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Review

Olfactory and Gustatory Perception among Plant-Based vs. Omnivorous Dieters: A Systematic Review and Meta-Analysis

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Abstract: Driven by heightened awareness of environmental sustainability, personal health, and animal welfare, there has been a rapid surge in adoption of plant-based diets (PBDs) by global consumers. Despite the important implications of potential links between PBDs and chemosensory (e.g., olfactory and gustatory) perception, the empirical evidence has yet to be comprehensively reviewed. This systematic review aims to synthesise existing data comparing olfactory and gustatory perceptions among individuals following plant-based (including vegan, vegetarian, and flexitarian) and omnivorous diets. Seven databases produced 1038 publications for screening against the pre-registered criteria. Eleven studies were included in this review, with three focusing on olfaction and eight on gustation. Of these, three gustatory studies provided sufficient data for meta-analysis, revealing little difference between plant-based and omnivore dieters on an overall level. The PBD group exhibited a significantly lower threshold (i.e., higher sensitivity) to sweetness compared to the omnivore group (ES = −0.336, 95% CI between −0.630 and −0.042, $p < 0.05$). Additionally, olfactory studies indicated that PBD followers perceived meat-related odours to be less pleasant compared to omnivores. Overall, this review points to a sensory–diet relationship, highlighting the potential role of sensory perception in sustainable plant-based dietary behaviours. The findings also encourage food manufacturers to consider potential chemosensory alterations among plant-based consumers.

Keywords: plant-based diet; vegan; vegetarian; omnivorous diet; chemosensory perception; gustation; olfaction

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1. Introduction

Animal agriculture has a significant impact on environmental sustainability, personal health, and animal welfare [1]. Reducing the consumption of animal-derived products aligns with the urgent need for global sustainability. Broadly, a plant-based diet (PBD) is defined as a dietary regimen that partially or completely excludes the consumption of animal-derived foods, and/or avoids the use of animal products in food manufacturing [2,3]. In research, PBD is often used as an umbrella term for various dietary patterns, typically categorised by the extent of meat restriction, including vegan, vegetarian, semi-vegetarian, and flexitarian diets [4,5]. The present study similarly uses PBD in accordance with this general definition.

Individual food choices are shaped by numerous factors, including cultural values, religious and moral beliefs, attitudes, and social influences [6]. Similarly, adoption of PBD is motivated by various factors. Protecting animal welfare is considered a primary factor [7,8]. Another key motivator is environmental sustainability, given that greenhouse gas emissions from meat production accelerate global warming and climate change [9]. Evidence from New Zealand suggests that greenhouse gas emissions from a vegan diet are 65.98% lower

than a typical diet [10]. Similarly important, concern for personal health represents another key motivator for adhering to a PBD. Well-planned PBDs have been shown to enhance nutritional status [11,12], offering benefits in weight management, reduced risk of diabetes, and improved inflammation control [13–15]. Driven by these various motivators, the number of PBD followers has surged in recent decades [16].

While interest in PBD continues to grow on an overall level, not everyone can sustain the dietary transition from omnivore to a PBD. In the United States, studies have shown that 34% of individuals who tried PBDs gave up within three months, and more than 80% eventually returned to an omnivore diet [17,18]. Research revealed a number of challenges to adhering to PBDs, including strong preferences for meat, lack of variety and availability of plant-based product options, and inadequate information about alternative food choices [19,20]. Of these challenges, sensory satisfaction represents a major factor in successful adherence to PBDs [21,22]. Understandably, it is challenging for individuals who have negative sensory experiences with plant-based products to maintain such a diet. Indeed, one recent dietary intervention of 78 healthy omnivore young adults (45% men) found that households randomised to eat plant-based meat alternatives reported less satisfaction with their meals at the end of the 10-week intervention and showed lower adherence to their dietary intervention compared to those randomised to eat lean red meat protein on top of a basal vegetarian diet [23]. This finding reiterates the significant influence of sensory perception on the consumption experience, including appetite, food selection and satiation [24–26]. Food taste is considered to have the most direct impact on food choices [27].

Association between individual chemosensory perception and acceptance of vegetables has been a subject of exploration for a long time. For instance, individuals who are more sensitive to sweetness tend to prefer vegetables associated with sour or bitter taste [28]. Umami sensitivity was shown to be positively linked with the consumption of non-cruciferous vegetables [29,30]. Additionally, sensitivity to astringency has been shown to be negatively associated with preferences for polyphenol-rich foods such as fruits and vegetables [31]. Furthermore, in a study by Louro and Simões [30], a lower bitter sensitivity was associated with a higher preference for vegetables.

Similarly, individual olfactory sensitivities also appear to play a role in vegetable preference and consumption. Lim and Padmanabhan [32] found sensitivity to certain volatiles in vegetables, such as sulfurous volatiles, can influence one's preference for vegetables. A recent study by Duffy and Hayes [33] demonstrated that heightened retronasal olfactory sensitivity can be linked to decreased vegetable intake. While these findings consistently point to an important role of taste and smell perception in vegetable preference and intake, it remains uncertain whether sensory functions are directly linked with a specific dietary pattern, such as a vegetarian or vegan diet.

In recent years, there has been an increasing research interest in comparing sensory responses between individuals following PBDs and omnivorous diets. However, a comprehensive systematic review of this topic has not yet been attempted. The aim of this systematic review is to synthesise existing data on olfactory and gustatory perception among individuals following PBDs and omnivorous diets. These findings will enhance the current understanding of sensory links to plant-based dietary regimens, thus providing new insights into supporting sustained PBDs.

2. Methodology

This systematic review and meta-analysis were conducted following the Joanna Briggs Institute (JBI) methodological guidelines [34] and reported using the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) [35]. The protocol was registered with PROSPERO (CRD42023468633).

2.1. Literature-Search Strategy

An initial search strategy was developed using keywords related to PBD and sensory perception published in known, relevant articles, and expanded with the help of an information specialist. This strategy was expanded to utilise subject headings. Informal validation was performed to ensure two known, relevant articles were identified by the search strategy. A complete list of searches performed is available in Appendix A.

Database searches were conducted on the following databases between the 5th and 6th of December 2023: MEDLINE, Embase, PsycInfo, Web of Science all databases, Scopus, ProQuest, and CABI. Following screening, reference lists of eligible reports were manually searched to identify any relevant studies, and corresponding authors were contacted to enquire if they had any relevant, pre-published manuscripts. No filters were applied during database searching to ensure a complete set of results was obtained.

2.2. Eligibility Criteria

Studies were eligible for inclusion if they met the following criteria:

- Quantitative studies using validated or recognised protocols for sensory testing;
- Participants aged 14 or over following a clearly defined PBD;
- Control group or condition following an omnivorous diet;
- English language publications in peer-reviewed journals or theses at Masters or above published or completed within the last 30 years.

In this review, a PBD was characterised as a spectrum of dietary preferences [36], whereby an individual's energy intake from animal sources is minimal and offset by an increased intake of plant-based foods [2,37]. PBD encompasses various dietary patterns, including vegan, vegetarian, and in some cases semi-vegetarian, flexitarian, and Mediterranean diets [2,37], as detailed in Table 1.

Table 1. Definitions of plant-based and omnivorous diets.

Dietary Pattern	Definition
Omnivore	No restrictions on animal products.
Plant-based [2,37]	Predominantly foods of plant origin, minimal intake of foods of animal origin.
Flexitarian, semi-vegetarian	Reduced or selective meat consumption, includes fish, eggs, dairy.
Pesco-vegetarian	Excludes meat except fish and seafood, includes eggs, dairy.
Vegetarian	Excludes meat and fish, may include eggs or dairy.
Ovo-lacto-vegetarian	Excludes meat and fish, includes eggs and dairy.
Vegan/Strict vegan	Excludes all foods of animal origin, including honey.
Mediterranean [38]	Reduced poultry, fish, and eggs with minimal red meat consumption.

Relevant sensory outcome measures of eligible studies included the following measures of olfaction, gustation, and texture: detection or recognition threshold, discrimination, identification, or hedonic. Studies investigating other sensory modalities (such as hearing, e.g., [39]) and studies focused on vegetable or product acceptance were excluded. The population was restricted to individuals above 14 years of age, to enable representation of habitual dietary patterns [40] and sensory development [41], and studies involving participants with disorders that may impact sensory function were excluded.

Database search results were saved, and uploaded to Rayyan (Qatar Computing Research Institute, Doha, Qatar) where duplicates were removed using Rayyan's automated tools, which allows for reviewing of each suspected duplicate record. Following duplicate removal, independent blind screening of title and abstracts was performed by three authors (YM (100%), SM (100%), JM (34%)). Once all records had been screened, the authors

discussed and resolved any conflicts, and YM and SM independently screened full texts of selected studies to assess eligibility.

2.3. Data Extraction

Study information was extracted from all eligible studies into a bespoke spreadsheet by the first author and reviewed by the second author. Any discrepancies were discussed and resolved between reviewers. Corresponding authors of selected eligible studies were contacted when results were found missing or to be unclear based on available information provided.

Extracted information included the following: study characteristics and demographic data (including age, sex/gender, ethnicity, sample size (n), and outcome data for both the plant-based and omnivorous groups). In addition, the type and criterion used to define PBDs were extracted. Data items directly relevant to the current study outcomes were extracted, including sensory modality (olfaction, gustation, texture perception), measure used (sensory threshold, discrimination, identification, or hedonic liking), and some elements of study methodology, including stimuli and administration. For studies where information was not presented in tables or text, data were extracted from graphs using WebPlotDigitizer (v5.0) [42].

2.4. Study Risk of Bias Assessment

The Mixed Methods Appraisal Tool (MMAT) [43] was used to determine the risk of bias in the included studies, and to assess both quality and risk of bias within five domains: participants, measurements, outcome data, confounding factors, and administration of the exposure. The first and second authors completed the MMAT independently and met to discuss and resolve any discrepancies.

2.5. Synthesis Method

A systematic narrative synthesis was performed by summarising and comparing the characteristics and findings of the included studies. Where the same measures were reported in a sufficient number of studies (i.e., $n \geq 3$ studies), standardised mean differences (SMD, Cohen's d) were calculated as the effect size, with Hedges' small sample size correction applied. For studies providing Standard Error (SE), the Standard Deviation (SD) was recalculated using the formula: SD = SE $\times$ sqrt(n). When studies only presented minimum, median, and maximum values in boxplots, mean and SD were estimated using the methods described by Luo and Wan [44] and Wan and Wang [45]. For studies analysing more than one plant-based dietary pattern (e.g., vegan and vegetarian), the mean and SD for both groups were combined using the Cochran formula [46]. All effect size estimates and variances were computed in R Statistical Software (v4.2.3; R Core Team 2023).

Meta-analyses were conducted using SPSS (Version 29, IBM, Armonk, NY, USA). A random-effects model was employed as the statistic model owing to heterogeneity among studies. Forest plots were utilised to summarise the results of individual studies, presenting the overall effect size (ES) with a 95% confidence interval (CI). Publication bias was assessed through funnel plots and Egger's regression asymmetry test. I-squared (I^2) was employed to quantify the level of heterogeneity among effect sizes across each study.

3. Results

A total of 1038 records were obtained after comprehensively searching in seven databases. After removing the duplicates, 555 studies were screened against the criteria and 543 studies were excluded. Primary reasons for exclusion included: animal studies, commercial research, outdated publications, and irrelevant findings. One pre-published study was obtained after contacting the first and corresponding authors of the twelve included studies. After full-text screening, eleven studies were included in the systematic review. However, due to insufficient data or differences in method and measure, only three studies were able to contribute to the meta-analysis. See Figure 1.

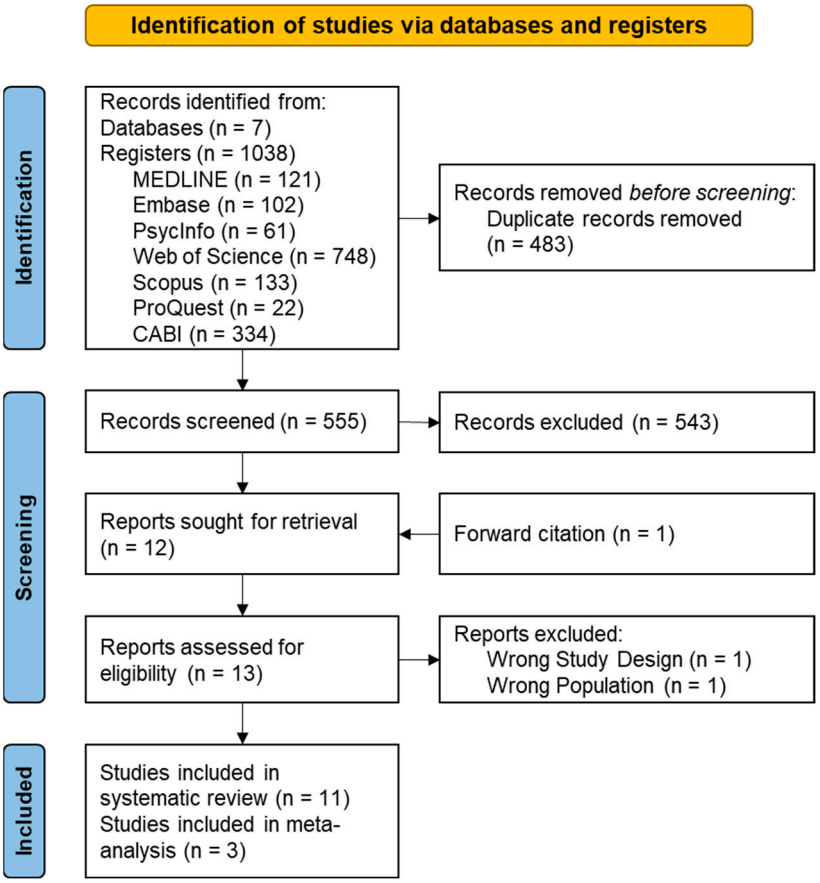

Figure 1. PRISMA flow diagram of the selection process.

The systematic review identified a total of 11 studies, with eight focusing on gustation and three on olfaction. The characteristics of the studies are summarised in Table 2. There were seven studies on vegetarian diets, three on vegan diets, three on flexitarian diets, and three on Mediterranean diets. Across these studies, five examined more than one plant-based dietary pattern, with three comparing vegetarian and flexitarian diets to omnivores [47–49], and two comparing vegan and vegetarian diets to omnivores [50,51]. Most of the studies were based on a cross-sectional design, with one study using a comparative design [48], and another using a pre-post design [52]. Female participants comprised the majority of participants in all studies, with three studies exclusively testing female participants. All included studies were published within the past ten years. Six of the studies were from Europe (i.e., Italy, Croatia, France, and Switzerland), two studies were from the Middle East (Turkey and Israel), and one each from the United States, New Zealand, and Sri Lanka.

This review included studies that tested gustatory or olfactory perception, including thresholds, intensity, and hedonic perception to supra-threshold stimuli. Gustatory studies encompassed assessments of five basic tastes (sweet, salty, sour, umami, bitter) and metallic. One tactile taste was also included, specifically, astringency. Olfactory studies assessed a range of odours related to either meat or vegetables and employed different psychophysical methods for assessing sensory functions. None of the included studies evaluated texture perception.

Table 2. Summary of studies included in systematic review.

Author, Year	Study Design	Country	Sample Size (Group)	Female %, (Group)	Mean Age, SD (Group)	PBD Criterion	Sensory Outcome Measure	Stimuli, Administration	Sensory Methods
					Gustation				
Cattaneo, 2023 [52]	Pre-post	Italy	51	60.7	43.7 ± 12.5	Exposure to Med diet	Recognition threshold	- Salty (NaCl) - Sweet (sucrose) Aqueous solution on filter paper strips	Ascending forced choice triangle test
Choi, 2015 [53]	Cross-sectional	USA	94, 42 (V) 52 (O)	100	23.1 ± 0.4	Pre-defined (based on dietary intake)	Intensity	- Bitter (PROP) PROP taster strip	General labelled magnitude scale
Cliceri, 2018 [49]	Cross-sectional	Italy	125, 31 (V) 55 (FL) 39 (O)	77.4 (V) 76.4 (FL) 64.1 (O)	28.6	Pre-defined	Intensity	- Bitter (PROP) 3.2 mM PROP solution	General labelled magnitude scale
Dastan, 2015 [54]	Cross-sectional	Turkey	2500 942 (low) 684 (normal) 874 (plenty)	60.4	15.0–65.0	Vegetarian nourishment	Perception	- Bitter (PTC) 10 mg/L PTC solution on filter paper	Unclear
Jalil Mozhdehi, 2021 [50]	Cross-sectional	New Zealand	80, 22 (VG) 23 (V) 35 (O)	100	23.0 ± 6.0 (VG) 22.6 ± 6.0 (V) 24.0 ± 7.0 (O)	Self-report	Detection threshold	- Sweet (sucrose) - Salty (NaCl) - Sour (citric acid) - Umami (MSG) - Bitter (caffeine) - Metallic (iron II sulphate heptahydrate) Aqueous solution	Ascending method of limits, 2 Alternative forced choice presentation
Leshem, 2022 [51]	Cross-sectional	Israel	123, 30 (VG) 37 (V) 56 (O)	66.7 [a]	22 ± 0.8 (VG) 24.6 ± 1.7 (V) 23.4 ± 0.3 (O)	Self-report	Intensity, Liking	- Sweet (sucrose) - Salty (NaCl) Aqueous solution sprayed onto tongue	Visual analogue scale

Table 2. *Cont.*

Author, Year	Study Design	Country	Sample Size (Group)	Female %, (Group)	Mean Age, SD (Group)	PBD Criterion	Sensory Outcome Measure	Stimuli, Administration	Sensory Methods
Gustation									
Nuvoli, 2023 [55]	Cross-sectional	Switzerland	54, 24 (VG) 30 (O)	70.8 (VG) 70 (O)	30.0 ± 11.5 (VG) 35.0 ± 11.5 (O)	Pre-defined	Detection threshold	- Sour (citric acid) - Bitter (quinine) - Umami (MSG) - Astringent (tannic acid) Aqueous solution	Ascending method of limits, 3 Alternative forced choice presentation
Veček, 2020 [56]	Cross-sectional	Croatia	2798	62.8	>18.0	Med Diet Serving Score (MDSS)	Recognition threshold, Intensity, Liking	- Salty (NaCl) Aqueous solution	Labelled magnitude scale; Labelled affective magnitude scale
Olfaction									
Abeywickrema, 2024 [47]	Cross-sectional	Sri Lanka	143, 55 (V) 26 (FL) 62 (O)	41.0 (V), 13.0 (FL), 46.0 (O)	25.0 ± 4.0 (V), 22.0 ± 3.0 (FL), 27 ± 5 (O)	Pre-defined	Suprathreshold sensitivity, Liking	- Mushroom (1-octene-3-ol) - Cooked green leaves (2-Isopropul-3-methoxypyrazine) - Soya (4-methylguaiacol) - Chicken (2,3,4-Trimethylthiazole) - Steak (12-methyltridecanal) - Cooked-fish (2-Methyl-3-furanthiol)	Method of constant stimuli, 2 Alternative forced choice presentation Visual analogue scale

Table 2. *Cont.*

Author, Year	Study Design	Country	Sample Size (Group)	Female %, (Group)	Mean Age, SD (Group)	PBD Criterion	Sensory Outcome Measure	Stimuli, Administration	Sensory Methods
					Olfaction				
Bontempi, 2023 [48]	Comparative	France	60, 20 (V) 20 (FL) 20 (O)	100	22.8 (V) 20.55 (FL) 20.15 (O)	Pre-defined	Intensity, Hedonic, Edibility	- Meat (bacon, veal, beef 'pot au feu') - Vegetable (celery, fennel, asparagus) Other food (Roquefort cheese, coffee, chocolate) - non-food (smoke, gasoline, glue) Aqueous solution	Visual analogue scale
Velluzzi, 2023 [57]	Cross-sectional	Italy	68	75	54.87 ± 1.76	Med Diet Score (MDS)	Threshold, Discrimination, Identification	n-butanol, 'Sniffin' Sticks'	'Sniffin' Sticks' protocol

Note. PROP, 6-n-propyl-2-thiouracil; PTC, Phenylthiourea; V, Vegetarian; VG, Vegan; FL, Flexitarian; O, Omnivore; Med, Mediterranean diet; PBD, Plant-based diet. [a] Data missing.

3.1. Gustatory Perception

Three of the reviewed studies had measured the intensity and sensitivity to bitterness using either 6-n-propylthiouracil (PROP) or Phenylthiocarbamide (PTC). Choi [53] noted significantly higher sensitivity to PROP in vegetarians compared to omnivores, and with fewer non-tasters found in vegetarians. In contrast, Cliceri and Spinelli [49] found that vegetarians and flexitarians perceived PROP to be less intense when compared with omnivores, with a higher proportion of non-tasters amongst vegetarians and flexitarians. Furthermore, a study by Dastan and Degerli [54] found that individuals who reported higher 'vegetarian nourishment' were more sensitive to PTC than omnivores or those who reported low 'vegetarian nourishment'. Another recent study by Leshem and Shaul [51] assessed the intensity and hedonic perception among vegans, vegetarians, and omnivores, for saltiness and sweetness. Their results revealed that vegans and vegetarians perceived higher intensity for sodium chloride (NaCl) and sucrose, as well as higher hedonic liking for sucrose, compared to omnivores.

To date, four studies have endeavoured to compare taste thresholds between plant-based and omnivorous dieters [50,52,55,56], although different taste qualities were assessed. Three studies tested saltiness [50,52,56]; two studies tested bitterness, using caffeine [50], or quinine [55]; two studies assessed sweetness [50,52]; and two assessed sourness and umami [50,55]. Metallic [50] and astringency [55] were only evaluated in one study each. Furthermore, the studies differed in their choices of psychophysical measures, with two of the studies measuring detection thresholds [50,55], and the other two measuring recognition thresholds [52,56].

Of these studies, two found that participants following PBD had higher thresholds (i.e., lower sensitivity) than omnivores, with respect to salt and metallic compounds in Jalil Mozhdehi and Abeywickrema [50], and bitter, umami, and astringency in Nuvoli and Fillion [55]. In direct contrast, Cattaneo and Mambrini [52] found that following a plant-dominating diet was associated with a significant decrease in thresholds to saltiness. Adding to these paradoxical pieces of evidence, Veček and Mucalo [56] found no association between adherence to the Mediterranean diet and salt intensity and preference. Jalil Mozhdehi and Abeywickrema [50] also found a significantly lower threshold for detecting bitter and sweet compounds in vegetarians compared to omnivores.

A meta-analysis was conducted to evaluate the effect of PBDs on taste thresholds across three studies [50,52,55], involving 120 plant-based dieters and 116 omnivorous controls (see Figure 2). The results revealed no significant difference in the overall effect size between the plant-based and omnivorous groups. None of the individual taste qualities was significant, except for sweet, where a significant negative difference was observed (ES = −0.336, 95% CI between −0.630 and −0.042, $p < 0.05$), suggesting that plant-based dieters were more sensitive to sweetness. High heterogeneity between studies was indicated by an I-squared statistic of greater than 90%. The funnel plot showed asymmetry, with a non-significant Egger's co-efficient ($p > 0.05$), suggesting a high risk of publication bias.

3.2. Olfactory Perception

Three studies compared olfactory perception between plant-based and omnivorous dieters [47,48,57]. Due to heterogeneity across studies, a meta-analysis for olfactory perception was unable to be performed. Bontempi, Jacquot [48] and Abeywickrema, Gunathunga [47] investigated smell sensitivity and hedonic responses among vegetarians, flexitarians, and omnivores to meat-related odours (such as bacon, veal, beef 'pot au feu', chicken, steak, and cooked fish) and vegetable-related odours (such as celery, fennel, asparagus, mushroom, cooked green leaves, and soya). Both studies found that vegetarians and flexitarians rated meat odours as less pleasant compared to omnivores, with vegetarians showing greater sensitivity to meat odours.

Velluzzi and Deledda [57] utilised 'Sniffin' Stick to evaluate olfactory threshold, discrimination, and identification, correlating them with participants' Mediterranean Diet Scores (MDSs). The findings revealed a positive correlation between MDS and the sum

of scores for threshold, discrimination, and identification (TDI) ($p < 0.0001$), particularly among females, indicating a strong relationship between adherence to the Mediterranean diet and olfactory sensitivities.

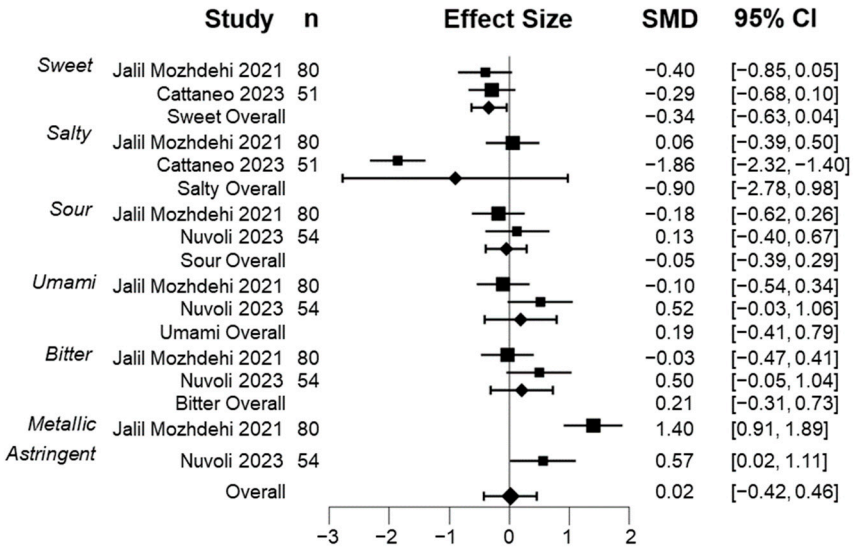

Figure 2. Forest plot of taste threshold measure between plant-based and omnivorous groups [50,52,55]. Each square shows the effect size of a study and its 95% CI. The size of the squares indicates the weight of each study. The diamond represents the overall effect size and 95% CI.

3.3. Study Quality

The evaluation of the methodological quality and data reliability of all included studies is summarised in Table 3. Overall, most studies showed moderate quality, meeting three to four out of five of the requirements of MMAT. Two studies met only two of the requirements. Among the included studies, the predominantly observational designs did not provide sufficient information to evaluate intended controlling of the exposure (habitual PBD), with the exception of the study on Mediterranean diet intervention by Cattaneo and Mambrini [52].

Table 3. Evaluation of study quality using Mixed Methods Appraisal Tool (MMAT).

Author, Year	1. Are the Participants Representative of the Target Population?	2. Are Measurements Appropriate Regarding Both the Outcome and Intervention (or Exposure)?	3. Are There Complete Outcome Data?	4. Are the Confounders Accounted for in the Design and Analysis?	5. During the Study Period, Is the Intervention Administered (or Exposure Occurred) as Intended?
Choi, 2015 [53]	Yes	Yes	Yes	Yes	Unclear
Dastan, 2015 [54]	Yes	Unclear	Yes	Yes	Unclear
Cliceri, 2018 [49]	Unclear	Yes	Yes	Yes	Unclear
Vecek, 2020 [56]	Yes	Yes	Unclear	Yes	Unclear
Jalil Mozhdehi, 2021 [50]	Yes	Yes	Yes	Yes	Unclear
Leshem, 2022 [51]	Unclear	Yes	No	Yes	Unclear
Bontempi, 2023 [48]	Yes	Unclear	Yes	No	Unclear
Cattaneo, 2023 [52]	Yes	Yes	Yes	Yes	Yes
Nuvoli, 2023 [55]	Yes	Yes	No	Yes	Unclear
Velluzzi, 2023 [57]	Yes	Yes	Yes	Yes	Unclear
Abeywickrema, 2024 [47]	Yes	Yes	Yes	Yes	Unclear

4. Discussion

4.1. Gustatory Perception

Our finding that adherence to PBD may be associated with different sensory profiles is consistent with previous findings regarding dietary changes. Previous research has demonstrated that individuals with different eating patterns tend to exhibit distinct taste profiles [58]. For example, individuals with higher perceptions of all tastes except bitter are more likely to follow a relatively less healthy Western-style diet [58–60].

Vegetables contain various phytochemicals that provide health benefits but also impart a bitter taste [61], which has long been considered a deterrent for vegetable consumption [62,63]. Previous studies have suggested that individuals who are less sensitive to bitter taste tend to have a greater liking and familiarity with vegetables [64], which in turn facilitate adherence to a plant-rich diet [65]. However, this is not consistent with our findings of increased sensitivity or intensity perception of bitterness amongst those classified as plant-based dieters, although our meta-analysis failed to find any notable difference in bitter thresholds between these two dietary groups. These discrepant results may be attributable to inconsistencies in diet classification (i.e., restriction of meat consumption) and study designs. Additionally, genetically determined PROP sensitivity is also considered an important factor for influencing vegetable consumption [66–68]. Furthermore, it is also likely that plant-based dieters consider bitterness in vegetables as a desirable sensory characteristic, thereby having enhanced sensitivity to bitter compounds [69]. More research is warranted to gain a more comprehensive understanding of bitter taste among plant-based dieters.

The low sweetness and high bitterness are generally recognised as the main barriers to improve the acceptance of vegetables [61,70]. Sweetness, in particular, has a positive impact on taste preference [71]. Individual sensitivity to sweetness can be influenced by various factors, including genotype, dietary experience, and appetite [72,73]. In a study of children from Portugal, schoolgirls with higher sensitivity to sweetness showed stronger preferences for certain vegetables, such as Brussels sprouts, rapeseed leaves, and watercress [28]. Results from the present meta-analysis suggest that individuals following a PBD exhibit a lower sweet taste threshold compared to omnivores, although caution should be applied to interpreting these results due to the small number of studies included. Meanwhile, several attempts have been made to add sweeteners to mask and suppress the bitterness of vegetables in order to increase the acceptance of vegetables [74,75]; however, this raises nutritional concerns regarding energy and calorie intake [76]. Future efforts can explore the rejection threshold of sweetness among plant-based dieters, aiming to achieve sensory satisfaction without compromising health.

The studies included in this review also explored differences in salty, sour, umami, metallic, and astringent tastes between the two dietary groups. Due to the limited number of studies, it presents a challenge to draw reliable conclusions through meta-analysis. Differences in individual gustation have a great impact on their habitual food consumption and intake [77]. However, food perception is not solely driven by a single taste sensitivity, as sweetness and bitterness jointly influence the acceptance of vegetables. This is also evident in other food products, such as the sweetness and sourness in fruits, the combination of sourness, salty, and fatty tastes in dairy products, and salty and umami tastes in meat and fish [61]. Regarding the chemosensory perception of plant-based dieters discussed in this study, future research can focus more on the correlation (enhancement or suppression) between multiple taste sensitivities and PBD.

4.2. Olfactory Perception

Consistently, the olfactory studies synthesised in this review suggest that individuals following PBDs tended to find meat odours less pleasant than omnivores. This suggests that an aversion to meat odours may drive individuals towards a PBD, thereby facilitating long-term adherence to the diet. Notably, all of these studies were observational studies, it is thus not possible to determine a causative relationship between adherence to PBDs and

hedonic perception of meat odours. In addition, hedonic ratings of vegetable odours did not show any difference between the two dietary groups, suggesting that vegetable odours are unlikely to be a deterrent for adopting PBD. Future research can employ experimental designs to understand the causative relationship between PBD adoption and various odour perceptions.

4.3. Study Disparities

The studies in our analysis include mostly Western countries such as North American and Western European countries where those following PBDs represent a growing minority of consumers, with only four studies from Mediterranean and Asian countries where PBDs are more common. The sensory changes brought by adherence to PBDs from childhood, compared with adopting PBDs in adulthood are also worth exploring in future research. The cultural and religious influences on dietary patterns also require more attention, as PBDs or vegetarian diets have different meanings in different regions. For example, compared to Western diets (i.e., North America, Oceania), traditional Asian and Mediterranean diets predominantly consist of plant foods [78]. Individuals in these regions likely adopt PBDs from an early age, whereas those in Western countries mostly transition to a PBD in adulthood due to changes in personal dietary motivation [79]; therefore, the exposure duration and timing to PBDs differs considerably between Western and non-Western adherents to PBDs.

When reviewing dietary pattern definitions across the eleven included studies, discrepancies emerged among studies. The definition of vegan remained relatively consistent across studies and was characterised by the strict exclusion of animal-derived products. However, while most studies defined vegetarian as abstaining from red meat and poultry, some studies extended this restriction to include fish or other animal products. Conversely, the Mediterranean diet was usually defined by an a priori approach, with researchers employing validated diet scores such as the Mediterranean Dietary Serving Score (MDSS) in Veček and Mucalo [56] and the Mediterranean Diet Score (MDS) from Velluzzi and Deledda [57,80,81]. Additionally, most studies specified a minimum duration of the dietary patterns of at least twelve months, indicating medium- to long-term adherence among plant-based dieters. However, in the study by Cattaneo and Mambrini [52], the Mediterranean diet was implemented as a four-week weight-loss intervention. This study differed from the others included in the current analysis in that any sensory changes were attributed to a short-term dietary intervention, while observational studies may suggest inherent sensory characteristics of plant-based dieters.

4.4. Limitations

Through a comprehensive search, it was found that the number of empirical studies comparing sensory perception between individuals following PBDs and omnivorous diets was still limited. Although childhood is considered a fundamental stage for developing eating habits [82], this study did not include studies with child participants. Due to the limited number of studies on children's plant-based dietary patterns, and children's food choices being easily influenced by family environment habits, we chose to limit the analysis in our study to adults and adolescents 14 years and older.

A limitation of our analysis relates to the quality and methodological heterogeneity of the studies identified in our search. Notably, the included studies varied in their design, in particular, cross-sectional versus pre-post design. Similarly affecting the findings are variations in the stimuli compounds, administration methods, and measurement techniques. These methodological factors undoubtedly contribute to variation in the results. Despite our best efforts to contact authors, we were unable to access some relevant data, again impacting our ability to conduct a meta-analysis. The concept of PBDs has existed for a long time, and research on the topic has steadily emerged in recent decades. The articles that fit the research scope of this review were all published after 2015. We expect an increase

in evaluations of the link between PBDs and sensory perception in the future, leading to more robust findings.

4.5. Implications

This study provides valuable insights into the influence of sensory factors on food preference and nutrition intake. With the widely recognised health benefits of PBDs, understanding the sensory characteristics of plant-based dieters helps to identify intrinsic factors that guide healthy dietary choices. Moreover, establishing the sensory profile of plant-based dieters can motivate food manufacturers to create products that meet the sensory preferences of different consumer groups. A diverse range of products can attract more consumers to choose plant-based products, reducing the consumption of animal-derived foods and promoting environmental sustainability.

5. Conclusions

This systematic review synthesised existing evidence comparing chemosensory perception between plant-based dieters and omnivores. Findings suggested moderate differences in sensitivity and preference for specific gustatory stimuli across these dietary groups. Along similar lines, the meta-analysis indicated that PBD followers had a significantly lower threshold (i.e., high sensitivity) for sweetness than omnivores, while little difference was observed for other taste qualities or overall taste. Additionally, individuals following a PBD perceived meat-related odours as less pleasant compared to omnivores. However, given the limit number of studies and methodological heterogeneity affecting meta-analysis, further empirical research is warranted to confirm the chemosensory role in adherence to a sustained PBD.

This study revealed the potential association between PBD and individual chemosensory sensitivities, which highlights the importance of sensory perception in following a sustained PBD regimen. Future research should delve into the underlying mechanisms of how sensory perception influences eating behaviours, providing insights into sustaining the adoption of PBD through sensory cues.

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Appendix A

Table A1. Search strings in MEDLINE and date of searches.

OvidSP: Medline (R) (1946–Present)	**5 December 2023**
plant-based.mp. or exp Diet, Vegetarian/	10,780
exp Diet, Vegetarian/or exp Vegetarians/or vegetarian*.mp. or exp Diet, Vegan/	6285

Table A1. *Cont.*

OvidSP: Medline (R) (1946–Present)	**5 December 2023**
exp Diet, Vegan/or exp Vegans/or vegan*.mp. or exp Diet, Vegetarian/	4815
exp Diet, Mediterranean/or Mediterranean.mp.	46,499
DASH.mp.	6513
"blue zones".mp.	31
exp Diet, Mediterranean/or "New Nordic".mp.	5484
exp Diet, Vegetarian/or pescetarian.mp.	4174
exp Diet, Vegetarian/or pescatarian.mp.	4186
exp Diet, Vegetarian/or ovolacto*.mp.	4174
exp Diet, Vegetarian/or lactoovo*.mp.	4175
exp Diet, Vegetarian/or lactovegetarian*.mp.	4194
exp Diet, Vegetarian/or ovovegetarian*.mp.	4173
OLV.mp.	600
exp Diet, Mediterranean/or Diet/or exp Diet, Ketogenic/or diet.mp. or exp Diet, Vegan/or exp Diet, Vegetarian/	509,988
exp Diet/or "dietary pattern*".mp.	335,965
"dietary habit*".mp.	10,887
"dietary preference*".mp.	613
1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 10 or 11 or 12 or 13 or 14	65,652
15 or 16 or 17 or 18	571,406
19 and 20	17,393
((plant-based or vegetarian* or vegan* or Mediterranean or DASH or "New Nordic" or "blue zones" or pesc?tarian* or pollovegetarian* or ovolacto* or lactoovo* or lactovegetarian* or ovovegetarian* or OLV) adj3 (diet or "dietary pattern*" or "dietary habit*" or "dietary preference*")).mp. [mp = title, book title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms, population supplementary concept word, anatomy supplementary concept word]	13,819
exp Taste Threshold/or exp Taste/or exp Taste Perception/or taste.mp.	45,718
smell.mp. or exp Smell/	24,408
olfaction.mp. or exp Smell/	24,988
gustation.mp. or exp Taste/	26,802
exp Touch Perception/or "texture perception".mp.	5342
orosensory.mp.	397
"oro-sensory".mp.	53
"oral kin?esthetic".mp.	2
flavo*r.mp.	16,135
aroma.mp. or exp Odorants/	27,527
palatability.mp.	3520
exp Sensory Thresholds/or sensory.mp.	258,172
23 or 24 or 25 or 26 or 27 or 28 or 29 or 30 or 31 or 32 or 33 or 34	338,152
exp Food Preferences/or hedonic.mp. or exp Taste/	43,412

Table A1. *Cont.*

OvidSP: Medline (R) (1946–Present)	**5 December 2023**
threshold.mp.	245,057
detection.mp.	967,894
exp Discrimination, Psychological/or discrimination.mp.	159,635
identification.mp.	713,015
intensity.mp.	373,341
sensitiv*.mp.	1,772,830
36 or 37 or 38 or 39 or 40 or 41 or 42	3,632,055
21 and 35 and 43	121

Table A2. Search strings in EMBASE and date of searches.

OvidSP: Embase (All Years, 1947–Present)	**5 December 2023**
plant-based.mp. or exp vegetarian diet/	16,897
exp vegetarian diet/or vegetarian*.mp.	11,103
exp vegan diet/or vegan*.mp.	3477
Mediterranean.mp. or exp Mediterranean diet/	68,105
exp DASH diet/or DASH.mp.	11,353
exp Nordic diet/or "New Nordic".mp.	268
"blue zones".mp.	57
pescetarian*.mp. or exp vegetarian diet/	6668
exp vegan diet/or exp vegetarian diet/or pescatarian*.mp.	6691
exp vegetarian diet/or pollo vegetarian*.mp. or exp vegan diet/	6661
ovolacto*.mp.	39
exp lactoovovegetarian diet/or lactoovo*.mp. or exp lactoovovegetarian/	292
exp lactovegetarian diet/or exp lactovegetarian/or lactovegetarian*.mp.	317
exp vegan diet/or exp vegetarian diet/or exp ovovegetarian diet/or ovovegetarian*.mp. or exp lactoovovegetarian diet/	6679
OLV.mp.	1088
exp DASH diet/or exp vegan diet/or exp lactovegetarian diet/or exp diet/or exp vegetarian diet/or exp Mediterranean diet/or exp Nordic diet/or exp ovovegetarian diet/or exp fruitarian diet/or diet.mp. or exp lactoovovegetarian diet/or exp pescovegetarian diet/	929,144
"dietary pattern*".mp. or exp dietary pattern/	20,184
"dietary habit*".mp.	18,005
exp food preference/or "dietary preference*".mp.	16,655
1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 10 or 11 or 12 or 13 or 14 or 15	100,483
16 or 17 or 18 or 19	950,671
20 and 21	30,460
((plant-based or vegetarian* or vegan* or Mediterranean or DASH or "New Nordic" or "blue zones" or pesc?tarian* or pollovegetarian* or ovolacto* or lactoovo* or lactovegetarian* or ovovegetarian* or OLV) adj3 (diet or "dietary pattern*" or "dietary habit*" or "dietary preference*")).mp. [mp = title, abstract, heading word, drug trade name, original title, device manufacturer, drug manufacturer, device trade name, keyword heading word, floating subheading word, candidate term word]	24,722

Table A2. *Cont.*

OvidSP: Embase (All Years, 1947–Present)	**5 December 2023**
exp taste discrimination/or exp taste acuity/or exp taste/or exp taste preference/or taste.mp.	77,262
smell.mp. or exp odor/	46,599
olfaction.mp. or exp smelling/	22,385
gustation.mp. or exp taste/	30,540
"texture perception".mp.	329
orosensory.mp.	513
"oro-sensory".mp.	83
"oral kin?esthetic".mp.	5
exp flavor/or flavo*r.mp.	26,260
aroma.mp. or exp aroma/	12,898
exp palatability/or palatab*.mp.	12,318
sensory.mp. or exp quantitative sensory testing/or exp sensory stimulation/	450,569
24 or 25 or 26 or 27 or 28 or 29 or 30 or 31 or 32 or 33 or 34 or 35	581,461
hedonic.mp.	7476
exp perceptive threshold/or threshold.mp.	403,860
detection.mp.	1,611,847
exp olfactory discrimination/or discrimination.mp. or exp perceptive discrimination/or exp taste discrimination/or exp tactile discrimination/	240,990
identification.mp.	1,299,346
intensity.mp.	672,822
sensitiv*.mp.	2,678,603
37 or 38 or 39 or 40 or 41 or 42 or 43	5,860,311
22 and 36 and 44	102

Table A3. Search strings in PsycInfo and date of searches.

OvidSP: APA PsycInfo (1806–December 2023)	**5 December 2023**
exp Vegetarian Diet/or exp Vegan Diet/or plant-based.mp.	559
exp Vegetarian Diet/or vegetarian*.mp.	737
exp Vegetarian Diet/or exp Vegan Diet/or vegan*.mp.	416
Mediterranean.mp.	2155
DASH.mp.	591
"New Nordic".mp.	11
"blue zones".mp.	11
exp Vegetarian Diet/or exp Vegan Diet/or pescetarian*.mp.	212
exp Vegetarian Diet/or pescatarian*.mp.	160
lactoovo*.mp.	1
lactovegetarian*.mp.	2
exp Vegetarian Diet/or exp Vegan Diet/or ovo vegetarian*.mp.	222
OLV.mp.	2

Table A3. *Cont.*

OvidSP: APA PsycInfo (1806–December 2023)	**5 December 2023**
diet.mp. or exp Diets/	43,883
"dietary pattern*".mp.	1150
exp Eating Behavior/or "dietary habit*".mp.	28,500
exp Food Preferences/or "dietary preference*".mp.	6421
1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 10 or 11 or 12 or 13	3851
14 or 15 or 16 or 17	69,910
18 and 19	1622
((plant-based or vegetarian* or vegan* or Mediterranean or DASH or "New Nordic" or "blue zones" or pesc?tarian* or pollovegetarian* or ovolacto* or lactoovo* or lactovegetarian* or ovovegetarian* or OLV) adj3 (diet or "dietary pattern*" or "dietary habit*" or "dietary preference*")).mp. [mp = title, abstract, heading word, table of contents, key concepts, original title, tests & measures, mesh word]	1203
taste.mp. or exp Taste Stimulation/or exp Taste Perception/	19,822
exp Odor Discrimination/or exp Olfactory Perception/or exp Olfactory Stimulation/or smell.mp.	15,532
exp Odor Discrimination/or exp Olfactory Perception/or exp Olfactory Thresholds/or exp Olfactory Stimulation/or olfaction.mp.	13,177
exp Taste Stimulation/or exp Taste Perception/or gustation.mp.	8680
"texture perception".mp. or exp Texture Perception/	1640
orosensory.mp.	269
"oro-sensory".mp.	29
exp Kinesthetic Perception/or "oral kin?esthetic".mp.	7389
flavo*r.mp.	4042
exp Olfactory Perception/or exp Olfactory Stimulation/or aroma.mp. or exp Odor Discrimination/	11,735
palatability.mp.	1134
sensory.mp.	105,971
22 or 23 or 24 or 25 or 26 or 27 or 28 or 29 or 30 or 31 or 32 or 33	142,392
exp Hedonism/or exp Food Preferences/or exp Taste Perception/or hedonic.mp. or exp Olfactory Perception/	29,476
threshold.mp. or exp Olfactory Thresholds/	52,065
detection.mp.	77,410
exp Discrimination/or exp Odor Discrimination/or discrimination.mp. or exp Perceptual Discrimination/	135,625
identification.mp. or exp Identification/	141,988
exp Stimulus Intensity/or intensity.mp.	78,648
sensitiv*.mp.	208,459
35 or 36 or 37 or 38 or 39 or 40 or 41	631,880
20 and 34 and 42	61

Table A4. Search strings in Web of Science and date of searches.

Web of Science (All Databases)	**6 December 2023**
("plant-based" OR vegetarian* OR vegan* OR Mediterranean OR DASH OR "New Nordic" OR "blue zones" OR pesc?tarian* OR pollovegetarian* OR ovolacto* OR lactoovo* OR lactovegetarian* OR ovovegetarian* OR OLV) AND (diet OR "dietary pattern*" OR "dietary habit*" OR "dietary preference*") AND taste OR smell OR olfaction OR gustation OR "texture perception" OR orosensory OR "oro-sensory" OR "oral kin?esthetic" OR flavo*r OR aroma OR palatab* OR sensory AND hedonic OR threshold OR detection OR discrimination OR identification OR intensity OR sensitiv*	748

Table A5. Search strings in Scopus and date of searches.

Scopus	**6 December 2023**
("plant-based" OR vegetarian* OR vegan* OR mediterranean OR dash OR "New Nordic" OR "blue zones" OR pesc?tarian* OR pollovegetarian* OR ovolacto* OR lactoovo* OR lactovegetarian* OR ovovegetarian* OR olv) AND (diet OR "dietary pattern*" OR "dietary habit*" OR "dietary preference*") AND (taste OR smell OR olfaction OR gustation OR "texture perception" OR orosensory OR "oro-sensory" OR "oral kin?esthetic" OR flavo*r OR aroma OR palatab* OR sensory) AND (hedonic OR threshold OR detection OR discrimination OR identification OR intensity OR sensitiv*)	133

Table A6. Search strings in ProQuest and date of searches.

ProQuest	**6 December 2023**
("plant-based" OR vegetarian* OR vegan* OR Mediterranean OR DASH OR "New Nordic" OR "blue zones" OR pesc?tarian* OR pollovegetarian* OR ovolacto* OR lactoovo* OR lactovegetarian* OR ovovegetarian* OR OLV) adj3 (diet OR "dietary pattern*" OR "dietary habit*" OR "dietary preference*") AND (taste OR smell OR olfaction OR gustation OR "texture perception" OR orosensory OR "oro-sensory" OR "oral kin?esthetic" OR flavo*r OR aroma OR palatab* OR sensory) AND (hedonic OR threshold OR detection OR discrimination OR identification OR intensity OR sensitiv*)	22

Table A7. Search strings in MEDLINE and dates of searches.

CABI	**6 December 2023**
(("plant-based" OR vegetarian* OR vegan* OR Mediterranean OR DASH OR "New Nordic" OR "blue zones" OR pesc?tarian* OR pollovegetarian* OR ovolacto* OR lactoovo* OR lactovegetarian* OR ovovegetarian* OR OLV) AND (diet OR "dietary pattern*" OR "dietary habit*" OR "dietary preference*")) AND ((taste OR smell OR olfaction OR gustation OR "texture perception" OR orosensory OR "oro-sensory" OR "oral kin?esthetic" OR flavo*r OR aroma OR palatab* OR sensory)) AND ((hedonic OR threshold OR detection OR discrimination OR identification OR intensity OR sensitiv*))	334

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