Table 3 shows the results from the unpaired *t* tests investigating the difference in feeding duration on the dyed and undyed feeder, in both autumn and winter months.

Table 2. p values from unpaired t tests investigating the difference in feeding duration on the dyed and undyed feeder between seasons. The dyed column shows results comparing species feeding durations on the dyed feeder for the autumn and winter experiment.

Species	Dyed (Autumn v Winter)	Undyed (Autumn v Winter)
E. rubecula	0.479	0.025
P. domesticus	0.218	0.323
C. carduelis	0.939	0.452
P. modularis	0.564	0.341
S. europaea	0.204	0.259
P. major	0.062	0.083

Table 3. p values from unpaired t tests testing significance in difference of feeding durations for the dyed and undyed feeder. The table displays the results for the autumn and winter experiment for the 6 commonly observed species.

Species	Autumn (Dyed v Undyed)	Winter (Dyed v Undyed)
E. rubecula	0.0787	0.7169
P. domesticus	0.354	0.495
C. carduelis	0.202	0.882
P. modularis	0.019	0.087
S. europaea	0.421	0.393
P. major	0.215	1

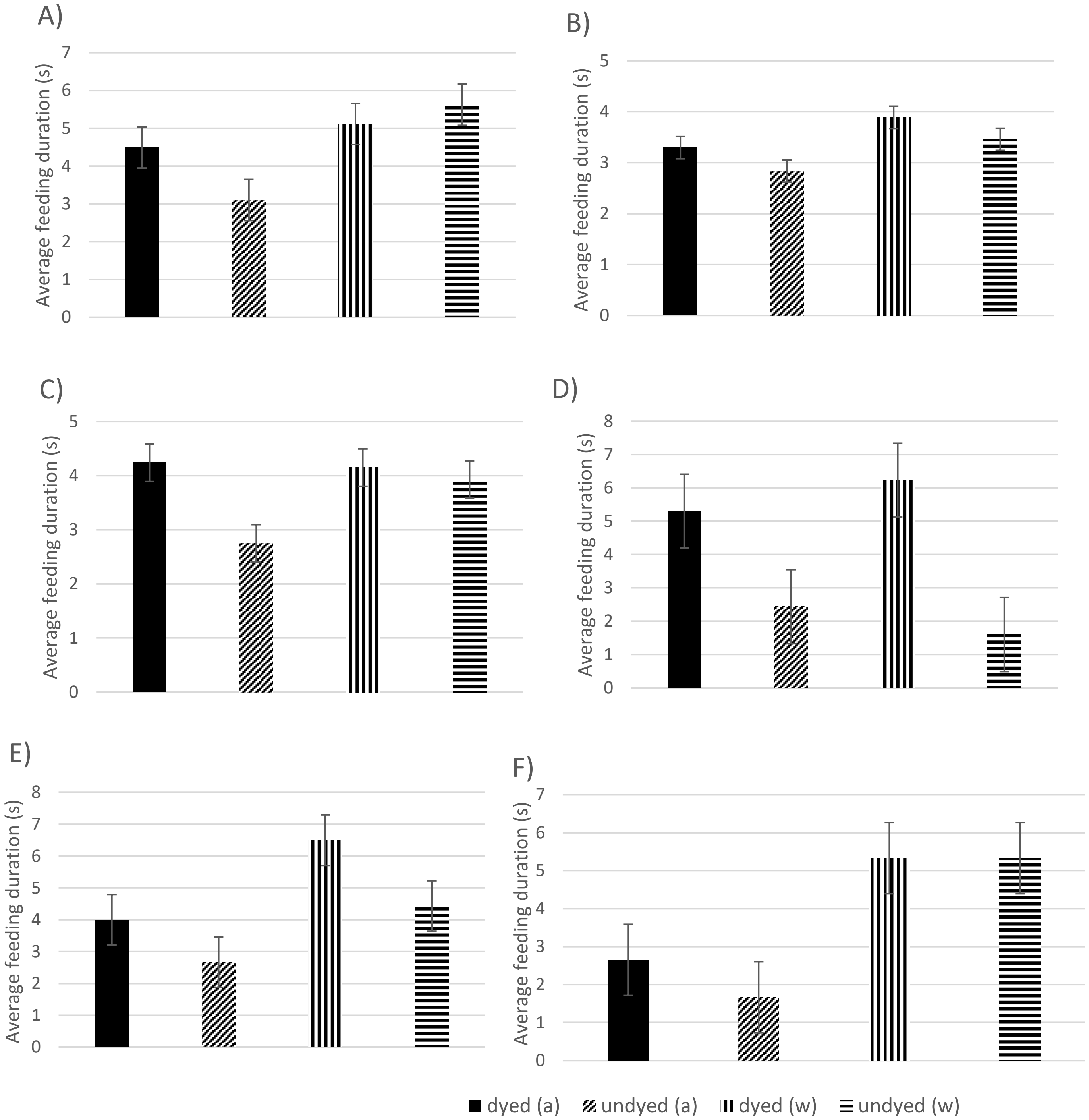

Figure 9. Bar charts showing the average feeding durations of the 6 commonly observed species across the 4 data sets. The (a) represents data collected from the autumn experiment, and the (w) represents the winter experiment. The mean value represents the average, and the error bars depict a 95% confidence interval. Feeding durations in the winter are primarily greater than those in the autumn. (A= E. rubecula, B=P. domesticus, C= C. carduelis, D=P. modularis, E= S. europaea, F= P. major)

3.3 Influence of weather on bird feeding activity

No statistical analysis was completed concerning weather as a variable as it was not recognised as an objective of this study. However, it is important to understand the impact it had on the data. Figure 10 depicts how feeding activity varied with changing weather conditions. Feeding time/hr was noticeably greater in good weather conditions (79s of feeding/hr of good weather), with the poorest conditions receiving the least (32s of feeding/hr of bad weather). This was not the case with feeding duration.

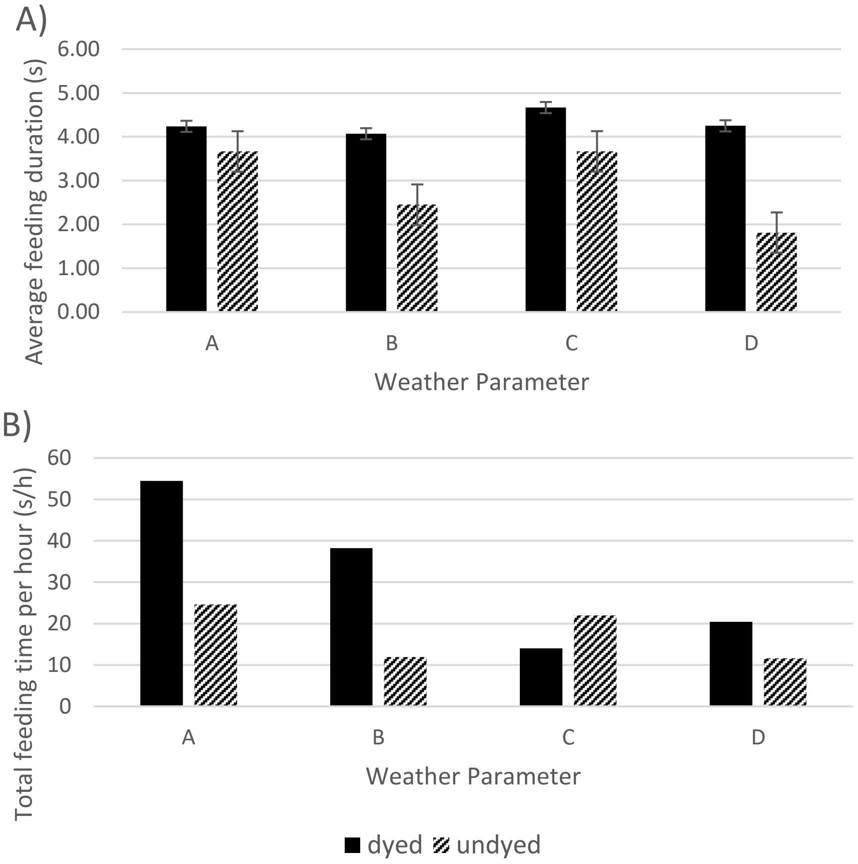

Figure 10. Bar charts showing how average feeding duration (A) and total feeding time/hr (B) changed between weather parameters. Graph A shows the mean feeding duration of all recorded data, across both seasonal experiments. This includes all species. The error bars represent a 95% confidence interval. Graph B shows total feeding time per hour of respective weather parameter. The total is a sum of recorded data of all species, and both experiments. (A: <15km/h winds, <1mm/h precipitation, B: ≥15km/h winds, <1mm/h precipitation, C: <15km/h winds, ≥1mm/h precipitation, D: ≥15km/h winds, ≥1mm/h precipitation)

4 Discussion

Understanding supplementary feeding is significant for raising public awareness on an increasingly popular pastime (Tryjanowski et al., 2018). Supplementary feeding has shown to improve bird health (Wilcoxen et al., 2015), reducing stress and foraging time, while improving antioxidant levels and feather growth (Burt et al., 2020). However, the use of bird feeders has shown to create nutrient and diversity imbalance, while also promoting disease spread (Wilcoxen et al., 2015; Burt et al., 2020). Therefore, understanding food preferences of bird species can increase public knowledge on these issues, and ensure these ramifications are reduced. Studies have shown bird species to choose food based on colour (Duan et al., 2014), and this study aimed to explore the role of colour and apply it to UK garden birds. And, viewing the data, a preference for red-dyed food was evident.

The dyed feeder received more visits, resulting in a greater overall feeding time than its undyed counterpart. This preference was seen in all frequently observed species, and the data showed the majority of frequenting species to feed for a greater total time, and duration, on the dyed feeder across both seasonal experiments.

Species variation was seen to play a significant role in dyed/undyed preference, as was season. In terms of the initial aims, objectives and hypothesis, the data collected was effective in providing conclusions.

This study design and setup was effective in collecting a large dataset, while also remaining accessible and repeatable. Due to the nature of the study, it can be recreated on a small scale (e.g. school children making dyed fat balls and observing differences in behaviour), with a short time scale and small research team. Or, it could be repeated and explored on a larger scale, with multiple experiments exploring additional colours and time of year changes.

With most scientific research methods requiring a large workload with sophisticated resources, it is not accessible or repeatable for a cohort of scientists and researchers. Therefore, this study was designed to maintain a straightforward methodology, with attainable resources, which can be scaled up or down, for a range of people. Such an experiment can be taken to students of all levels (Primary school to university), or researchers, and create an activity that is engaging, accessible and enjoyable, potentially inspiring future research.

4.1 Influence of colour

Focusing specifically on the comparison between the dyed and undyed feeder, a preference is clear. In both autumn and winter, the red feeder had a greater total feeding time (25% more in autumn, 10% in winter) than the undyed feeder. While it cannot be said whether this preference was innate or learnt, a similar trend was seen in a study by Duan et al., 2014. The sample populations (both wild-caught and hand-raised) consistently preferred the red food over other colours, as also seen in results by Larrinaga, (2011) and Puckey et al., (1996). Referring to Table 1, it shows an overall preference for the dyed feeder. This preference was maintained through all study days, and across all species. Figure 1, and data concerning feeder visits support this, with a clear inclination for the red food.

Furthermore, a significant difference was seen between feeding durations in the autumn months. It was observed that, on average, birds fed on the dyed feeder for 3.91 seconds, compared to 2.83 seconds for the undyed feeder. Similarly, in the winter, the dyed feeder received a greater average feeding duration (4.65s) than the undyed (3.9s), but no significant difference was observed. From this, it can be said bird species preferred to feed on the red food for longer than the undyed (brown) food source.

These results align with those of Teichmann et al. (2020). Their work demonstrated an innate preference for red food when presented with green food, and further colour dyes. Much like this study, Teichmann et al. (2020) observed wild UK birds, specifically *Parus*, meaning the results found reinforce the relationships seen in this study. Upon further review, a significant difference was found in the Teichmann et al. (2020) study, similar to that of this study. While it did not concern feeding duration, it showed colour to make a significant difference in time taken for birds to feed, particularly red. This was evident for the red against green, as well as red and orange when compared with purple and green. Orange and red share similar wavelengths (orange:580-625nm, red:625-740nm) (Malacara, 2011), with bird species able to distinguish and categorise both (Zipple et al., 2019). Therefore, an association of nutritional value may be established with perceptual similarity, and explain the relationship seen.

Another supporting study showed naive *S. atricapilla* to significantly prefer red to green, blue, white and yellow (Schaefer, 2004). While *S. atricapilla* were not observed within this study, the results are still comparable with the species being native to the UK. Also, the insectivorous and frugivores diet of the *S. atricipilla* resembles that of the *E. rubecula*, or *P. domesticus* (Jordano and Herrera, 2008), suggesting similar food preference.

As a whole, literature concerning the role of colour in influencing feeding duration was scarce, highlighting the significance of this study.

The red preference seen in this study, and supporting literature, could be explained by the role of colour in optimal foraging. As previously mentioned, colour is commonly used within organisms to display and understand signals (Osorio and Yorobyev, 2008). This is typically observed within attraction displays (Warner and Dill, 2000), but is also recognised to indicate palatability and profitability in food (Teichmann et al., 2020). Red, in particular, increases perceived sweetness, and decreases bitterness, with birds opting for a sweet diet consisting of fruits and nectar (Spence, 2019). UK bird species regularly consume fruits and berries, electing for fruit that is ripe and palatable (Sorensen, 1981). The tetrachromatic vision of birds allows for ripeness recognition, perceiving UV reflectivity in anthocyanin rich fruit (Schaefer et al., 2007). Anthocyanin concentration increases as fruit ripens (Zhou et al., 2020), as does sugar content and digestibility (Phillips et al., 2021). Therefore, the ability to recognise fruit ripeness is nutritionally beneficial for birds, and may show the preference seen within this study. With most ripe fruits being red, the preference for the red feeder can be explained by the preference for ripe fruit. With colour discrimination and categorisation, the red feeder would be associated with ripeness, sweetness, palatability, and profitability.

In contrast, work conducted by Willson et al. (1990) show little tendency for birds to select food based on colour alone, but rather colour distribution and contrast. While the study shows colour to make a difference in food choice, there was not a clear preference for red fruit over other colours. Results from a study conducted by Stanley et al. (2002) show a similar trend. Their conclusion stated that sugar content was the main driver of food preference, with no significant difference between colours (Stanley et al., 2002). Both of these studies counter this investigation, where colour is the main driving factor.

However, results of these studies may not be comparable to relationships found in the UK birds. The use of different sample populations (carnivorous migratory birds e.g. *Vultur* *gryphus*, and Australasia native species) introduce additional variables that may influence food choice. While *Zosterops lateralis* recorded in Stanley et al.'s (2002) share a similar diet to that of frugivorous UK birds, the disparate environments would alter optimal foraging. Tropical regions possess a larger range of ripe fruit colours, including mangoes (orange and green), papaya (green), pineapple (yellow and brown) and bananas (yellow) (Sayago-Ayerdi et al., 2021), meaning red colouring may hold no association with ripeness, and sweetness would be more indicative of palatability and profitability. Therefore, frugivorous tropical birds may opt for sweet ripe fruit rather than a red ripe fruit, potentially explaining the results seen in Stanley et al. (2002).

Time of day was not seen to have a significant impact on bird feeding activity, as confirmed by a two-way ANOVA (p=0.412). Figures 1,2,5 and 7 however, show feeding activity (visits, total feeding and average duration) to decrease as the day progressed. Additionally, Figures 5 and 7 show the majority of species to record their highest total feeding time before 10am. Feeding duration on the dyed feeder was seen to decrease as the day went on.

Birds are recognised to be early feeders, with feeding beginning at sunrise (Bonter et al., 2013). This is potentially due to the reduced predation risk, making it more efficient, with minimal risk and high reward (Farine and Lang, 2013). These results are supported by work conducted by Farine and Lang (2013), showing considerably more feeder visits in the morning compared to afternoon. When looking at Figure 1, it shows the highest number of visits to be between 8-10am, decreasing towards midday. While no data was recorded for the afternoon, the correlation seen means it can be predicted that this decline in activity would continue into the afternoon.

However, work by Bonter et al. (2013) disagrees with this pattern, finding bird foraging to gradually increase through the day. This increase continued until 2 hours before sunset where it eventually declined. And, as mentioned, in this experiment, all feeders saw a decrease in visits, regardless of season. With Bonter et al. (2013) observing passerines in the winter, the results are comparable to that of this experiment. Bonter et al. (2013) concluded that the constant foraging throughout the day was driven by starvation risk. With unreliable food sources and predation risk, birds may be driven to feed at a constant rate to ensure a nutritional threshold is met (Bonter et al., 2013). Added predation risk would expend energy and nutrition, meaning more constant foraging is required. With the sampled birds facing predation pressure from predatory bird species, it may explain the difference between results. This study was conducted in a residential garden, with regular food sources and very little predation, meaning foraging done in the morning would be sufficient, and reduce the need to continue foraging.

This may be the driver of the trends seen in Figures 1,2,5 and 7. And although time of day specifically was not seen to significantly impact feeding duration, conducting the experiment in the morning was logical, with results, and supporting literature showing feeding activity to be high in the morning.

To summarise, the dyed feeder was observed to receive greater total feeding time, with birds opting to feed on the red food for a longer average duration. This preference may be driven by sweetness perception, with colouring increasing perceived sugar content (Spence, 2015). All feeding activity decreased throughout the day, potentially to reduce energy expenditure.

4.2 Influence of species

As a whole, all species showed a clear preference for the dyed feeder (excluding *P. major* in the winter experiment). This included total feeding time across all study days, as well as average feeding duration (as seen in Figures 3,5,6,8 and 9). *E. rubecula* and *P. domesticus* were the most frequently observed bird species, with the highest total feeding time. Both species are widespread and commonly recognised, with stable populations across the UK (Hanson et al., 2020; Gwiazdowska et al., 2021). Additionally, work by Galbraith et al. (2017) has shown *Passeridae* species to dominate feeders, with considerably more daily visits than other visiting species.

Of the commonly observed species, *P, modularis* showed a consistent preference for the red feeder, with 80% of total feeding in autumn on the red feeder, and 91% in the winter (Figures 4 and 7). This was noticeably higher than other species, who spent roughly 60-70% of total foraging time on the red feeder. *P. modularis* also showed to have the proportion of dyed feeding duration across both seasons. This trend, however, has not been observed in other literary papers.

P. modularis activity is at its highest in the morning, with higher energy consumption to fuel flight (Akesson et al., 2021). Additionally, the species make short flights, with regular feeding stops (Michalik et al., 2020), explaining the results seen within this study. The longer feeding times show the need to reach an energy threshold before flying again, and as mentioned, the red "sweet-looking" feeder would be the most profitable place for this.

Tests revealed species to make a significant difference when concerning feeding duration, but very little significance was recorded in terms of dyed vs undyed feeding. ANOVA tests revealed species to make a significant difference on the feeding duration of the dyed feeder in autumn. But species showed to make very little difference in the selection of dyed and undyed food. *P. modularis* was the only species to show a significant difference in feeding duration between the dyed and undyed feeder (autumn).

There are few literary papers concerning species and colour influence on food choice. But, the literature investigating colour influence on avian food choice show a diverse range of bird species to exert the same preference. The previously mentioned studies of Teichmann et al. (2020), Duan et al. (2014), Larrinaga (2011) and Puckey et al. (1996) have shown preference for red food in *Cyanistes caeruleus*, native tropical Asian birds, *Turdus* and *Z. lateralis* respectively. Furthermore, Schaefer et al. (2008) showed the same preference in *S. atricapilla*.

The results of these studies show an innate preference for red food in a broad range of bird species, with very little evidence to contradict this. And this may explain the lack of difference seen in this study, with all observed bird species having an inherent inclination for red food.

The lack of varied preference between species may be due to physiological and ecological similarities. With all the frequenting birds being passerines, seeds make up a large portion of their diet (Field, 2019). Therefore, it could be assumed the majority of passerines share the same dietary preferences when not feeding on supplementary feeders.

However, work conducted by Tryjanowski et al. (2018) showed passerine species to have diverse preferences. Their results show how wild birds opted for different food types, with observed species such as *P. major, P. domesticus* and *S. europea*. Sunflower seeds were the most popular food of choice, but the results showed alternate preferences for millet and fat. Their study concluded stating that sunflower seeds were used by most species (*P. major* being the most common), but passerines such as *Passer* and *Turdus* favour a combination of foods (millets, fats and berries). This conclusion portrays selectivity between species.

However, Tryjanowski et al.'s (2018) results do not discredit the results of this study. While it does show selectivity, it does not suggest selective preference for food colours. In fact, a large portion of observed species in their study, have been shown to have an innate preference for red food. *C. caeruleus* and *Turdus* showed to favour red food, when presented with additional colours (Larrinaga, 2011; Tryjanowski et al., 2018).

Therefore, looking back to Figures 3,5,6,8 and 9, it can be said species influences feeding duration of UK birds. These species showed a large preference for red-dyed food altogether, but this preference showed little variation between species. While *P. modularis* fed on the dyed feeder for significantly longer, this was the only significant observation.

4.3 Influence of season

The change in season saw greater average feeding durations and increased feeding on the undyed feeder. Looking at Figure 9, it shows that all species on average fed for longer on the dyed and undyed feeder in winter months compared to summer (excluding the dyed feeding of *C. carduelis* and undyed feeding of *P. modularis*). This is particularly evident in *E. rubecula*, feeding on the undyed feeder for significantly longer in the winter experiment (Table 2). Additionally, *P. modularis* fed for significantly longer on the dyed feeder in autumn, but this difference was not seen in the winter.

Table 1 shows total feeding to decrease in the winter months (151s/day), compared to autumn (250s/day). However, the total proportion of dyed to undyed feeding is more balanced in the winter (dyed: 78s/day, undyed: 73s/day), with autumn feeding showing a more prominent preference for the dyed food (dyed:140s/day, undyed: 110s/day).

This increase may be due to the seasonal changes and pressures that winter bring. Birds must increase food intake to survive winter nights and lowering temperatures, with fats being of particular focus (Brodin, 2000). Increased fat stores provide energy stores and insulation, increasing fitness (Brodin et al., 2017). To build these fat stores, bird species are recognised to increase dedicated foraging time, and therefore food intake, in addition to selecting fat-dense foods (McWilliams et al., 2021).

This was observed by Wu et al. (2014), finding that *Pycnonotus sinensis* had increased body mass and body fat in the winter. Additionally, those foraging in the winter consumed up to 69% more energy than the spring and summer counterparts (Wu et al., 2014). Furthermore, Renner et al. (2012) recorded significantly more foraging activity of birds in the winter. This shows evidence of birds increasing energy consumption leading up to, and in winter months. As well as this, it shows that foraging behaviours can differ between seasons, supporting the results of this study.

The greater average feeding durations seen in Figure 9 and Table 1 show an increased winter feeding, with bird species allocating more time to feeding and increasing fat stores. This foraging, however, increases predation risk, with bird species balancing risks and predation and starvation (Turbill and Stojanovski, 2018; Zimmer et al., 2011). Therefore, the need to forage is much less prominent in summer, reducing predation risk. This difference in nutritional needs between seasons drives the differences seen in feeding duration and total feeding time for the species of this study.

Referring to optimal foraging theory, the most effective and efficient method of increasing fat intake would be selective intake of fat dense foods. When alluding to a passerines diet, nuts and seeds (particularly peanuts) would be the optimal choice, being fat dense and energy rich (Lonnie et al., 2018; Nyffeler et al., 2018).

Renner et al., (2012) showed this to be the case, with greater consumption of fat dense foods, and less intake of carbohydrates in winter. In the colder period, bird species preferred peanuts over grains, but this switched as spring approached (Renner et al., 2012). This peanut profitability preference was also observed by Molokwu et al. (2011).

With bird species actively selecting peanuts for winter bulking, it may offer an explanation for the results of this study. Peanuts, and most nuts, occupy shades of brown, resembling the colour of the undyed fat ball used in this experiment. Therefore, much like the way bird species select red for its associated sweetness and energy richness, the undyed brown fat ball may be selected for its perceived fat density. However, this is only a suggestion with a lack of literature to support this. But based on the innate preference for red, and evidence for the optimal foraging theory, it seems a logical explanation for the results seen.

As a whole, season was seen to impact feeding behaviour of observed foraging birds, with the feeding duration increasing for most of the species in the winter. Additionally, the undyed winter feeder recorded proportionally more feeding time, as well as significantly greater feeding duration, than its autumn counterpart. These results can be explained by the increased daily energy needs of birds during winter months.

4.4 Influence of weather

Rainfall and wind are recognised to influence ecological behaviour of birds (Mainwaring et al., 2021), including foraging (Chard et al., 2018), with rainfall impairing senses and increasing energetic costs (De Pascalis et al., 2022). Similarly, high wind speeds can interfere with heat gain/loss, senses (Walther et al., 2017), while also preventing accurate landings and perching (Shepard et al., 2019).

While not investigated as an objective in this study, weather was observed to influence the recorded data. Birds recorded a greater total feeding time in clear weather than any other weather parameter. Looking at Figure 10, high rainfall was seen to have the biggest influence on total feeding time, more so than high wind speeds. This may be due to the aforementioned effects, with rain influencing foraging behaviour, and reducing effectiveness (Chard et al., 2018).

High wind speeds, wind direction and crosswinds are all recognised to determine foraging efficiency of birds (Alsteram et al., 2019). Stronger winds and flying across a crosswind can reduce efficiency and range of foraging flights (Alsteram et al., 2019). This was observed by Rose, (2009), with *Tachycineta* reducing allocating foraging time with strong winds. Therefore, parameter D (high winds and rain) would introduce foraging pressures that may reduce effectiveness and quality.

However, average feeding duration was not noticeably affected by varying weather conditions. In fact, parameter C showed the highest average duration across both feeders. And, parameter D, despite the poor weather conditions, resembled the average duration of the good weather conditions.

Referring to optimal foraging theory, it may offer an explanation. With traversing poor weather conditions, energy expenditure is greater (De Pascalis et al., 2022), making it more beneficial for bird species to forage for a greater duration, to make the commute 'worthwhile'.

It is important to acknowledge the influence of weather in this study, as Figure 10 shows it to have an effect. While the extent and significance of this effect was not investigated, it does create a foundation for future research. With data showing weather to influence feeding, a repeat experiment could consider how far weather influences food choice.

4.5 Conclusion

Supplementary bird feeding is becoming an increasingly popular activity across UK homes, with 63% of households providing food/water for wild birds (Davies et al., 2012). However, supplementary feeding is recognised to bring impactful side effects, including reduced biodiversity and disease (Wilcoxen et al., 2015; Burt et al., 2020). This may be driven by a lack of knowledge of bird feeding behaviour, with behaviours varying between species, season, food type and colour. Combined with a gap in literature concerning the influence of food colour on UK wild bird feeding, it placed importance on developing an understanding of the factors that determine bird feeding.

This study observed variation in bird foraging behaviour between season, species and food colour, with bird species showing a preference for red dyed fat balls, over undyed fat balls. The recognition of this preference, and other significant behavioural differences, within a short time period, indicate the extent of behavioural diversity within birds. Repeat experiments, or a larger study, would truly acknowledge the magnitude of behavioural and preferential differences of wild UK bird species. From this, the public can be better educated on supplementary feeding and how to avoid the ramifications.

Additionally, this study provides evidence to support the optimal foraging theory, with passerine birds selectively choosing food, based on colour and season, that most benefits them. Again, this is important as it recognises variation in animal foraging behaviour and supports other studies in which optimal foraging theory has been observed.

The importance of this study cannot be understated, with an urgent need for public knowledge. With research and literature becoming increasingly inaccessible, this study provides a straightforward method which can be received by the general public; this is critical in conveying the results, conclusion and meaning of this study, creating a basis which can further explored and developed.

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6 Appendices

6.1 Appendix 1: Learning Contract

Bournemouth University

LEARNING CONTRACT:

INDEPENDENT RESEARCH PROJECT

The learning contract is an agreement between student and supervisor: it should clearly indicate what is expected from both sides. The text in Sections 2 and 3 provides guidance and can be modified to give more details reflecting what has been agreed, such as deadlines for submission of drafts and provision of feedback, word count limits/exclusions and number/timing of meetings. **Importantly, the document checklist helps students to follow the required procedures (e.g. ethical approval and risk assessment) and communicate what has been done to the supervisor.** **The student should submit a draft of the completed form to the supervisor and request a meeting to discuss and finalise the content. Both the student and the supervisor are responsible for keeping a signed copy of this document and following what has been mutually agreed.**
1. YOUR DETAILS
Student name: George Wallbridge
Degree Programme: Biological Sciences
Proposed IRP Title or Set Project: Food choice in birds 3 - colour preference UV excited dyes
Supervisor name: Paul Hartley
2. As the student undertaking the above project I agree to:
• E-mail my supervisor on a fortnightly basis with a progress report • Meet with my supervisor at least once a month to discuss progress and I understand that it is my responsibility to organise these meetings • Comply with the terms of this learning contract and the guidance set out in the Guide to Independent Research Projects • I understand that this is an *independent* project and that I am solely responsible for its completion • I agree to comply with all ethical, laboratory and fieldwork protocols established by the Faculty.
3. As the supervisor of this project I agree to:

- Meet with the student undertaking this project on at least a monthly basis and to respond to the progress e-mails as appropriate
- To meet formally with the student during the first week in November to undertake the interim interview
- To provide guidance and support to the student undertaking this project bearing in mind that it is an *independent* research project. This is inclusive of commenting on drafts of the final report in a timely fashion.

3. DOCUMENT CHECKLIST

Research Proposal or Plan Attached? ☐ **YES** ☐ **NO**

☐ **YES**	☐ **NO**	**Risk Assessment for fieldwork and evidence of COSSH assessment for all laboratory procedures (online risk assessment completed)**
☐ **YES**	☐ **NO**	**Completed booking for all field equipment**
☐ **YES**	☐ **NO**	**Letters of permission where appropriate providing evidence of access to such things as field sites and/or museum archives**
☐ **YES**	☐ **NO**	**Completed Ethics Checklist**

4. INTERIM INTERVIEW – Progress evaluation

Add here the key points of discussion and what has been agreed, particularly if different from Sections 2 and 3. Please indicate the date of your Interim Review (preferably in October within a month of starting Level 6).

Interim Review Date:

5. Variance from the Independent Research Project Guide

The IRP assessment is normally governed by the guidance provided in the Independent Research Project Guide. Any variance in terms of format (e.g. technical report, scientific paper) and word limit should be agreed and specified here. Submission date cannot be changed unless evidence of mitigating circumstances is provided in accordance with the standard BU Guidelines.

Any changes? ☐ **YES** ☐ **NO** If YES please provide details below:

Both of the undersigned parties agree to be bound by this learning contract:	
Student Signature:	George Wallbridge
PRINT NAME:	GEORGE WALLBRIDGE
Date:	13/05/2022

Supervisor Signature:	
PRINT NAME:	Paul S. Hartley
Date:	16th May 2022

6.2 Appendix 2: Interim comments

Independent Research Project
Interim Interview - Agreed Comments Form

Student Name: George Wallbridge	Programme: Biological Sciences
Date: 28/11/2022	IRP Title: Food Choices in Birds – colour preference
Supervisor Name: Paul Hartley	

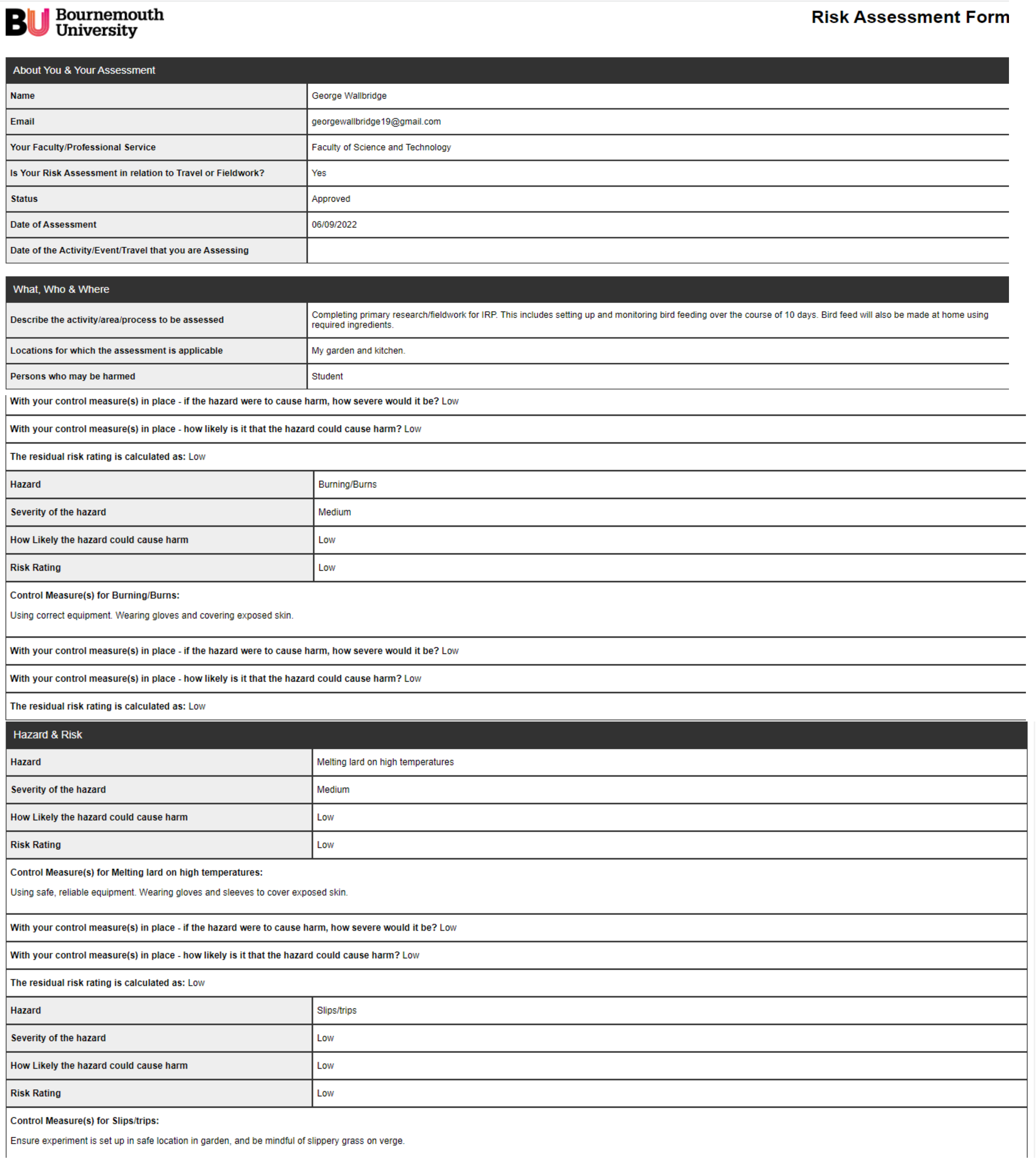
Agreed comments – to include progress and plans for completion:

- Discuss method and materials for experiment
- Discuss structure of results, data presentation and analysis
- Make plan for completion timeline
- Discuss accessibility of science
- Make multipaneled graphs
- Ensure species naming is consistent (common or binomial)
- Mention recommendations/ limitations of data
- Ensure figure/table legends are detailed and explain what the figure shows

Two copies of this form are needed – student to retain one copy and include in the appendices of the dissertation the other is to be emailed to the supervisor.

Student Signature: GWallbridge	Supervisor Signature:

6.3 Appendix 3: Risk Assessment



Bournemouth University

Risk Assessment Form

About You & Your Assessment

Name	George Wallbridge
Email	georgewallbridge19@gmail.com
Your Faculty/Professional Service	Faculty of Science and Technology
Is Your Risk Assessment in relation to Travel or Fieldwork?	Yes
Status	Approved
Date of Assessment	06/09/2022
Date of the Activity/Event/Travel that you are Assessing	

What, Who & Where

Describe the activity/area/process to be assessed	Completing primary research/fieldwork for IRP. This includes setting up and monitoring bird feeding over the course of 10 days. Bird feed will also be made at home using required ingredients.
Locations for which the assessment is applicable	My garden and kitchen.
Persons who may be harmed	Student

With your control measure(s) in place - if the hazard were to cause harm, how severe would it be? Low

With your control measure(s) in place - how likely is it that the hazard could cause harm? Low

The residual risk rating is calculated as: Low

Hazard	Burning/Burns
Severity of the hazard	Medium
How Likely the hazard could cause harm	Low
Risk Rating	Low

Control Measure(s) for Burning/Burns:

Using correct equipment. Wearing gloves and covering exposed skin.

With your control measure(s) in place - if the hazard were to cause harm, how severe would it be? Low

With your control measure(s) in place - how likely is it that the hazard could cause harm? Low

The residual risk rating is calculated as: Low

Hazard & Risk

Hazard	Melting lard on high temperatures
Severity of the hazard	Medium
How Likely the hazard could cause harm	Low
Risk Rating	Low

Control Measure(s) for Melting lard on high temperatures:

Using safe, reliable equipment. Wearing gloves and sleeves to cover exposed skin.

With your control measure(s) in place - if the hazard were to cause harm, how severe would it be? Low

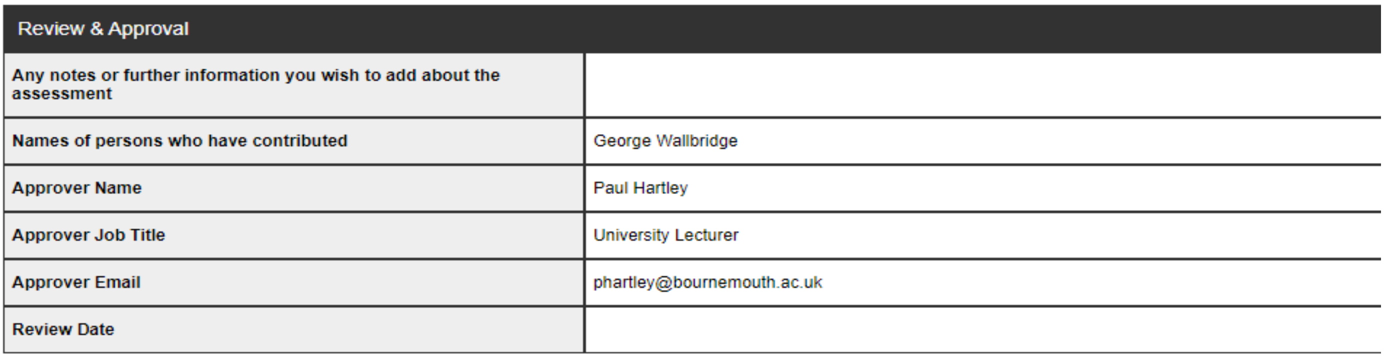
With your control measure(s) in place - how likely is it that the hazard could cause harm? Low

The residual risk rating is calculated as: Low

Hazard	Slips/trips
Severity of the hazard	Low
How Likely the hazard could cause harm	Low
Risk Rating	Low

Control Measure(s) for Slips/trips:

Ensure experiment is set up in safe location in garden, and be mindful of slippery grass on verge.



Review & Approval	
Any notes or further information you wish to add about the assessment	
Names of persons who have contributed	George Wallbridge
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Approver Job Title	University Lecturer
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Review Date	

6.4 Appendix 4: Experiment Setup