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Perceptions and Acceptance of Robotic Apple Harvesting

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Abstract

Apples are a significant dietary staple in the world, and with the global population expected to reach 9.7 billion by 2050, which represents a 25.7% increase from 2020, the agricultural sector faces a massive surge in demand. This growth creates an urgent need to develop new systems that can harvest apples effectively while maintaining sustainable farming practices. Traditional apple harvesting relies heavily on manual methods that are not only labour-intensive but also pose significant risks to the musculoskeletal health of human fruit pickers. The repetitive nature of the task and the physical strain involved make traditional picking an increasingly unsustainable practice. Therefore, an automated and more efficient harvesting solution is envisioned as a necessary requirement to address the evolving societal and ethical demands. Before developing such technical systems, it is imperative to understand the consumer needs and acceptance of harvesting apples using systems such as robots. This research aims to understand the public perception of robotic apple harvesting, including an investigation of nine distinct scenarios. The research considers both the advantages and the potential societal risks associated with technologies available today and those expected to emerge in the near future. A questionnaire has been designed to incorporate all the possible considerations to capture sufficient data for analysis. By collecting data from a population of 240 samples using questionnaires and conducting statistical analysis, the study shows that consumers care significantly about the size and colour of apples as an indication of quality. The majority of consumers have no preference for or welcome robotic harvesting and tend to believe the harvested quality is better.

Keywords

Robotic Apple Harvester, Consumer Perceptions, SPSS, Agricultural Robotics

1. Introduction

Apples are a very common crop worldwide, and the U.S. Department of Agriculture estimated a global apple production of 75.8 million tons in 2019/2020, which was a near 5-million-ton increase from the previous year [1]. Apples for direct consumption are commonly harvested by hand, which is both laborious and time-consuming. Workers often experience musculoskeletal problems. One cause of this is due to the picker's arm being exposed to negative loads for long periods of time, causing their hands to stretch above the line of shoulders for approximately 40% - 50% of the total working time [2]. Additionally, the industry has struggled to employ fruit pickers for the past few years. In 2019, UK farmers reported a 30% shortage of pickers [3]. Emergency situations often worsen the labour shortage, as shown by the COVID-19 pandemic and travel restrictions, which have further fuelled the decline in available fruit pickers.

A robotic apple harvester (RAH) can potentially alleviate the above societal workforce challenges and associated problems. The evolution of relevant technologies has reached a threshold that facilitates the creation of a new generation of robotic harvesting systems [4]. These systems will enhance harvesting efficiency, alleviate farm labour shortages, and strengthen the food supply chain. The technical implications of using robotic harvesters are evidenced well from its potential ability to operate long hours, produce a consistent output and can already have picking accuracy of up to 77% [5]. However, the non-technical implications are unclear, as consumer buying behaviours are influenced by many factors and often unpredictable. Consumers have preferences over the source of their food, as shown in public consumption trends, for instance, the choice between organic and non-organic fruits [6]. Similarly, consumers may have preferences over how their apples are harvested, processed, and packaged before they are presented in a supermarket. There may not be a definitive single, homogeneous perspective. This highlights the importance of first researching the buying behaviour of consumers of apples so a fuller understanding can be made before spending the resources to develop such systems.

Therefore, this study aims to evaluate consumers' attitudes and perceptions of apple harvesting and final packaging using robots. To assess the perception and likelihood of acceptance of robot harvesting among consumers in the general public, it is essential to present a holistic futuristic projection of the potential outlook if future-generation robotic harvester and packaging systems are deployed. These could include dedicated robots for harvesting or emerging robots in packaging to be developed based on meeting consumers' needs for robot-harvested apples. From the state-of-the-art research detailed in Section 2, several prototype systems have demonstrated that well-designed robot systems are capable of consistent harvesting and real-time monitoring of fruit quality [7]. This consistency includes selective harvesting of apples of suitable quality, allowing smaller fruit more time to mature.

In this study, the size and colour of apples are considered as the key quality indi-

cators. Other indicators such as taste, texture and nutrient content of the apples are of equal importance and will be investigated later once an initial understanding of the consumers' perception toward robotic harvesting is established. Using a typical package size of 4 apples, commonly found in supermarkets, it is decided to focus on the perception of the sizes and colour as a representation of ripeness of apples for this study. Robotic capabilities can be enhanced by developing vision technology which can measure the sizes and colour of apples to be harvested. This hence provides potential improvements in precision harvesting, and it is considered that these may present benefits which not only liberate human fruit pickers from labour-intensive harvesting, but also improve apple harvesting quality through identifying ripe apples. For the packaging operation, it is also considered that robots in the future can sort apples with similarity in terms of size and colour to meet supermarket requirements [8].

Different size and colour permutations are possible for apple harvesting. Human hand picking may have challenges in remembering characteristics of all apples such as size and colour. It is, however, possible that robots can remember these characteristics and hence sort them to the needs of both apple growers and consumers. It is therefore necessary to study the impact of these variations in size and colour on the consumer's decision, and to indicate the difference between harvesting by hand and by robots; hence, the hypotheses are:

H1A: The size of apples has an effect on the consumers' buying preference.

H1B: The colour of apples has an effect on the consumers' buying preference.

H1C: There is an interaction between size and colour.

Other hypotheses (H) include:

H2: There is an association between a higher level of education and preference over how apples are harvested.

H3: Gender has an effect on the consumers' harvesting method preference.

H4: There is an association between one's perception of the quality of apples harvested by robots (QAH) and their preference over how apples are harvested.

2. Related Work

The exact research hypothesis proposed in this work has yet to be examined, and there is no known research methodology or validated questionnaires which can be directly applied. Whilst van der Burg *et al.* study the ethical aspects of agri-food robots, it does so only from the view of 33 experts within the field and does not consider the end consumers' acceptance of agri-robotics [9]. Therefore, relevant research work on Consumer perception and robot-human interaction has been investigated to develop an appropriate research method.

2.1. Consumer Perception

Massaglia *et al.* studied the consumer preferences in Fruit and Vegetable purchasing decisions [10]. A choice experiment was conducted in two metropolitan areas in Northwest Italy. Face-to-face interviews using a paper questionnaire were con-

ducted for 1170 consumers at different FV purchase points. The best-worst scaling (BWS) methodology was used, allowing the relative importance (Best and Worst) assigned by consumers to 12 intrinsic and extrinsic fruit and vegetable product attributes to be assessed. Different attribute combinations are used for each question within the questionnaire. BWS rank the items in order and indicate the level of relative importance for each attribute using the average BW raw score. BW raw score is calculated by dividing the BW score by the number of observations and the frequency that each attribute appeared in the questionnaire. A two-tailed t-test was used to assess whether one attribute was preferred to another within the sample of respondents.

Petrescu *et al*. explored consumers' perceptions of organic food in the North-West Region of Romania [11]. In particular, they studied if consumers viewed organic food as healthy and environmentally friendly or just another fashion trend. A twice pre-tested survey was used with a probabilistic sample size of 420 subjects from the studied region. The survey involved face-to-face interviews conducted by a trained assistant. The questionnaire used agreement/disagreement style questions. Spearman's Rank Order Correlation was used to indicate the strength of correlation between fashion-fad, fashion out of curiosity and fad out of curiosity. Stoleru *et al*. carried out a similar study in Romania of organic products [12]. The study focused upon the influence of sociodemographic factors upon consumers' perception of organic products.

Singh *et al*. conducted an empirical evidence study of consumer perception and socioeconomic profiles for digital stores in Vietnam [13]. A questionnaire was adapted using Likert questions with six different segments, all based on validated scales in the literature [14] related to online purchasing orientation. The data were first analysed by employing Harman's single-factor test. The authors achieved this through prescribing the exploratory factor analysis (EFA) by SPSS-22 for all items measured and studied the Cronbach's alpha value to ensure good consistency of reliability.

2.2. Human Robot Interactions

Research regarding the human attitude towards robots has been conducted under various settings. Social-psychological views of humans play a huge role in the acceptance of robots under any environment. Schermerhorn *et al*. researched the connection between robot social presence and gender [15]. The methodology consisted of three phases, including a survey, two arithmetic tasks and another survey. A within-subjects design was used with one robot condition (robot-first vs robot-second), one gender condition (male vs female), and an order condition for the arithmetic tasks (easy-hard vs hard-easy). 47 participants were randomly split into two groups and completed the experiment with different orderings of the robot condition. The survey included a mixture of robot-related and personal questions. The survey also included five items of the Marlowe-Crowne (MC) Social Desirability Scale. The five selected items proved to be sensitive to the mode of survey

administration and therefore were included.

The results of the first survey from both groups aimed to determine if the robot's presence and gender would affect the subjects' responses. A factor analysis was implemented on the responses to survey one. Based on the factor analysis, the responses to the robot items and personal items were analysed separately, generating two factor scores (RScore and PScore). The scores indicate the subjects' attitude towards robots and honesty, respectively. A two-way ANOVA test was conducted for the dependent variable (DV) RScore against the independent variables (IV) gender and robot presence. A Fisher's LSD test confirmed the results of the ANOVA. This was repeated for PScore and robot presence. The above process was repeated for survey two, except the aim was to determine the subjects' reported views with the removal and introduction of the robot. A two-way ANOVA between the MC-Five total score and the independent variables Robot Presence and Gender was conducted.

Krageloh *et al.* used an iterative search strategy to review current psychometrically validated questionnaires which measure social acceptability factors related to social robots [16]. Six questionnaires were identified and explained in detail. These include the Negative Attitudes towards Robots Scale (NARS), Robotic Social Attributes Scale (RoSAS), Ethical Acceptability Scale, Technology-Specific Expectation Scale (TSES), Frankenstein Syndrome Questionnaire (FSQ) and Multi-Dimensional Robot Attitude Scale (MDRAS). NARS and FSQ both investigate attitudes and anxieties about robots; however, NARS has a heavier focus on factors directly related to robot interactions, whereas FSQ covers broader societal implications regarding humanoid robots. The MDRAS enables a greater range of attitudes to be expressed. The RoSAS uses a semantic differential scale as opposed to statements and agreement ratings. Hence, it allows a heavier focus on more fundamental associations with robots. The Ethical Acceptability Scale specifically studies issues related to the use of social robots in therapy for autistic children.

3. Methodology

The above literature presents the various tests and methods used within the relevant topics. Following this, the following method has been developed to aid the evaluation of the hypothesis. It is necessary to define a formal methodology in order to conduct this long-term research goal of ultimately designing a technologically feasible, societally acceptable and cost-effective harvester. **Figure 1** shows a formal research and design methodology for such an effort proposed in this study. It is aimed at defining a robust and effective way of tackling this societally important challenge. It consists of four main stages: stage 1, represented by three green activities, aims to gain a deeper understanding of the challenge of fruit harvesting in general and apple harvesting specifically. These involve literature-based market and demand research, on which a set of hypotheses can then be defined before a set of questions are formulated to find out the public view on apple harvesting using new technologies, specifically robots. At stage two, questionnaire-

based surveys are launched to sample as many members of the general public as possible. It is imperative to capture as diverse members of the public as possible from as many backgrounds as possible. Analyses of these survey results are then conducted to reveal public views on their preference and acceptance of deploying new technological robotic solutions in harvesting. Based on these results, it is then possible to recommend some design specifications from consumers' perspective so the new robotic solution contains the desirable features defined by consumers. This stage of work would then be followed by further design and manufacturing of a suitable robotic harvesting system at stage four. A technological review of robotics deployed in other fields which could be useful should be investigated, and some of these technologies could be used to enhance the performance of the harvesting robots. A range of conceptual solutions should then be explored in order to produce an optimal solution for a traditional industrial sector whose profession has become very unattractive. Following this, it is then necessary to embody all desirable features at the conceptual design stage into a detailed embodiment design solution before a prototype system is constructed for testing and field trials.

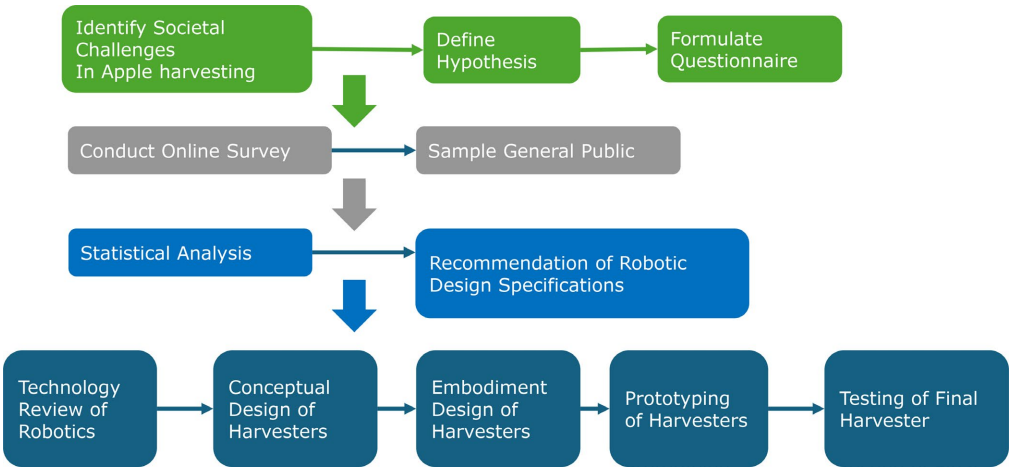


Figure 1. Apple harvester research and design methodology.

Due to space limitations, the focus of this paper is on the first three stages of this long-term project and solutions for harvesting will be reported in the future.

3.1. Questionnaire Design

This study aims to find out the perception of apple harvesting from the general public, and hence the study requires data on the views from representative consumers on apple harvesting. As there are no such data readily available publicly, a new questionnaire needs to be designed suitably to capture necessary data for a meaningful analysis of consumers' perceptions of harvesting and their preferences. Questionnaires are preferred over focus groups as participants are more likely to answer honestly when anonymous. The questionnaire has been designed to comply with the legal requirements of the General Data Protection Regulation (GDPR) and the Data Protection Act 2018 by informing the participants of their rights under GDPR

and following the relevant protocols of the University of Lincoln. The questionnaire was designed using a hybrid approach to address the hypothesis. A mixture of novel questions and existing questionnaire questions from the literature was used. Throughout, a mixture of positive and negative framing methods was used to ensure no bias. Moreover, the questions were designed to collect a mixture of nominal, scale and ordinal data, allowing inferential statistical tests to be conducted. The questionnaire was piloted initially using a group of 10 people across STEM, psychology and HR majors to ensure clarity. This pilot study showed overall satisfaction with the questionnaire, and little change to the design was required. The pretest was considered a validation process. Moreover, some items have been validated in previous studies. Following on the experience gained from the literature review and adopting the structure of reviewed topics, the questionnaire was split into sections targeting specific topics. The questionnaire was provided in both English and Mandarin to increase the cultural diversity of the participants. A summary of the questionnaire is shown in Table 1, and the techniques used are detailed below.

Table 1. Questionnaire design summary.

Section	Topic	Questions
1 (5 items)	General Sociodemographic Profile	Five questions have been designed to gain an understanding of a participant's age group, gender, employment/technical background, country of residence and education level.
2 (12 items)	Apple consumer preference	Twelve questions are designed to find out the preferences of consumers in terms of their apple shopping preferences, including nine combinations of different sizes and colours of four apples in a package. These are the key questions to find out consumers' preferences without influencing their opinion by explicitly telling them the way the apples are harvested. The focus presented to the participants is the final packaged apple combinations, and their decisions are intended to be based on the quality and size of the apples.
3 (8 items)	Robotic Harvester Perceptions	Eight research questions are designed to find out the preference for harvesting using either human pickers or a robotic system.
4 (3 items)	NARS Social Influence of Robots	Three research questions are created to assess the social influence of a robotic system in harvesting by using 5 levels of choices from Strongly Disagree to Strongly Agree for five statements.
5 (5 items)	MC 5-items	Five questions are designed to understand the participant's social bias.

1) As proven by Stoleru *et al.*, the sociodemographic background of participants has a heavy influence on food perceptions [12]. This may also be the case for robot harvesters; thus, standard background data were collected. To ensure inclusion of all participants, the options for personal questions regarding, say, gender were worded cautiously, following best practices.

2) To investigate H1A/B/C, 9 combinations (size and colour) of apples were presented to the participants. For each combination, the participant was asked to write how many packs of each combination they would be willing to buy. To produce the intended combinations of apples, the author carefully selected the apples and took adequate pictures of each combination to provide pictorial aids for par-

ticipants to select within the questionnaire. A within-subjects design was used where both the size and colour have three levels. Each combination consists of four apples with different sizes and colours to represent ripeness. The three levels for size and colour respectively include: the same size 2 small and 2 large, all different sizes; and all red two red and two unripe, and very mixed-colour apples. These size and colour combinations provide 3 × 3 or 9 combinations. By considering the individual permutations of the four apples in a package, there are a total of 9 × 9 × 9 × 9 or 6561 combinations, assuming that identical apples are available when required. An experimental design was used to significantly reduce the number of combinations that participants need to select. An L9 orthogonal experimental design was created to include the following nine combinations. In order to simplify the complexity of the many possible combinations and avoid bias in size, an assumption is made that the total weight of a package of four apples of any combination is equal. This has been made clear in the questionnaire, and the following initial four combinations are created.

Figure 2 shows an image of the details of the first combination of four apples as case (a) for survey Question 8: all 4 apples are ripe, as shown by their red colour and being the same size. These are an ideal combination and are normally difficult for a human picker to achieve. Figure 3 shows a combination of four apples as case (b), where all 4 apples are ripe as shown by their red colour, but two apples are large in size, and the other two are small in size. Figure 4 is case (c) and has a combination of four apples: all 4 apples are ripe as revealed by their red colour, but they are all different sizes. In case (d), Figure 5, two apples are ripe, with red



Figure 2. Sample question 9: Case (a) with a pack of 4 apples that are ripe, as shown by their red colour and are of the same size.



Figure 3. Case (b) Question 10 with a pack of 4 ripe apples with two apples are large and the other two small ones.



Figure 4. Case (c) Question 11 with a pack of 4 ripe apples, as shown by their red colour, but the sizes of the apples are varied.



Figure 5. Case (d) Question 12 asks about a pack of 4 apples, of which two are ripe with red colour, but the other two are less ripe, and all of them have the same size.

colour but the other two are less ripe, as shown by the yellow background colour, which means it might be nearly ripe, and all apples in the pack have the same size.

It is reasonable to assume the more varied apple combinations of different sizes and colours are harvested by hand. On the contrary, apples of a consistent colour (all red) and size (the Same) can be achieved as the result of a harvest completed by a robot with accurate vision and manipulation systems. Even though these capabilities are unavailable in the current harvesting methods, they could be developed and deployed in the system to be designed from this study.

Expanding on the analysis, Figure 6 shows another variation of two ripe and two less ripe apples with two large apples and two small apples. Figure 7 is intended to ask participants for a further variation of one ripe and large apple, combined with two less ripe ones of one large and one small, and a final ripe and small apple. Figure 8 (Question 15) displays one ripe apple and three others of indeterminate ripeness, and they all have the same or similar sizes. In case (h), two large and two small apples with less certainty on their ripeness are selected and displayed in Figure 9 for Question 16. Figure 10 is a picture of the last combination, which consists of only one ripe apple, and the other three are less ripe, and all are of varied sizes for Question 17. With these nine combinations, it is believed they are representative of all possible combinations from a statistical point of view.



Figure 6. Question 13 for case (e) asks the view of a pack of 4 apples, of which two are ripe with red colour; the other two apples are less ripe. Two are large, and two are small apples.



Figure 7. Question 14 for case (f) asks the view of a pack of 4 apples, of which two are ripe with red colour; the other two apples are less ripe. The size of the apples is mixed.



Figure 8. Question 15 for case (g) seeks a view of a pack of 4 apples: three or more are less ripe, and all are of the same or similar size.



Figure 9. (h) Question 16 seeks view of a pack of 4 apples: three or more are less ripe and two are large and the other two are small in size.



Figure 10. Question 17 for case (i) seeks a view of a pack of 4 apples: three or more are less ripe, and all apples are varied sizes.

Additionally, the Likert scale was used to determine how much they agreed with the following statements:

a) I prefer apples harvested by hand over robots.

b) Is the quality of apples harvested by robots significantly better than that of apples harvested by humans?

These data were both used for H2 and H4.

1) A set of questions was asked aimed at determining the participants' views of the quality of apples harvested by robots, the impact on jobs, food wastage, production efficiency, and the cost of robots.

2) To determine H3, items from the NARS were adopted for the robotic apple harvester (RAH). NARS was selected as it is a validated scale and has been used widely with a focus on general robots, and alternatives such as FSQ are more suitable for humanoid robots. As the purpose of this study is to only determine if consumers are willing to buy apples which are harvested by robots as opposed to if they are willing to work alongside robots, it was decided to remove the Interaction Scales and only use select items from the Social Influence of Robots scale. This targeted item reduction was also necessary to maintain high participant engagement. Content validity was maintained post-reduction by ensuring the remaining items continued to capture the essential factors associated with the social perception and technological trust relevant to agricultural automation.

3) Following the work of Schermerhorn *et al.* [15], 5 items from the Marlowe-Crowne Social Desirability Scale were used to determine social bias. The same items used by Schermerhorn *et al.* were also deployed within this study as they were proven to be sensitive to social bias in previous human-robot interaction studies. Thus, the validity of the content was maintained by retaining these validated items,

3.2. Statistical Analysis

After collecting data, the following tests in Table 2 were run in SPSS to test for each of the aforementioned hypotheses.

The above tests were run primarily based on previous literature and standard

Table 2. Statistical analysis summary.

H	IV(s)	DV	Test
H1A/B/C	Size and Colour (3 Levels each) (Nominal)	Number of packs (4/pack) of apples people are willing to purchase (Scale)	**A-:** a two-way repeated measures (RM) ANOVA **B-:** Post-hoc
H2	Education (Ordinal)	Harvesting method preference (HMP) (Ordinal)	Spearman correlation
H3	Gender (Nominal)	NARS (Scale)	**A-**Cronbach **B-**1Way ANOVA
H4	QAH (Ordinal)	HMP (Ordinal)	Spearman correlation

statistic flowcharts indicating which test to use when faced with different types of data.

H1: The Independent variables are ordinal, and the dependent variables are scale-based; therefore, based on the test selection, ANOVA may be suitable. Massaglia *et al.* [10]. used paired t-tests to test data of the same type. However, paired t-tests require repeated hypothesis testing, which will increase the probability of a type I error and generate a much larger significance level than the anticipated 5%. ANOVA can avoid this problem; therefore, it is the preferred choice of analysis. The data on how many packs of apples participants are willing to buy for different size and colour combinations are measured more than once for each subject. Hence, the standard two-way ANOVA is not suitable. Instead, the two-way RM ANOVA was used, which is dependent on the following assumptions:

1) No significant outliers—proven through box plots.

2) Data are normally distributed—proven through a QQ plot.

3) Assumption of sphericity—tested through Mauchly test of sphericity.

Therefore, after conducting ANOVA testing, it is important to test that these assumptions are met and confirm the results are accurate. Following Schermerhorn *et al.* [15], a post-hoc test was completed to ensure accuracy in testing the hypothesis. Instead of Fisher's LSD test, Pairwise comparison with Bonferroni correction [16] was implemented.

H2 and H4: Similar to Petrescu *et al.* [11], a Spearman correlation was implemented to investigate the strength of the correlation between education and the consumers' HMP and HMP and QAH.

H3: Cronbach's alpha was first implemented across the NARS scale to ensure internal consistency. One-way ANOVA was carried out between gender and NARS. As a sanity check for bias, the average MC score was calculated.

4. Results

4.1. Survey Result Summary

The Institute of Food Research determined that apples can be considered a staple fruit amongst the majority of the population, given their nutritional benefits. This

is emphasised by questionnaire data received from the Institute of Food Research, where young women in Norfolk aged 24 - 34 eat up to one per day [17]. Therefore, the data used for the questionnaire could be from a large majority of the public. A 'snowballing' sampling method is a non-probability sampling method and is also called chain-referral sampling, as the sample subjects are not randomly selected and are referred and chosen by the previous subjects. This method is widely used in social science studies where opinions are the focus of an investigation. In this method, initial research participants who completed a study then recruit future subjects to help increase the sample size. This method does help to increase the sample size and has the advantage of accessing subjects when the members of the whole sample population are difficult to identify or locate. However, it is acknowledged that this method is limited due to the possibility of bias appearing in the results obtained, due to the non-probability nature of the subject selection process, where subjects might refer other subjects who might share the same or similar views, opinions, and thoughts. As a result, the results will not always reflect the outcomes of the greater population. It is also difficult to calculate the sampling errors due to its non-probability sampling approach [18].

Whilst this limitation is acknowledged, the approach was deemed sufficient for this research because the initial distribution was strategically targeted towards a diverse group of "seed" participants. This included individuals from various demographic backgrounds such as students, retirees, and technology professionals from different geographic locations. As the survey progressed through these distinct social and professional networks, it naturally expanded beyond the researcher's immediate circle to capture a wide spectrum of societal viewpoints. This resulting diversity provided a sufficiently varied dataset for meaningful statistical analysis regarding the acceptance of robotic harvesting. Therefore, the "snowballing" sampling method was implemented whereby known contacts and their contacts completed the survey. The same questionnaire was issued on two different websites in order to increase the representation from different demographic regions of the world's apple consumers. One was launched using Google Docs, whereas the other was launched in China in Mandarin. A total of 240 responses were received, and 218 responses were used for analysis, which were filtered based on incomplete surveys, outliers or no apple purchase experience. A key summary of answers to questions 9 to 18, shown in **Figure 2** to **Figure 10**, is displayed in **Figure 11**. It is clear from **Figure 11** that case (1) packages of ripe and same-size apples are most popular. It is observed by reviewing the preference for colour selection indicated by the nine combinations of apples that 1022 apple packages, or 46.9%, were selected by participants to choose all red apples or ripe apples in their section. In terms of sizes, 976 apple packages or 44.9% are selected to be identical size of all four apples, whereas 1598 apple packages of 73.4% are preferred by participants that the package of apples should have two or more apples of the same size. Further testing of the four hypotheses using inferential statistical analyses is required.

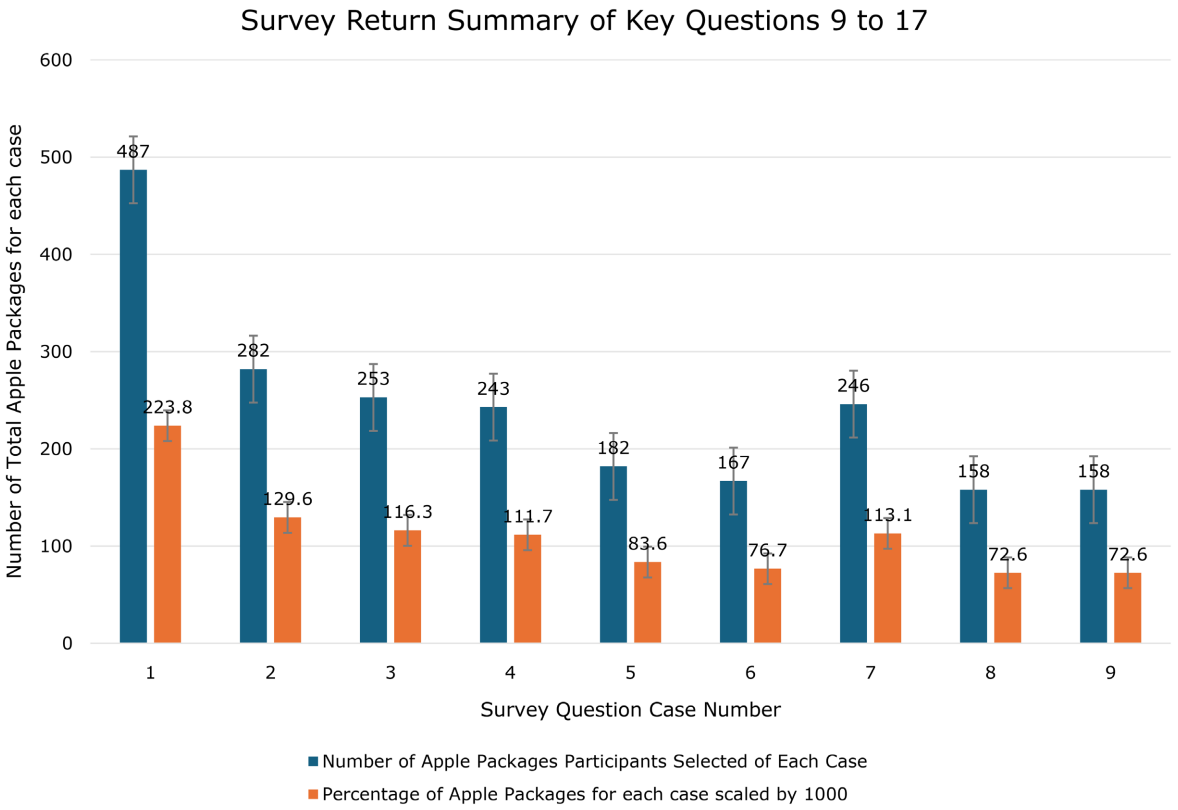


Figure 11. Survey summary of key apple selection preferences.

4.2. Analysis Results

The following section analyses the data collected from the surveys and applies the relevant tests mentioned in Section 3.2 for each hypothesis.

H1: The average MC score of participants was 3.3, which is neutral and shows that the majority of participants were likely to have provided honest, balanced responses rather than leaning toward social desirability. This distribution, combined with the scale's established sensitivity, confirms the reliability of the instrument for exploring participant sentiment in this study. Following this, a RM 2-way ANOVA was conducted to examine the effects of apple colour and size. Initial testing of the data showed that not all the data were normally distributed, with the highest skewness of >1. Hence, a square root transformation was used on the data. The box plot for the transformed data in **Figure 12** showed no outliers, meeting Assumption 1 of RM ANOVA.

There is some skewness, which is likely caused by the fact that only whole numbers (number of packs of apples) were provided by correspondents; however, the F-test in ANOVA is robust enough to withstand this. Normality was tested using QQ plots, and the data were normally distributed (points were close to the line) skewness value was <1.

Mauchly's test was used to assess the assumption of sphericity. The results in **Table 3** show that the assumption was violated, as $P < 0.05$. Therefore, corrections must be applied to the degrees of freedom to obtain a valid critical F-value. Fol-

lowing the standard criterion, the Huynh-Feldt correction was applied because the Greenhouse-Geisser correction resulted in $\varepsilon > 0.75$ [19].

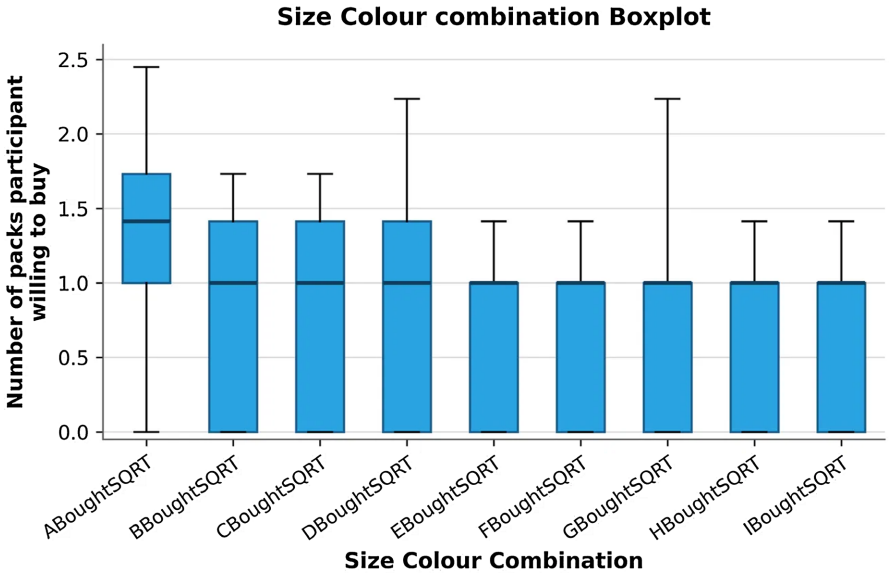


Figure 12. Box plot of the size and the colour combination.

Table 3. Mauchly test.

Within-Subjects Effect	Mauchly's W	Approx Chi-Square	df	Sig.	Greenhouse-Geisser	Epsilon[b] Huynh-Feldt	Lower-Bound
ColourFac	0.736	66.334	2	0.000	0.791	0.796	0.500
SizeFac	0.919	18.360	2	0.000	0.925	0.932	0.500
ColourFac * SizeFac	0.824	41.598	9	0.000	0.924	0.942	0.250

After proving the assumptions of ANOVA had been met, the most important Tests of within-subjects effects were analysed. Each time the Huynh-Feldt results were reported, and for both cases of size and colour $P < 0.05$. Hence, both size and colour are significant, and the null hypothesis of H1 is rejected. Therefore, consumers care significantly about the size and colour of apples that are purchased. There is also significant interaction between colour and size ($P < 0.05$). To understand more about which size and colour combinations are significantly different from others, a Bonferroni post hoc test was run for size and colour in the table shown in Table 4.

This revealed significant differences for all pairs of colour levels except (2, 3), as $P = 0.205 > 0.05$. Hence, participants prefer all red apples over any mixed colours (2 or 3) but have no preference between colour levels 2 and 3. A similar result is shown for size below in Table 5.

There were no significant differences between size levels 2 and 3 as $P > 0.05$. However, participants showed a significant preference ($P < 0.05$) for equal-size apples over mixed sizes (2 or 3). Hence, the introduction of robotic apple harvesters, which can harvest more consistent colour and size apples, would be beneficial

Table 4. Bonferroni post hoc test of colour.

(I) ColourFac	(J) ColourFac	Mean Difference (I – J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
1	2	0.361*	0.030	0.000	0.288	0.434
	3	0.398*	0.033	0.000	0.318	0.479
2	1	−0.361*	0.030	0.000	−0.434	−0.288
	3	0.037	0.020	0.205	−0.012	0.086

Table 5. Bonferroni post hoc test of size.

(I) SizeFac	(J) SizeFac	Mean Difference (I – J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	0.288*	0.022	0.000	0.234	0.341
	3	0.315*	0.024	0.000	0.257	0.373
2	1	−0.288*	0.022	0.000	−0.341	−0.234
	3	0.027	0.019	0.448	−0.018	0.072

and is desired by consumers. Following this, 43.12% of the participants stated they had no preference for the harvesting method, and 18.8% preferred harvesting by robots more.

H2: Spearman correlation was implemented, and the assumptions of Spearman correlation were met (monotonic assumption shown by scatter plot). There was a weak positive correlation between Education and Harvesting preference, which was statistically significant at $P < 0.05$, but had a Spearman correlation coefficient (Sr) = 0.295. Hence, higher education is weakly associated with a higher preference for harvesting by robots.

H3: The reliability of the adapted NARS was assessed using Cronbach's alpha, and an α value of 0.622 was obtained, which is deemed "acceptable" for exploratory research according to the criteria set by George and Mallery [20]. The α is lower than the ideal high reliability value of 0.7, possibly because there are only 3 items on the scale. Despite this, the scale demonstrated sufficient consistency for the study's objectives. Relevant ANOVA assumptions were met $P = 0.061$ hence, there is no evidence to reject the null hypothesis. In turn, there is no evidence that gender influences the attitudes of participants towards robotic apple harvesters. Descriptive statistics revealed that men have a more positive attitude towards robotic apple harvesters (Mean NARS = 9.4) compared to women (Mean NARS = 10.1). However, ANOVA revealed this difference in means was insignificant. The average NARS of 9.75/15 indicates a slightly negative attitude towards RAH on

any social level.

H4: Spearman correlation was implemented, and again the assumptions were met. There was a significant ($P < 0.05$) and fairly weak positive correlation ($Sr = 0.313$) between the perception of participants on the quality of apples harvested by robots and the harvesting preference. Hence, participants who believed robots harvest better quality fruit also tended to prefer apples harvested by robots.

4.3. Design Specification Recommendations

An important expected outcome of the study is to help future designers identify critical needs from consumers' perspective for a future robotic harvesting system design. This is undertaken by reviewing the findings from the survey, further analyses of the choices made by potential consumers, and understanding the key implications of the hypothesis tested on colour, sizes of apples and their interactions. Firstly, in general, the majority of the subjects did not care for how the apples are harvested but cared more for the quality of apples that they were buying. This is shown by both the statistical tests carried out and the summary from **Figure 11**. This convincingly indicates that the capability of sorting apples according to their ripeness, as indicated by the apples' colour, is of significant importance in apple harvesting and sorting. Using these and other observations, the following key design specification statements are formulated:

- The robotic system must have a colour detection capability which can distinguish mostly ripe red apples, maybe ripe yellow and unripe bright green or lighter green colour or any other possible colours;
- Ideally, this colour detection capability needs to be developed such that a numerical value is assigned for the broad red or ripeness colour spectrum so that a smart apple ripeness detection decision could be made;
- The robotic system must also have an apple size measurement capability from a two-dimensional visual image;
- The size of apples is important for consumers, and this measurement should be quantified to support real-time on-site decision-making in terms of sorting apples into more acceptable packages;
- The capability of measuring the colour in three dimensions has not been asked, but it is reasonable to infer from the survey that this would be a desirable feature.
- Three-dimensional assessment of the apple size should also be a desirable feature to provide 3D assessment.

It is also worth noting that the variety of apples also plays a role in their colour changing from unripe to ripe during their growth. For example, Golden Delicious apples change their colour from green to yellow instead of red when they are ready for picking. These differences require further investigation.

5. Conclusions

In conclusion, the size and colour do influence the consumers' buying preference significantly. In particular, there are significant differences between all-red, uni-

form-size apple combinations, and those that are mixed in colour and size. This means that given a robot harvester, which can detect apples' size and colour features precisely, consumers would prefer to buy apples harvested by a RAH.

The average NARS score of all participants was 9.75/15, meaning a slightly negative attitude towards robotic apple harvesters on the social influence scale. There was no significant relationship between gender and negative attitudes towards robotic apple harvesters, despite females showing a slightly higher mean NARS score. There was a weak positive correlation between gender and harvesting preference (Sr = 0.295), and between the quality of apples harvested by robots and harvesting preference (Sr = 0.313), with the latter holding a stronger correlation.

Overall, the attitude towards robotic apple harvesters is positive and 61.92% (43.12% + 18.8%) of participants either favoured or welcomed RAH. Hence, it can be concluded that robotic apple harvesters would be welcomed by society primarily based on their ability to provide good quality apples. These results have also allowed a specification to be recommended. There is still a need to educate and reassure the public regarding the introduction and use of robots. This is to enable more social acceptance of robots and to create a utopian rather than dystopian outlook on robotic apple harvesters.

Future work is required to collect a follow-up questionnaire in which qualitative methods are used for a better understanding of the concerns of buying robot-harvested apples. The study concludes and confirms a feasible research proposal on developing a robotic apple harvester. This will lead to further investigation of a technical robotic solution planned and detailed in the methodology proposed for the research shown in Figure 1.

Ethics

The questionnaire has been designed to comply with the legal requirements of the General Data Protection Regulation (GDPR) and the Data Protection Act 2018 by informing the participants of their rights under GDPR and following the relevant protocols of the University of Lincoln.

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Data Availability

Data available upon request.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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