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Raising Awareness of Consumers on Domestic Pesticide Reduction Methods



“Reducing pesticide use for environmental sustainability and raising awareness of farmers on alternative control methods; Safe Food for Consumers”

[SafeFoodTR]

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1. Introduction

The widespread use of pesticides in modern agriculture has contributed significantly to stable food production and the year-round availability of fruits and vegetables. At the same time, the presence of pesticide residues on food products has become a growing concern for consumers, particularly in relation to food safety, environmental sustainability and long-term health protection. While regulatory frameworks and maximum residue limits aim to ensure food safety at the production and market levels, consumers remain the final link in the food chain and play a crucial role in reducing potential exposure through everyday household practices.

In recent years, increasing media attention and public discussion around pesticide residues have led to heightened awareness among consumers. However, this awareness is often accompanied by uncertainty, misconceptions and unrealistic expectations regarding what can be achieved at the household level. Many consumers rely on traditional or improvised practices, such as prolonged washing, soaking in various solutions or the use of commercial produce washes without clear, evidence-based guidance on their actual effectiveness or possible limitations. As a result, household practices intended to reduce pesticide residues may sometimes be ineffective, unnecessarily complex, or even counterproductive.

This digital textbook has been developed within the framework of the SafeFoodTR project to address this gap by providing consumers with clear, practical and scientifically grounded guidance on domestic pesticide residue reduction methods. Rather than focusing on general information about pesticides or regulatory aspects, the content is specifically designed to support informed decision-making at the household level. Emphasis is placed on commonly consumed fruits and vegetables and on preparation methods that are realistically accessible in everyday domestic settings.

The structure of this textbook reflects the diversity of household processing practices and the factors that influence their effectiveness. Mechanical actions such as peeling, trimming and washing, the use of household solutions, and thermal processing methods are presented in a systematic and consumer-oriented manner. Importantly, the limitations of household interventions are also addressed in order to promote realistic expectations and responsible practices. By highlighting both the benefits and constraints of different methods, the textbook aims to empower consumers without creating unnecessary concern or false assurances.

In addition, the textbook adopts a sustainability-oriented perspective by considering the environmental implications of household practices, including the excessive use of chemicals, water and commercial washing agents. Safe food consumption is approached not only as a matter of residue reduction, but also as part of a broader culture of environmentally responsible and health-conscious food handling.

Overall, this digital textbook serves as a practical educational resource to raise consumer awareness, support safer household food practices and contribute to the development of a balanced, evidence-based understanding of pesticide residue reduction at home. It is intended for a wide audience, including adult learners, households and vocational education contexts, and forms an integral part of the SafeFoodTR project's commitment to promoting safe food for consumers through informed and sustainable choices.

2. Pesticide Residues from the Consumer Perspective

For most consumers, fruits and vegetables are an essential part of a healthy daily diet. They are often purchased fresh from markets, grocery stores or directly from local producers and are usually consumed raw or with minimal processing. However, consumers may not always be aware that small amounts of pesticide residues can remain on fruits and vegetables by the time they reach the household. These residues may originate from crop protection practices applied during cultivation or from post-harvest treatments used to maintain quality and prevent spoilage during storage and transportation [1, 2].

From a consumer perspective, pesticide residues are not an abstract or technical issue but a practical concern encountered in everyday life. Questions such as “Is washing enough?”, “Should I peel this product?” or “Are some fruits and vegetables more risky than others?” are commonly raised in households. Media reports and social discussions often increase awareness but may also lead to confusion, fear or misunderstandings about the actual level of risk and the effectiveness of simple household practices [3]. As a result, consumers may adopt habits that are based more on assumptions than on reliable information.

It is important to recognize that food safety controls and regulations are mainly applied before products reach the market, yet consumers represent the final stage in the food chain. What happens in the kitchen—washing, peeling, soaking or cooking—can influence the level of

pesticide residues that remain on food at the time of consumption. Although household processing cannot completely eliminate all residues, it can play a meaningful role in reducing exposure when applied correctly and realistically [2, 3].

2.1. Pesticide Residues in Fruits and Vegetables: What Consumers Encounter

From the consumer's point of view, pesticide residues are most commonly associated with fresh fruits and vegetables that are purchased for daily consumption. These products are often eaten raw or with minimal processing, which means that any residues present on their surface or within plant tissues may reach the consumer directly. Although food safety regulations aim to keep residue levels below established maximum limits, monitoring studies consistently show that trace amounts of pesticide residues can still be detected in a wide range of fruits and vegetables available on the market [1, 2].

Consumers usually encounter pesticide residues in an indirect way. Residues are invisible, cannot be smelled or tasted, and are only detected through laboratory analysis. As a result, consumer awareness is often shaped by external factors such as media reports, public discussions or personal experience rather than direct observation. Certain fruits and vegetables, particularly leafy vegetables, fresh herbs, and products with edible skins, are more frequently associated with residue concerns because of their large surface area or because they are consumed without peeling [3, 4].

It is important to understand that the presence of pesticide residues does not necessarily indicate unsafe food. Residues may remain even when pesticides are applied according to good agricultural practices. Factors such as the type of pesticide used, the time between application and harvest, weather conditions, and post-harvest handling can all influence the amount of residue that remains on the product when it reaches the consumer [1]. However, this complexity is not always communicated clearly to the public, leading to the common perception that all detected residues pose a significant health risk.

Another issue frequently encountered by consumers is the misunderstanding of differences between food categories. For example, leafy vegetables tend to retain residues more easily due to their structure, while fruits and non-leafy vegetables may accumulate residues on their skin or waxy surface layers. Root and tuber crops may be exposed to residues through soil contact. These

differences explain why a single household practice, such as simple washing, may work well for some products but be less effective for others [3, 5].

Consumer concerns are also influenced by assumptions about production systems. Many people believe that organic products are completely free of pesticide residues, or that washing alone can fully remove any residues present. Scientific evidence, however, shows that residues can occasionally be detected in organic produce and that washing typically leads to partial, rather than complete, removal of residues [3, 6]. Such misunderstandings highlight the need for clear and realistic information tailored to everyday household practices.

Overall, what consumers encounter is not only the physical presence of pesticide residues on fruits and vegetables, but also uncertainty about their significance and about the most effective ways to reduce exposure at home. Understanding which products are more likely to carry residues and why residues may persist despite basic cleaning practices is a crucial first step. This awareness provides the foundation for discussing the role of household processing and for identifying practical actions that consumers can take to reduce residue levels in a realistic and informed manner, which is further explored in the following sections.

2.2. Why Household Processing Matters

Household processing plays an important role in reducing consumer exposure to pesticide residues because it represents the final opportunity to influence food safety before consumption. While regulatory controls, monitoring programs and good agricultural practices are applied during production and distribution, consumers ultimately decide how fruits and vegetables are handled in the home. Simple actions taken in the kitchen—such as washing, peeling, soaking or cooking—can affect the amount of pesticide residues that remain on food at the time it is eaten [1, 3].

For many consumers, household processing is already a routine part of food preparation. Fruits and vegetables are commonly washed, trimmed or cooked for reasons related to cleanliness, taste and convenience. However, these practices are not always applied with pesticide residue reduction in mind. As a result, consumers may either overestimate the effectiveness of certain methods, such as prolonged washing, or underestimate the value of others, such as peeling or thermal processing. Understanding why household processing matters helps consumers use these practices more effectively and realistically [5].

Scientific studies show that household processing can reduce pesticide residues to varying degrees, depending on the type of food, the nature of the pesticide and the method applied. In many cases, residues are mainly located on the surface of fruits and vegetables, making them more accessible to removal through mechanical actions such as washing or peeling. In other cases, residues may penetrate into outer layers or internal tissues, which limits the effectiveness of simple cleaning practices [3]. This explains why no single household method works equally well for all foods.

It is also important for consumers to understand the limitations of household processing. Domestic practices are not designed to completely eliminate pesticide residues, nor are they a substitute for proper regulation and safe agricultural practices. Instead, their main benefit lies in reducing overall exposure and lowering potential risk when applied appropriately. Promoting realistic expectations is essential to avoid unnecessary concern or the misuse of aggressive cleaning methods that may negatively affect food quality or the environment [2].

Another reason household processing matters is its accessibility. Unlike advanced technological treatments used in the food industry, household methods rely on tools and materials that are readily available in most kitchens. This makes them particularly relevant for a wide range of consumers, including households in rural areas, small-scale farmers consuming their own produce, and individuals with limited access to processed foods. Clear guidance on simple, effective practices can therefore contribute directly to safer food handling at the household level [1].

In this context, household processing should be viewed as a practical risk-reduction approach rather than a guarantee of complete safety. When consumers understand both what these methods can achieve and where their limits lie, they are better equipped to make informed choices. The following sections of this textbook focus on specific household practices and food groups, providing practical, evidence-based guidance to help consumers apply these methods in a safe, efficient and sustainable way.

3. Principles Governing Residue Removal at Home

Many consumers apply similar household practices to all fruits and vegetables, assuming that washing, soaking or cooking will lead to the same result in every case. In reality, the effectiveness of household methods in reducing pesticide residues varies widely. Some practices

work well for certain foods, while others have only a limited effect. This difference is not due to incorrect behaviour by consumers, but rather to the way pesticide residues interact with different foods and household processes [3].

Understanding the basic principles that govern residue removal at home helps consumers make more informed and realistic choices in the kitchen. Factors such as where the residue is located on the food, the physical characteristics of fruits and vegetables, and the type of household practice applied all influence the final outcome. For example, residues present mainly on the surface may be easier to remove through washing or peeling, whereas residues that penetrate deeper into plant tissues are less affected by simple cleaning methods [5].

It is also important to recognise that household processing is designed to reduce exposure rather than to completely eliminate pesticide residues. Domestic practices should therefore be viewed as practical risk-reduction tools that complement, but do not replace, food safety regulations and good agricultural practices. When consumers understand both the strengths and the limitations of household methods, they are less likely to rely on ineffective practices or to use excessive cleaning measures that may negatively affect food quality or the environment [2].

3.1. Key Factors Affecting Residue Removal Efficiency

The efficiency of household practices in reducing pesticide residues is determined by several interacting factors rather than by a single action or method. Consumers often expect similar results when applying the same practice, such as washing or soaking, to different fruits and vegetables. However, scientific evidence shows that residue reduction outcomes vary widely depending on characteristics related to the food, the pesticide involved and the way household processing is applied [3, 5].

One of the most influential factors is the location of pesticide residues on or within the food. Residues that remain primarily on the surface of fruits and vegetables are generally more accessible to removal through mechanical actions such as washing, rinsing or peeling. This is often the case for leafy vegetables and for fruits and non-leafy vegetables with exposed outer surfaces. In contrast, residues that have penetrated into outer layers or internal tissues are far less affected by surface-based treatments, which explains why washing alone frequently results in only partial residue reduction [3,4].

Closely related to residue location is the physical structure of the food itself. Leafy vegetables, such as lettuce and spinach, present large surface areas and complex structures with folds and crevices where residues can be retained. Fruits and non-leafy vegetables with smooth or waxy skins, such as apples, tomatoes or cucumbers, may accumulate residues on their surface wax layers, which can limit the effectiveness of simple water washing. Root and tuber crops may be exposed to residues through soil contact, and although peeling can be effective, washing alone may not sufficiently reduce residues adhered to rough or porous surfaces [5, 7].

Another critical factor influencing residue removal efficiency is the nature of the pesticide. Pesticides differ widely in their chemical properties, particularly in terms of water solubility, fat solubility and their ability to penetrate plant tissues. From a consumer perspective, this means that some pesticide residues are relatively easy to reduce, while others are more persistent. Pesticides that remain mainly on the surface and are more water-soluble tend to respond better to washing or soaking. In contrast, pesticides with higher fat solubility or systemic properties may bind more strongly to plant tissues or penetrate beneath the surface, making them less accessible to simple household practices [3, 8].

Systemic pesticides, which are designed to be absorbed and distributed within the plant, pose a particular challenge for household residue reduction. Because these substances are not limited to the surface, washing or soaking has limited impact on their removal. In such cases, peeling or thermal processing may lead to greater reductions, although complete removal is still unlikely. Several studies have shown that even intensive household treatments cannot fully eliminate residues of certain pesticides once they are incorporated into plant tissues [4, 7]. Understanding this limitation is essential to prevent unrealistic expectations and unnecessary concern among consumers.

The type of household practice applied further determines how effective residue reduction will be. Mechanical methods, such as washing, rely primarily on physical removal and are most effective for loosely attached surface residues. Chemical-based household treatments, including soaking in salt, vinegar or baking soda solutions, may enhance removal for specific surface residues but are still constrained by residue location and pesticide properties. Thermal processing methods, such as blanching or cooking, can reduce residues through degradation or transfer into

cooking water, but their effectiveness varies depending on processing time, temperature and the stability of the pesticide [3, 5].

Finally, the duration and intensity of household processing influence residue removal efficiency. Longer washing times, repeated rinsing or extended soaking may increase residue reduction to a certain extent. However, scientific evidence suggests that increasing processing intensity beyond moderate levels often provides limited additional benefit while potentially affecting food quality, nutrient content and environmental sustainability [2, 5]. This highlights the importance of balanced and informed household practices rather than excessive or aggressive treatments.

Taken together, these factors explain why no single household method can be considered universally effective. Residue removal at home depends on the combined effects of food characteristics, pesticide behavior and processing conditions. By understanding these key factors, consumers can better adapt household practices to specific foods and develop realistic expectations about what can be achieved through domestic pesticide reduction methods. This understanding provides the foundation for discussing the overall effectiveness and limitations of household practices.

3.2. Effectiveness and Limitations of Household Pesticide Reduction Practices

Household pesticide reduction practices are widely used because they are simple, accessible and part of everyday food preparation. Washing fruits and vegetables, peeling outer layers or applying basic cooking methods are often perceived as effective ways to remove pesticide residues. Scientific studies generally confirm that these practices can reduce residue levels, but the degree of reduction varies considerably depending on several conditions [9, 10].

One of the main advantages of household practices is their ability to reduce residues that are present on the surface of fruits and vegetables. Washing under running water, gentle rubbing and peeling of outer layers can remove a meaningful proportion of loosely attached residues. Experimental studies on commonly consumed products, such as tomatoes and other fresh vegetables, have shown that washing and cooking can significantly lower residue levels, particularly for non-systemic pesticides that remain on the surface [7, 10]. From a consumer perspective, these findings support the continued use of basic household practices as a first step in reducing exposure.

However, it is equally important to understand the limitations of these practices. Household methods are not designed to completely remove all pesticide residues. Residues that have penetrated into plant tissues or are strongly bound to waxy or fatty surfaces are much less affected by washing or soaking. Studies have shown that even when multiple household treatments are combined, complete removal of certain pesticide residues is rarely achieved [9, 10]. This limitation is particularly relevant for systemic pesticides and for fruits and vegetables that are consumed with their skins.

Another limitation arises from inappropriate or excessive use of household treatments. Consumers may increase washing time, apply strong household chemicals or combine multiple treatments in the belief that this will result in safer food. However, evidence suggests that excessive processing often provides limited additional residue reduction while increasing water consumption, causing nutrient losses or negatively affecting food quality [10]. In addition, unnecessary use of chemical-based washing agents may introduce new environmental concerns without offering clear safety benefits.

Household practices should therefore be understood as practical risk-reduction measures rather than as a guarantee of residue-free food. Their value lies in lowering overall dietary exposure, especially when applied correctly and in moderation. Monitoring studies from different regions, including Europe, show that pesticide residues can still be detected in fruits and vegetables at the market level, reinforcing the importance of informed consumer practices rather than reliance on a single solution [11, 12].

In summary, household pesticide reduction practices are useful, but their impact is inherently limited. They work best when applied correctly, moderately and in combination with an understanding of food type and preparation method. Recognizing these strengths and limitations helps consumers make realistic decisions and prepares them for the more detailed discussion of specific household techniques presented in the following sections.

4. Mechanical Household Practices

Mechanical household practices are among the most commonly used methods to reduce pesticide residues on fruits and vegetables. These practices are based on simple physical actions, such as removing outer parts or using water movement, and are easily applied in everyday kitchen routines. Because they do not require special equipment or chemical products,

mechanical methods are often the first choice for consumers seeking to improve food safety at home [3].

The effectiveness of mechanical practices mainly depends on their ability to remove residues present on the surface of fruits and vegetables. Washing, rinsing, peeling and trimming can reduce loosely attached residues, but they are generally less effective against residues that have penetrated into deeper layers of the food [10]. This section focuses on two key mechanical practices: peeling and trimming, as well as washing and rinsing. It explains how these practices work, highlights their main benefits and limitations, and supports informed and realistic household decision-making.

4.1. Peeling and Trimming Practices

Peeling and trimming are simple household practices that can help reduce pesticide residues by physically removing the parts of fruits and vegetables where residues are most likely to be present. Many pesticides, especially those applied close to harvest or sprayed on the plant surface, tend to remain on the skin or outer layers of produce. Removing these outer parts can therefore lower the amount of residues reaching the edible portion, making peeling and trimming useful steps in everyday food preparation [13, 14]. Table 4.1 presents selected examples from the literature illustrating the effectiveness of peeling under household conditions in reducing pesticide residues on fruits and vegetables.

Research shows that pesticide residues can differ substantially between the peel and the inner flesh of fruits and vegetables. For example, studies on tomatoes indicate that residues are often higher in the peel than in the pulp, and peeling can therefore significantly reduce residue levels in foods that are typically eaten without the peel [13, 14]. Similar patterns have been observed in other produce such as citrus fruits. When oranges are processed at home, the majority of pesticide residues remain with the peel, and peeling effectively lowers the residues in the part that people consume [15].

Trimming works on the same principle as peeling, but it is particularly relevant for vegetables where only certain parts are removed. For leafy vegetables and herbs, trimming can include discarding damaged or outer leaves and cutting away visibly soiled sections. For cabbage-like vegetables, removing the outer leaves may reduce residues that are concentrated on the exterior surfaces. For fruits and vegetables with stems, caps, or blossom ends (such as strawberries,

peppers, and some root vegetables), trimming these parts can also reduce residues and remove areas where dirt and residues may accumulate. While trimming is not a guarantee of residue-free food, it can provide an additional reduction step—especially when combined with proper washing and rinsing [3, 5].

Table 4.1. Effect of Peeling on Pesticide Residue Reduction in Fruits and Vegetables

Household processing condition	Produce	Residue reduction (%)	Reference
Peeling	Potato	91–98	[16]
Peeling	Cucumber	46	[17]
Peeling	Eggplant	75-85	[4]
Peeling	Mango	100	[18]
Peeling	Kaki fruit	88	[19]
Peeling	Melons	>50	[20]

For best results, consumers should wash produce before peeling or trimming. This initial washing removes loose dirt and some surface residues that might otherwise be transferred to the edible portion during cutting. After peeling and trimming, it is also good practice to wash hands, utensils and cutting boards to avoid cross-contamination between foods being prepared. These simple kitchen steps not only help reduce pesticide residues but also support general hygiene and food safety at home [10].

At the same time, consumers should be aware of the nutritional trade-offs associated with peeling. Many beneficial nutrients, including fibre and certain vitamins, are concentrated near or in the skin. Peeling can result in the loss of these nutrients [21], so it may be most appropriate for produce that is commonly consumed with the skin but is known to carry higher residue levels. For items where the peel is not normally eaten, such as citrus fruits, peeling is a natural and effective step. For items like apples, cucumbers and tomatoes, consumers may balance residue reduction with nutrition by using a combined strategy of thorough washing, selective trimming and peeling only when appropriate for the meal [15, 22]. Table 4.2 summarizes situations in which peeling and trimming can be particularly helpful for reducing pesticide residues on

different types of produce. The table highlights which parts are most commonly removed, explains why these actions are effective, and includes practical consumer tips that support safe and realistic household decision-making.

Table 4.2. When Peeling or Trimming Is Most Helpful for Reducing Pesticide Residues

Produce type	What to remove	Why this helps	Possible trade-off	Practical tip for consumers
Citrus fruits (orange, lemon, mandarin)	Peel	Pesticide residues are mainly associated with the outer peel	Minimal nutrient loss, as peel is not eaten	Rinse the fruit before peeling to avoid transferring residues to the pulp
Fruit vegetables (tomato, cucumber, pepper)	Peel or stem end	Residues often remain on the skin or around the stem area	Loss of fiber and some vitamins near the skin	Wash first, then peel or trim using a clean knife
Pome fruits (apple, pear)	Peel (when needed)	Residues may accumulate on waxy skins	Reduced fiber and antioxidant intake	Consider peeling for children; combine with thorough washing for adults
Leafy vegetables (lettuce, spinach, cabbage)	Outer leaves, damaged parts	Outer leaves have the highest surface exposure to pesticides	Increased food waste	Remove outer leaves first, then wash remaining leaves thoroughly
Root and tuber crops (potato, carrot)	Peel, cut off ends	Soil contact may increase residue retention on outer layers	Loss of nutrients under the skin	Scrub and rinse before peeling to prevent cross-contamination
Fresh herbs (parsley, dill, coriander)	Damaged or heavily soiled parts	Thin leaves and stems can retain residues	Limited reduction if residues are internal	Trim visibly dirty parts, then wash gently under running water

4.2. Washing and Rinsing Practices

Washing and rinsing under running water are the most common household practices used by consumers to reduce pesticide residues on fruits and vegetables. These methods mainly act by physically removing pesticide residues that are loosely attached to the surface of produce. The effectiveness of washing therefore depends largely on the location of the residue and the characteristics of the food surface [3]. Table 4.3 presents selected examples from the literature

illustrating the effectiveness of washing and rinsing under household conditions in reducing pesticide residues on fruits and vegetables.

Scientific studies show that washing and rinsing can reduce pesticide residues to a certain extent, particularly when residues are present on the surface. For example, Soliman investigated pesticide residues in potatoes and reported that washing under running water led to a noticeable reduction in residue levels, although the extent of removal varied depending on the pesticide [7]. Similar findings were reported by Abou-Arab, who showed that washing tomatoes reduced residues of several pesticides, particularly those remaining on the surface rather than inside plant tissues [8]. Washing under running tap water is generally more effective than washing in still water, as the continuous flow helps carry away detached residues. Gentle rubbing of the surface by hand can further enhance residue removal, especially for smooth-skinned fruits and vegetables such as apples, tomatoes and cucumbers [10]. However, the effectiveness of washing varies depending on the type of produce and the characteristics of the pesticide.

For leafy vegetables, washing and rinsing are especially important because large surface areas and leaf folds can retain residues. Separating leaves and rinsing them individually under running water can improve removal compared to washing whole heads at once. In root and tuber crops, washing mainly helps remove soil and surface contamination, while its effect on residues bound to the skin may be limited. These examples highlight that washing should be adapted to the structure of the food rather than applied in the same way to all produce [5].

Despite its benefits, washing has clear limitations. Residues that have penetrated into the inner tissues of fruits and vegetables are not easily removed by surface washing. Similarly, pesticides that are strongly bound to waxy surfaces or are systemic in nature may show only limited reduction after washing. Several reviews have shown that while washing can lower residue levels, it rarely leads to complete removal [3, 10]. This reinforces the importance of realistic expectations when using washing as a household practice.

Another important consideration is the correct use of washing methods. Excessively long washing times or very strong water pressure do not necessarily result in better residue reduction and may damage delicate produce or increase water consumption. The use of soaps or detergents is not recommended, as these products are not designed for food use and may leave unwanted

residues behind. Clean, potable water and moderate mechanical action are generally sufficient for routine washing and rinsing [2].

Table 4.3. Effect of Washing and Rinsing on Pesticide Residue Reduction in Fruits and Vegetables

Household processing condition	Produce	Residue reduction (%)	Reference
Washing under running tap water (5 min)	Leafy vegetables (lettuce, perilla leaves, spinach, crown daisy, and ssamchoo)	60–88	[23]
Washing and rinsing with tap water (30 s)	Cauliflower	25-27	[4]
Washing	Mango	21-68	[18]
Washing under running tap water (30 s)	Grapes	20-49	[24]
Washing (3 min)	Peach	40	[25]
Washing (3 min)	Broccoli	33-44	[26]
Washing	Apple	7-67	[27]

In summary, washing and rinsing are effective first-line practices for reducing surface pesticide residues and improving overall food hygiene. They are most effective when applied correctly and in combination with other appropriate household practices, such as trimming or peeling when needed. Understanding both the strengths and limitations of washing helps consumers use this method effectively without relying on it as a complete solution.

5. Soaking and Chemical-Based Household Treatments

In addition to mechanical practices, many consumers use soaking and other solution-based methods in an attempt to further reduce pesticide residues on fruits and vegetables. These

practices are based on longer contact time between the food and water or water-based solutions, rather than on physical movement alone. Soaking is often perceived as a simple extension of washing, yet the mechanisms involved and the outcomes achieved can be quite different. An overview of the main soaking and chemical-based household treatments discussed in this section is presented in Figure 5.1.

Soaking and chemical-based household treatments may offer additional residue reduction in certain situations, particularly for surface residues that are water-soluble or loosely attached. However, their effectiveness varies widely depending on the type of produce, the pesticide involved, the composition of the solution and the duration of treatment. In some cases, these practices may provide only limited benefits or may introduce new concerns related to food quality, nutrient loss or improper use of household chemicals, as illustrated by the different approaches summarized in Figure 5.1.

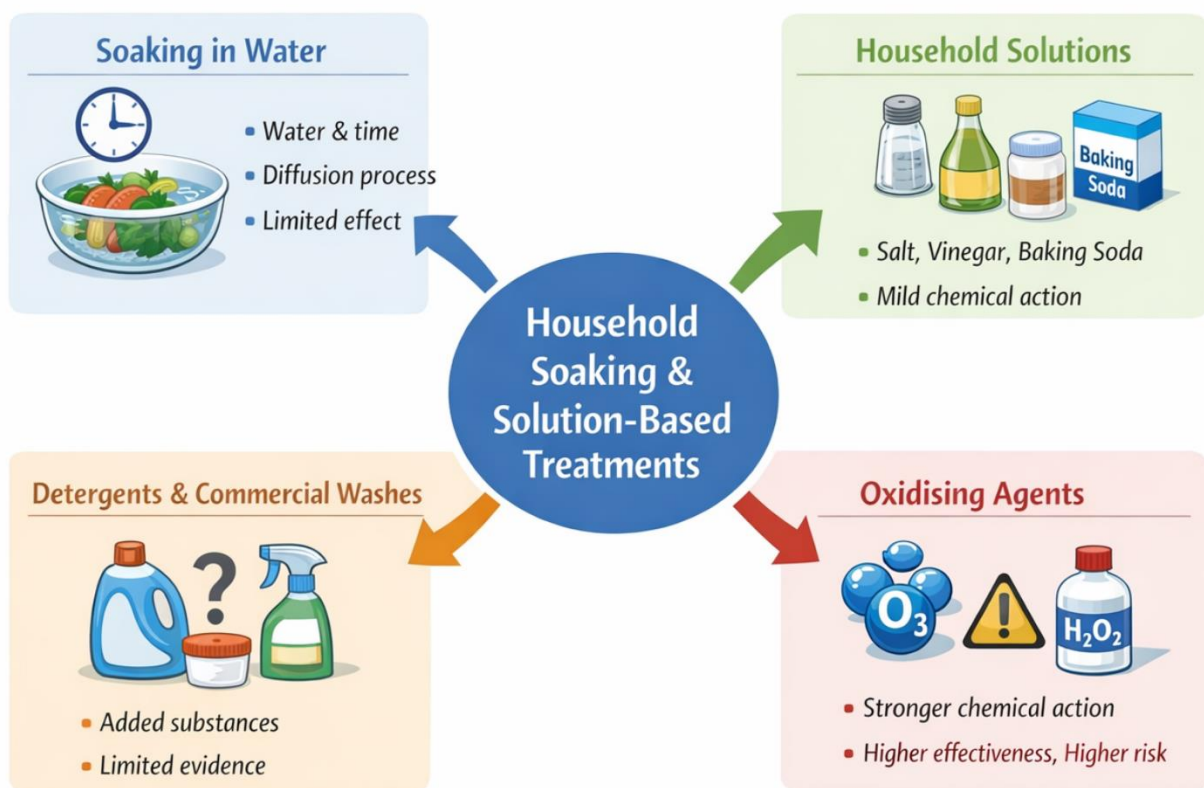


Figure 5.1. Overview of soaking and chemical-based household treatments for pesticide residue reduction. Source: Generated with ChatGPT (DALL•E) and modified by the authors using Microsoft PowerPoint (2026)

5.1. Soaking in Water

Soaking refers to placing fruits and vegetables in a large volume of water and keeping them immersed for a certain period of time. In household practice, soaking is often considered similar to washing or rinsing. However, unlike rinsing under running water, soaking involves little or no mechanical action and relies mainly on longer contact time between the produce and water. As a result, the mechanisms governing residue removal during soaking are different from those involved in washing [3]. Table 5.1 shows selected examples from the literature illustrating the effectiveness of soaking in water in reducing pesticide residues on fruits and vegetables.

Table 5.1. Effect of Soaking on Pesticide Residue Reduction in Fruits and Vegetables

Household processing condition	Produce	Residue reduction (%)	Reference
Soaking (5-60 min)	Date fruits	37-52	[28]
Soaking (10-30 min)	Cabbage, eggplant, tomato, cucumber, garlic sprouts	0.23-47	[29]
Soaking (20 min)	Cabbage	15-19	[30]
Soaking (10-30 min)	Cucumber, strawberry	10-20	[31]
Soaking (10 min)	Apple	33-52	[32]

In principle, the effectiveness of soaking in water depends on how easily a pesticide can dissolve in water and move away from the surface of fruits and vegetables. Studies reviewed in the literature indicate that pesticides that dissolve more readily in water tend to be reduced more effectively during soaking [28]. In contrast, not all pesticides respond positively to soaking. Ling et al. (2011) found that extending soaking time did not significantly affect the removal of chlorpyrifos in vegetable samples, indicating that longer contact with water does not necessarily improve residue reduction [29]. Similarly, results reported by Zhang et al. (2007) demonstrated that increasing soaking time beyond a few minutes resulted in only small additional reductions of pesticides in cabbage [30]. This pattern indicates a diminishing return, where most of the achievable reduction occurs early and further soaking provides little additional benefit. Overall,

these findings highlight that soaking is highly pesticide-specific and that prolonged soaking should not be expected to produce uniform or substantial improvements across different compounds or food types.

5.2. Use of Household Solutions

Household solutions such as salt water, vinegar, baking soda and citric acid-based solutions are widely used by consumers to reduce pesticide residues on fruits and vegetables. These practices are popular because the ingredients are easily available at home and are perceived as natural and safe. Unlike simple water soaking, household solutions may interact chemically with pesticide residues, which can enhance removal in specific situations. However, scientific evidence shows that their effectiveness varies widely depending on the type of solution, the pesticide involved and the characteristics of the produce. Practical guidance on when each household solution may be more suitable, along with key limitations and safe application tips, is provided in Table 5.2.

Salt water is commonly used for soaking vegetables, especially leafy vegetables. Studies indicate that salt solutions may help remove loosely attached surface residues by enhancing the release of residues into the soaking water. However, salt water does not consistently outperform plain water and is generally effective only for surface residues [3, 10]. Short soaking times followed by thorough rinsing under running water are recommended, as longer soaking does not provide additional benefit and may affect texture.

Vinegar, an acetic acidic solution is frequently used because of the belief that acidity helps break down pesticides. Studies show that vinegar can reduce certain pesticide residues on the surface of fruits and vegetables, mainly through partial dissolution or chemical instability of some compounds. However, the overall effect is often modest and highly pesticide-specific. Vinegar may be more appropriate for smooth-skinned fruits such as apples, tomatoes and cucumbers. It is important to note that vinegar does not effectively remove pesticides that have penetrated into plant tissues, and excessive concentrations may negatively affect taste and quality [3, 8].

Baking soda (sodium bicarbonate) has shown more promising results in some studies. A well-known study by Yang et al. (2017) demonstrated that soaking apples in a baking soda solution

resulted in greater removal of certain pesticide residues compared with water alone. This effect was attributed to enhanced degradation of some pesticides on the fruit surface [33]. Baking soda solutions appear to be particularly effective for residues present on the outer surface of fruits with edible peels, such as apples and pears. However, the effectiveness depends on the pesticide type, and residues located deeper in the peel or flesh are less affected. Moderate concentrations and limited soaking times are recommended to avoid changes in texture or flavor.

Table 5.2. Common Household Solutions Used for Pesticide Residue Reduction and Their Practical Use

Household solution	Produce where it may be more suitable	Main effect on pesticide residues	Key limitations	Practical household application
Salt water	Leafy vegetables (lettuce, spinach), herbs	Helps remove loosely attached surface residues	Not consistently more effective than plain water; limited effect on internal residues	Soak briefly (5–10 min), then rinse thoroughly under running water
Vinegar (acetic acidic solution)	Smooth-skinned fruits and vegetables (apples, tomatoes, cucumbers)	Partial reduction of some surface residues through dissolution or instability	Effect is pesticide-specific; may affect taste if concentrated	Use diluted vinegar for short soaking, always rinse with clean water afterwards
Baking soda (sodium bicarbonate)	Fruits with edible peels (apples, pears)	Can enhance degradation of certain surface residues	Less effective for residues beneath the peel; excessive use may affect texture	Use mild solution, soak for limited time, rinse well
Citric acid-based solutions	Small fruits and vegetables; surface treatment	May reduce some surface residues through acidic dissolution	Variable effectiveness; not consistently superior to water-based treatments	Apply for short surface treatments only; always rinse thoroughly afterwards

Citric acid-based solutions, representing the main acidic component of lemon juice, are also used as household treatments. Available studies indicate that citric acid solutions may contribute to the reduction of certain surface pesticide residues, mainly through acidic dissolution or instability of some compounds. However, the reported effects vary considerably across pesticides

and produce types, and current evidence does not support a consistent or universally superior effect of citric acid solutions compared with water-based or other mild acidic treatments [3, 5]. Selected literature examples showing the reported residue reduction percentages achieved with common household solutions are summarized in Table 5.3.

Table 5.3. Effect of Common Household Solutions on Pesticide Residue Reduction in Fruits and Vegetables

Household processing condition	Produce	Residue reduction (%)	Reference
5% sodium bicarbonate (immersion for 30 min)	Bell peppers	60-81	[34]
10% sodium bicarbonate (immersion for 20 min)	Tomato	2-71	[35]
0.9% NaCl (immersion for 15 min)	Beans	49-95	[36]
10% NaCl (immersion for 20 min)	Cabbage	65-74	[30]
9% citric acid solution (immersion for 5 min)	Cucumber Bell pepper	94 72	[37]
9% citric acid solution (immersion for 5 min)	Capia pepper	36-78	[38]
Grape vinegar (4% acetic acid) (immersion for 10 min)	Lettuce	26-92	[39]
1 and 2 % of acetic acid (immersion for 5-60 min)	Date fruits	87-99	[28]

Overall, household solutions can offer additional reduction of surface pesticide residues in specific situations, but none of these methods provide a universal or complete solution. Their effectiveness depends on matching the right solution with the right type of produce and using them correctly. For most consumers, household solutions should be considered optional supplementary practices rather than essential steps, and they should always be followed by thorough rinsing with clean water to remove loosened residues and solution remnants.

5.3. Detergents and Commercial Produce Washes

In addition to water and household solutions, some consumers use detergents or commercially available produce washes with the aim of improving pesticide residue removal from fruits and vegetables. These products are often marketed as being more effective than water alone and are promoted for their ability to remove dirt, waxes and chemical residues. However, scientific evidence regarding their effectiveness and safety remains limited and inconsistent.

Studies evaluating the use of household detergents show that, although detergents can enhance the removal of surface contaminants due to their surfactant properties, they are not specifically designed for food use. Detergents may help detach residues from the surface by reducing surface tension, but they can also leave chemical residues of their own if not thoroughly rinsed. Moreover, the use of detergents on food raises safety concerns, as these products are formulated for cleaning non-food surfaces rather than for ingestion-related applications [40].

Commercial produce washes are typically formulated as food-contact products and may contain mild surfactants and/or organic acids or plant-derived ingredients intended to improve cleaning performance. Evidence from comparative studies suggests that some commercial washing agents can provide additional removal of certain surface residues compared with water alone, particularly on smooth-skinned produce; however, the improvement is often modest and highly dependent on the pesticide, the produce surface, and whether residues have penetrated below the surface [33, 41]. Selected literature examples showing the reported residue reduction percentages achieved with detergents and commercial produce washes are summarized in Table 5.4.

Importantly, there is no consistent evidence that commercial produce washes are capable of removing pesticide residues that have penetrated into the internal tissues of fruits and vegetables. As with other household methods, their action is largely limited to surface residues. In addition, inappropriate use, such as excessive concentrations or insufficient rinsing, may negatively affect food quality or result in unwanted chemical residues remaining on the produce.

From a consumer perspective, detergents should generally be avoided for cleaning fruits and vegetables due to safety concerns. Commercial produce washes may be used as optional supplementary products, but they should not be regarded as essential or highly superior to proper

washing with clean running water. When used, they should always be followed by thorough rinsing to ensure the removal of both loosened pesticide residues and any remaining washing agents. Overall, informed and cautious use is essential to avoid creating a false sense of safety regarding pesticide residue removal.

Table 5.4. Effect of Detergents and Commercial Produce Washes on Pesticide Residue Reduction in Fruits and Vegetables

Household processing condition	Produce	Residue reduction (%)	Reference
Washing with vegetable detergent (soaking for 5 min)	Lettuce	58	[23]
	Perilla leaves	46	
	Spinach	44	
	Crown daisy	39	
	Ssamchoo	33	
Washing with commercial agent (soaking for 5 min)	Apple	86	[41]
	Grape	98	
	Lemon	98	
	Strawberry	88	
Washing with two commonly used kitchen dishwashing detergents (soaking for 20 min)	Cherry tomatoes	42-80	[42]
Washing with a commercially available vegetable detergent (soaking for 3 min)	Strawberry	45-60	[43]
Washing with a commercially available detergent	Cucumber	52-55	[44]
Washing with a commercially available vegetable detergent	Tomato	58	[45]

5.4. Oxidizing Agents in Household Practices

Oxidizing agents represent a distinct group of household practices that rely on strong chemical reactions to reduce pesticide residues on fruits and vegetables. Unlike water, household solutions or detergents, oxidizing agents act by chemically transforming pesticide molecules into less persistent compounds. The most commonly discussed oxidizing agents in household or semi-household contexts include chlorine-based solutions, ozone and hydrogen peroxide. Selected literature examples showing the reported residue reduction percentages achieved with oxidizing agents are summarized in Table 5.5.

Chlorine-based solutions (such as diluted sodium hypochlorite) have long been used in food sanitation, particularly for microbial control. Studies indicate that chlorine can also contribute to the reduction of certain pesticide residues located on the surface of fruits and vegetables. However, its effectiveness is highly pesticide-specific and mainly limited to surface residues. In addition, concerns related to chemical residues, by-product formation, improper concentration and potential negative effects on produce quality (such as changes in color, texture and flavor) have limited the recommendation of chlorine use at the household level for pesticide removal [33, 46, 47].

Table 5.5. Effect of Oxidizing Agents on Pesticide Residue Reduction in Fruits and Vegetables

Household processing condition	Produce	Residue reduction (%)	Reference
Washing with sodium hypochlorite (1%) for 30 min	Tomato	30-55	[46]
Washing in aqueous chlorine dioxide solution (20 mg/L) for 20 min	Lettuce	45-70	[47]
Ozone application in gaseous and aqueous form	Carrot	51-98	[48]
Application of aqueous ozone solution	Potato	70-76	[49]
Hydrogen peroxide immersion at 100 mg/L for 20 min	Cauliflower	72-75	[51]
Hydrogen peroxide immersion at 100 mg/L for 20 min	Tomato	65	[52]

Ozone has attracted increasing attention as an alternative oxidizing agent due to its strong oxidative capacity and rapid decomposition into oxygen, leaving no chemical residues. Experimental studies have shown that aqueous or gaseous ozone treatments can significantly reduce certain pesticide residues on fruits and vegetables [48, 49]. Nevertheless, achieving effective pesticide residue reduction through ozonation is challenging, as its efficiency is influenced by multiple factors, including the physical state of ozone (aqueous or gaseous), dosage, exposure time, temperature, pH and the surface characteristics of the food. Moreover, improper control of ozone concentration may negatively affect food quality and poses safety

concerns, particularly in settings where precise dosage and exposure conditions are difficult to maintain [50].

Hydrogen peroxide is another oxidizing agent occasionally discussed in the context of produce washing. While hydrogen peroxide can oxidize some pesticide residues, available studies suggest that its effectiveness is variable and generally limited to surface residues. Moreover, inappropriate concentrations may affect produce quality, including color and texture, and may pose safety concerns if misused [9, 51, 52].

Overall, oxidizing agents can provide higher residue reduction than simple washing or soaking under controlled conditions, but their use in household settings requires caution. The effectiveness of these agents is highly dependent on correct application parameters, and misuse may introduce new safety or quality concerns. For most consumers, oxidizing agents should therefore be considered specialized or optional methods rather than routine household practices for pesticide residue reduction.

6. Thermal Household Processing

Thermal household processing refers to the use of heat during food preparation, such as blanching, boiling and cooking, to reduce pesticide residues in fruits and vegetables. Unlike washing or soaking methods that mainly act on surface residues, thermal treatments can influence residues through a combination of heat, water contact and physical removal. These processes may lead to partial degradation or leaching of certain pesticide residues, but their effectiveness depends strongly on the type of pesticide, the food matrix and the processing conditions. This section focuses on common heat-based household practices and explains how blanching and cooking can contribute to pesticide residue reduction, along with their potential benefits and limitations in everyday food preparation. An overview of common thermal household processing methods and their effects on pesticide residue reduction is presented in Figure 6.1.

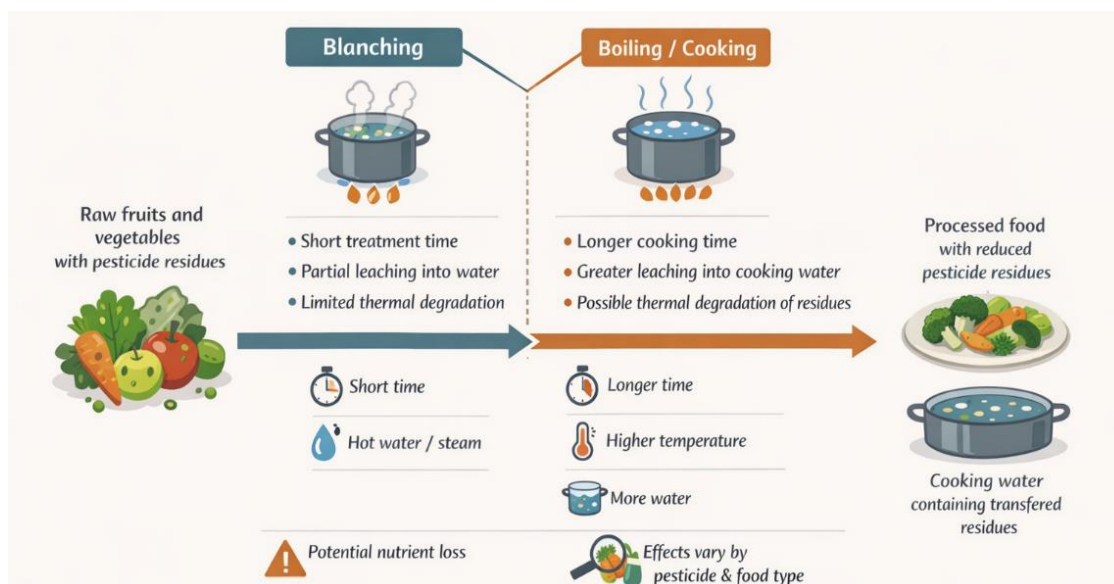


Figure 6.1. Overview of thermal household processing methods and their role in pesticide residue reduction. Source: Generated with ChatGPT (DALL•E) and modified by the authors using Microsoft PowerPoint (2026)

6.1. Blanching as a Residue Reduction Strategy

Blanching is a common household practice that involves exposing fruits or vegetables to hot water or steam for a short period of time, followed by rapid cooling. Although blanching is traditionally used to preserve color, texture and quality prior to freezing or cooking, it can also contribute to the reduction of pesticide residues. The primary mechanisms involved are leaching of residues into hot water and, to a lesser extent, thermal degradation of heat-sensitive pesticides [53, 54].

Several studies have shown that blanching can lead to measurable reductions in pesticide residues, particularly for water-soluble compounds and residues located on or near the surface of produce. Selected literature examples illustrating the impact of blanching on pesticide residue reduction are summarized in Table 6.1. During blanching, the combination of elevated temperature and water contact facilitates the migration of pesticide residues from plant tissues into the surrounding water. This effect is often more pronounced than simple washing, as heat can increase the permeability of plant tissues and accelerate diffusion processes [5, 54, 55].

The effectiveness of blanching, however, varies widely depending on the type of pesticide, the food matrix and the blanching conditions. Short blanching times may result in only partial residue reduction, while longer exposure can increase removal but also raises the risk of nutrient loss and quality changes. Studies on vegetables such as leafy greens, beans and root crops have reported that blanching can remove a significant proportion of certain residues, but the degree of reduction is highly pesticide-specific [5, 9, 54].

It is also important to note that blanching mainly affects residues that are water-soluble or loosely bound. Pesticides that are more lipophilic or have penetrated deeper into plant tissues tend to be less responsive to short heat treatments. As a result, blanching should not be viewed as a universal solution for pesticide residue removal, but rather as a complementary step that may enhance overall reduction when combined with prior washing or trimming [5, 9].

From a practical household perspective, blanching offers a balance between effectiveness and simplicity. When applied appropriately—using sufficient water, controlled temperature and short processing times—it can reduce certain pesticide residues while maintaining acceptable food quality. However, consumers should be aware that blanching may also cause losses of heat-sensitive nutrients, and the blanching water should be discarded, as it may contain transferred residues. Overall, blanching represents a useful but context-dependent strategy within thermal household processing for pesticide residue reduction.

6.2. Boiling and Cooking Effects

Boiling and everyday cooking (such as simmering, steaming or stir-frying) can further reduce pesticide residues beyond what is achieved by washing alone. This is mainly because heat-based cooking combines high temperature, longer contact time, and often water or oil as a processing medium, which can promote residue reduction through several pathways. A large meta-analysis of fruit and vegetable processing shows that boiling and related household cooking steps generally reduce residues, although the size of the reduction can vary substantially depending on the pesticide and the food type [5, 9].

Leaching into cooking water is one of the most important mechanisms during boiling and simmering. When vegetables are boiled, residues that are more water-soluble or loosely attached can migrate from the plant surface (and sometimes from near-surface tissues) into the cooking

water. In practical terms, this means that discarding the cooking water can be an important part of exposure reduction for certain pesticide–produce combinations. However, not all pesticides behave the same way; compounds that are strongly bound, less water-soluble, or located deeper in tissues may show smaller reductions. Reviews emphasize that the outcome depends on the pesticide’s physicochemical properties, the commodity (e.g., leafy vs. waxy surfaces), and the processing conditions (time, temperature, and whether water is replaced) [5, 9].

Controlled experimental studies support these general patterns. For example, a study on commonly consumed vegetables (Chinese kale and yard long bean) reported clear reductions in detected pesticide residues after household cooking processes, with boiling showing substantial decreases across several compounds, while the extent of reduction differed by pesticide and vegetable type [55]. Similar variability is also seen outside vegetables: in a study on rice prepared using a household-relevant method involving boiling and subsequent cooking, residue levels decreased across many pesticides, and the authors attributed reductions to a combination of volatilization, hydrolysis, and thermal degradation, again highlighting that “cooking effects” are not uniform for all chemicals [57]. Selected literature examples illustrating the impact of boiling and cooking on pesticide residue reduction are summarized in Table 6.1.

Cooking does not always guarantee large reductions in pesticide residues, as some compounds are relatively stable under typical cooking temperatures or may be protected by the food matrix. In addition, certain cooking methods involving high moisture loss can lead to apparent concentration effects, even when the absolute amount of residue is not increasing. For this reason, boiling and cooking should be viewed as supportive steps within a multi-step household approach rather than standalone solutions. In practice, washing produce first, followed by boiling and discarding the cooking water, can reduce exposure more effectively than washing alone for many vegetables. However, longer cooking times may also increase softening and reduce some heat-sensitive nutrients, highlighting the need to balance residue reduction with food quality and nutritional considerations.

Table 6.1. Effect of Thermal Household Processing on Pesticide Residue Reduction in Fruits and Vegetables

Household processing condition	Produce	Residue reduction (%)	Reference
Blanching	Potato	23-47	[7]
Frying		30-53	
Frying (1-5 min)	Cabbage	93	[29]
	Garlic sprouts	8	
	Tomato	10	
	Cucumber	5	
	Eggplant	63	
Stir-frying for 5 min	Cabbage	68-87	[30]
Blanching in hot water (80 °C) for 2 min	Spinach	4-41	[54]
Blanching in boiling water for 2 min	Chinese kale	36-100	[55]
Boiling for 10 min		18-71	
Stir-frying for 3 min		25-60	
Blanching in boiling water for 2 min	Yard long beans	27-28	[55]
Boiling for 10 min		38-100	
Stir-frying for 3 min		35-63	
Blanching in boiling water for 5 min	Pepper	46-100	[56]
	Eggplant	27-100	
Stir-frying (30 s-5 min)	Welsh Onion	40-63	[58]
Boiling (1-20 min)		80-91	
Baking (5-20 min)		51-77	
Steaming (5-20 min)	Cowpea	39-89	[59]
Boiling (1-5 min)		52-92	
Stir-frying(3-8 min)		45-88	

7. Food Group–Specific Guidance

The effectiveness of household practices for reducing pesticide residues can vary considerably depending on the type of food. Differences in surface structure, water content, peel characteristics and typical preparation methods all influence how residues behave during washing, soaking or cooking. For this reason, a single household approach cannot be applied equally to all fruits and

vegetables. This section provides food group–specific guidance by translating the general principles discussed in previous sections into practical recommendations tailored to leafy vegetables, non-leafy vegetables and fruits, and root and tuber crops, with the aim of supporting informed and realistic household decision-making.

7.1. Leafy Vegetables

Leafy vegetables such as lettuce, spinach, parsley, rocket and cabbage are among the food groups most frequently associated with pesticide residue concerns. Their large surface area, thin tissues and complex leaf structures provide multiple sites where pesticide residues can adhere or accumulate. In addition, these vegetables are often consumed raw or only lightly processed, which increases the importance of effective household practices to reduce potential exposure [23]. Recommended household preparation steps for leafy vegetables are given in Figure 7.1.

Among household methods, washing under running water is the most important first step for leafy vegetables. Gently separating leaves and washing them individually helps remove dirt, soil particles and loosely attached surface residues. Because many residues are located on the outer leaves, discarding damaged or outer leaves can further reduce residue levels before washing. Studies consistently show that washing is effective for removing a portion of surface residues, although its effectiveness depends on the pesticide and the way it was applied [23, 60].

Soaking leafy vegetables in water for extended periods generally offers limited additional benefit compared with proper washing. As discussed earlier, longer soaking times do not necessarily lead to greater residue reduction and may increase water uptake and quality loss. Therefore, soaking should not be relied upon as a primary strategy for leafy vegetables, especially when thorough washing is already performed [3, 23].

For leafy vegetables that are typically cooked, such as spinach or certain cabbage varieties, thermal processing can play a more important role. Blanching or boiling may lead to further reductions in pesticide residues through leaching into the cooking water, particularly for water-soluble compounds. Discarding the cooking water is essential, as transferred residues may accumulate there. However, the degree of reduction varies widely depending on the pesticide, and longer cooking times can result in losses of heat-sensitive nutrients and changes in texture [20, 55].



Figure 7.1. Household practices for reducing pesticides residues on leafy vegetables. Source: Generated with ChatGPT (DALL•E) and modified by the author using Microsoft PowerPoint (2026)

Chemical-based household treatments, including detergents or strong oxidizing agents, are not recommended for routine use on leafy vegetables. Their complex surface structure makes thorough rinsing difficult, increasing the risk that residues of cleaning agents themselves may remain on the leaves. Commercial produce washes may offer modest additional removal of some

surface residues, but they should be considered optional and must always be followed by thorough rinsing with clean water [23, 61].

In practical terms, the most effective household approach for leafy vegetables is a combination of simple, low-risk steps: removing outer or damaged leaves, washing thoroughly under running water with gentle handling, and applying cooking or blanching when the vegetable is normally consumed cooked. This combination provides meaningful residue reduction while preserving food quality and nutritional value [23, 55].

7.2. Non-leafy Vegetables and Fruits

Non-leafy vegetables and fruits, such as tomatoes, cucumbers, peppers, apples, pears and berries, differ from leafy vegetables in terms of surface characteristics, tissue structure and typical preparation practices. Many of these foods have smoother surfaces and firmer tissues, and some are protected by a natural peel or skin. As a result, pesticide residues are often concentrated on the outer surface, making household practices that target surface removal particularly relevant for this food group [3, 9]. Recommended household preparation steps for non-leafy vegetables and fruits are given in Figure 7.2.

Washing under running water remains the most important and widely applicable household practice for non-leafy vegetables and fruits. Gently rubbing the surface by hand during washing can help remove dirt and loosely attached residues, especially for smooth-skinned produce. For fruits and vegetables that are commonly eaten with the skin, such as apples, tomatoes and cucumbers, thorough washing is an essential first step and often provides meaningful residue reduction without affecting food quality [33, 61].

Peeling and trimming can further reduce pesticide residues for certain items, particularly when residues are concentrated on the outer layers. Peeling is especially effective for produce with thicker skins that are not normally consumed, such as citrus fruits or some melons. For foods where the skin is typically eaten, selective peeling or trimming may be used when residue concerns are high or when preparing food for more sensitive consumers. However, peeling also removes nutrients that are concentrated near the skin, so it should be applied thoughtfully rather than routinely [5, 9].

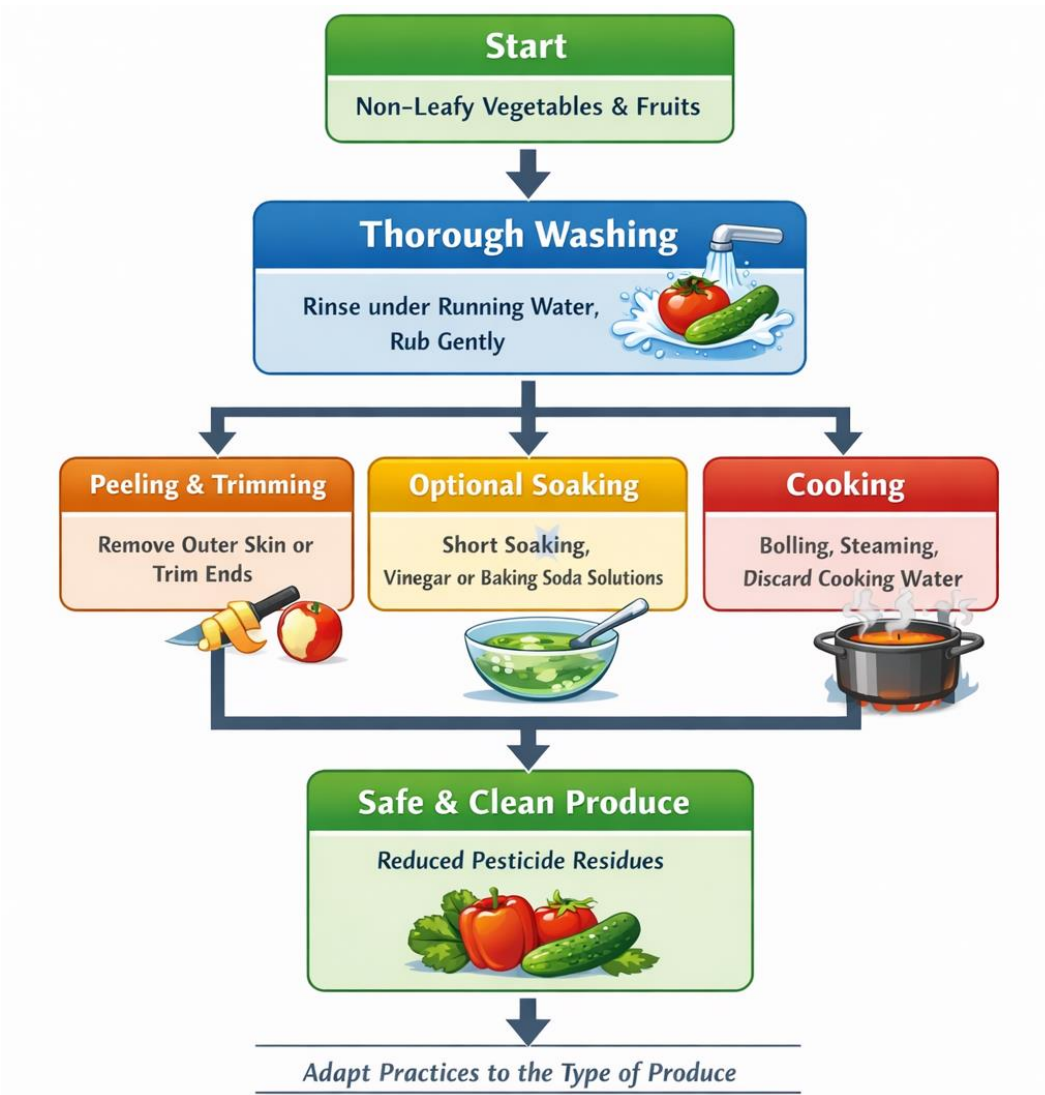


Figure 7.2. Household practices for reducing pesticide residues on non-leafy vegetables and fruits. Source: Generated with ChatGPT (DALL•E) and modified by the author using Microsoft PowerPoint (2026)

Soaking and household solutions may offer limited additional benefits for non-leafy vegetables and fruits. Short soaking in water can help loosen some surface residues, but extended soaking generally provides diminishing returns compared with proper washing. The use of household solutions such as vinegar, baking soda or citric acid-based solutions may improve the removal of certain surface residues under specific conditions, but their effectiveness varies widely depending on the type of produce and pesticide involved. These methods should therefore be considered optional and supplementary rather than essential [3, 33].

For non-leafy vegetables and fruits that are typically cooked, thermal processing can contribute further to residue reduction. Boiling or cooking can lead to the transfer of some pesticide residues into the cooking water or promote partial degradation of heat-sensitive compounds. As with other food groups, discarding the cooking water is important to avoid re-exposure. However, cooking is not a universal solution, and its effectiveness depends on the pesticide and the cooking method used [5, 55].

Overall, the most effective household strategy for non-leafy vegetables and fruits is a flexible, produce-specific approach. Thorough washing under running water should be the foundation, supported by peeling, trimming or cooking when appropriate for the specific food and preparation method. By matching household practices to the characteristics of each fruit or vegetable, consumers can achieve meaningful residue reduction while maintaining nutritional value and food quality [9, 61].

7.3. Root and Tuber Crops

Root and tuber crops, such as potatoes, carrots, beets, radishes and turnips, differ from other vegetable groups because the edible portion develops underground and is in direct contact with soil. As a result, these crops may carry both soil contamination and pesticide residues that are deposited on the surface or located in the outer tissue layers. In addition, root and tuber crops are rarely consumed raw and are usually peeled and cooked before consumption, which strongly influences household residue reduction strategies [3, 9]. Recommended household preparation steps for root and tuber crops are given in Figure 7.3.

Washing under running water is an essential first step for root and tuber crops, primarily to remove soil particles and surface-bound residues. Physical scrubbing with a brush is particularly effective for produce such as potatoes and carrots, where residues and soil may adhere to uneven surfaces. While washing alone may not eliminate residues that have penetrated deeper into the tissue, it can substantially reduce surface contamination and improve the effectiveness of subsequent preparation steps [3, 9].

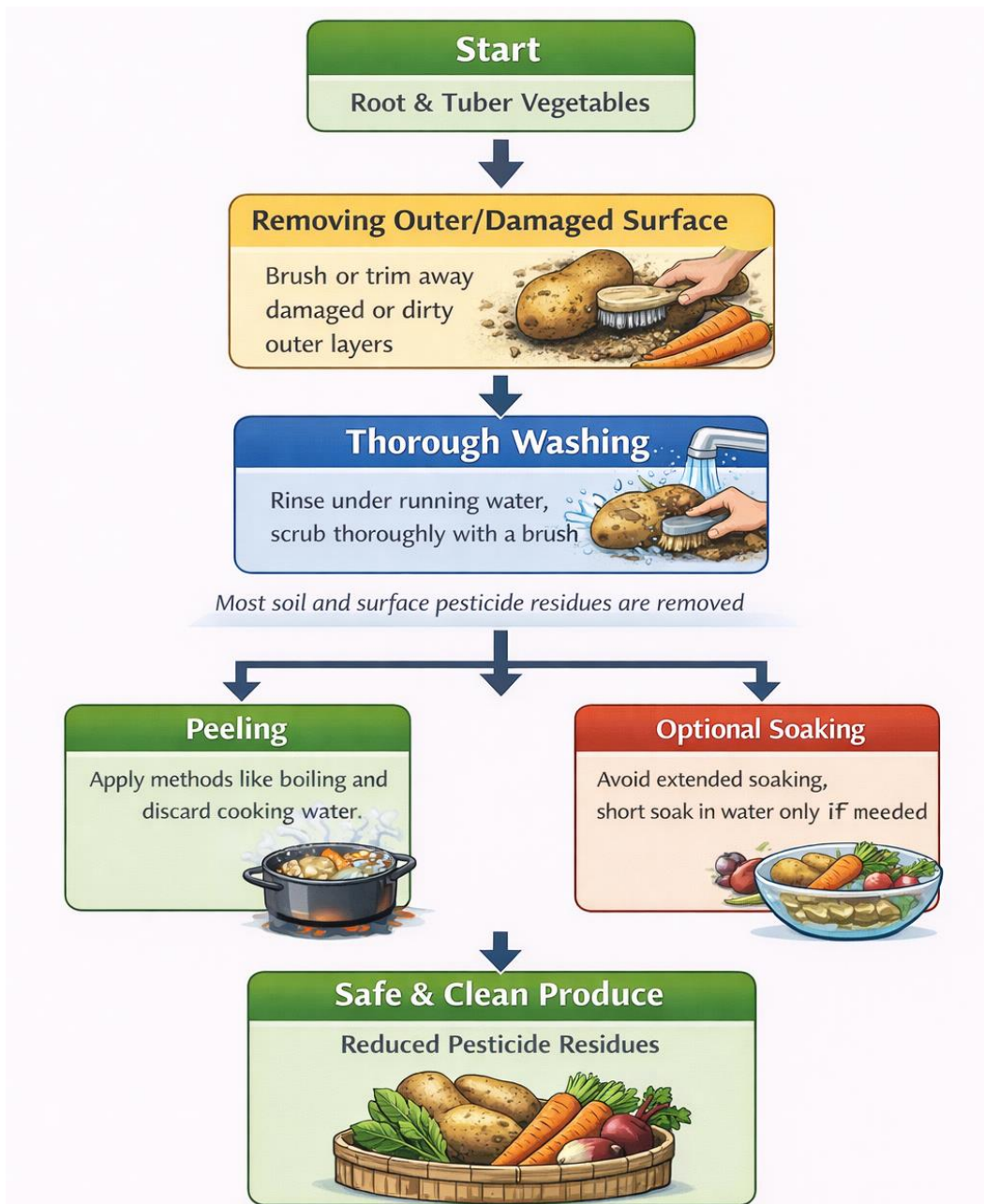


Figure 7.3. Household practices for reducing pesticide residues on root and tuber crops. Source: Generated with ChatGPT (DALL•E) and modified by the author using Microsoft PowerPoint (2026)

Peeling plays a major role in reducing pesticide residues in root and tuber crops, as many residues are concentrated in or just beneath the outer skin. Studies have consistently reported that peeling leads to significant reductions in residue levels in crops such as potatoes and carrots.

However, peeling also removes dietary fiber and micronutrients located near the peel, and therefore represents a trade-off between residue reduction and nutritional value [5, 9].

Because root and tuber crops are typically consumed cooked, thermal processing further contributes to pesticide residue reduction. Boiling, in particular, can reduce residues through leaching into the cooking water and partial degradation of heat-sensitive compounds. Discarding the cooking water is important to prevent re-exposure to transferred residues. Nevertheless, the extent of reduction varies depending on the pesticide's physicochemical properties and cooking conditions, and complete removal should not be assumed [5, 55].

Overall, the most effective household approach for root and tuber crops is a stepwise strategy that reflects common preparation practices. Thorough washing to remove soil, followed by peeling and appropriate cooking, provides substantial residue reduction for many pesticide–crop combinations. This integrated approach aligns with typical household habits and offers a practical balance between food safety, nutritional quality and ease of preparation [3, 9].

8. Safety, Sustainability and Consumer Awareness

While household practices can play an important role in reducing pesticide residues on fruits and vegetables, their application should be guided by considerations of safety, nutritional quality and environmental sustainability. Methods that appear effective in lowering residue levels may also lead to the formation of transformation products, losses of valuable nutrients or unintended exposure to other chemicals if used improperly. Therefore, pesticide residue reduction should not be viewed as an isolated goal, but rather as part of a balanced approach that takes into account potential trade-offs and long-term impacts. The key trade-offs involved in household pesticide residue reduction—between effectiveness, food quality and nutrition, and safety and sustainability—are summarized in Figure 8.1.

8.1. Formation of Metabolites during Household Processing

Household preparation methods can reduce pesticide residues on fruits and vegetables, but they may also alter the form in which residues are present on food. Rather than being completely removed, some pesticides can undergo chemical transformation during processes such as washing, heating, or exposure to oxidising conditions. As a result, the residue profile of a food after household processing may differ from that of the raw commodity, and both the parent

pesticide and potential transformation products need to be considered when evaluating food safety [3, 9].

Evidence from experimental studies shows that household processing can influence not only the level of the original pesticide but also the presence and behavior of its metabolites. For example, Ling et al. investigated the effects of washing and cooking on chlorpyrifos in vegetables and reported changes in both the parent compound and its toxic metabolites following household preparation. This finding highlights that reductions in the parent pesticide do not always fully describe the chemical changes occurring during processing, as some metabolites may persist or behave differently under the same conditions [29].

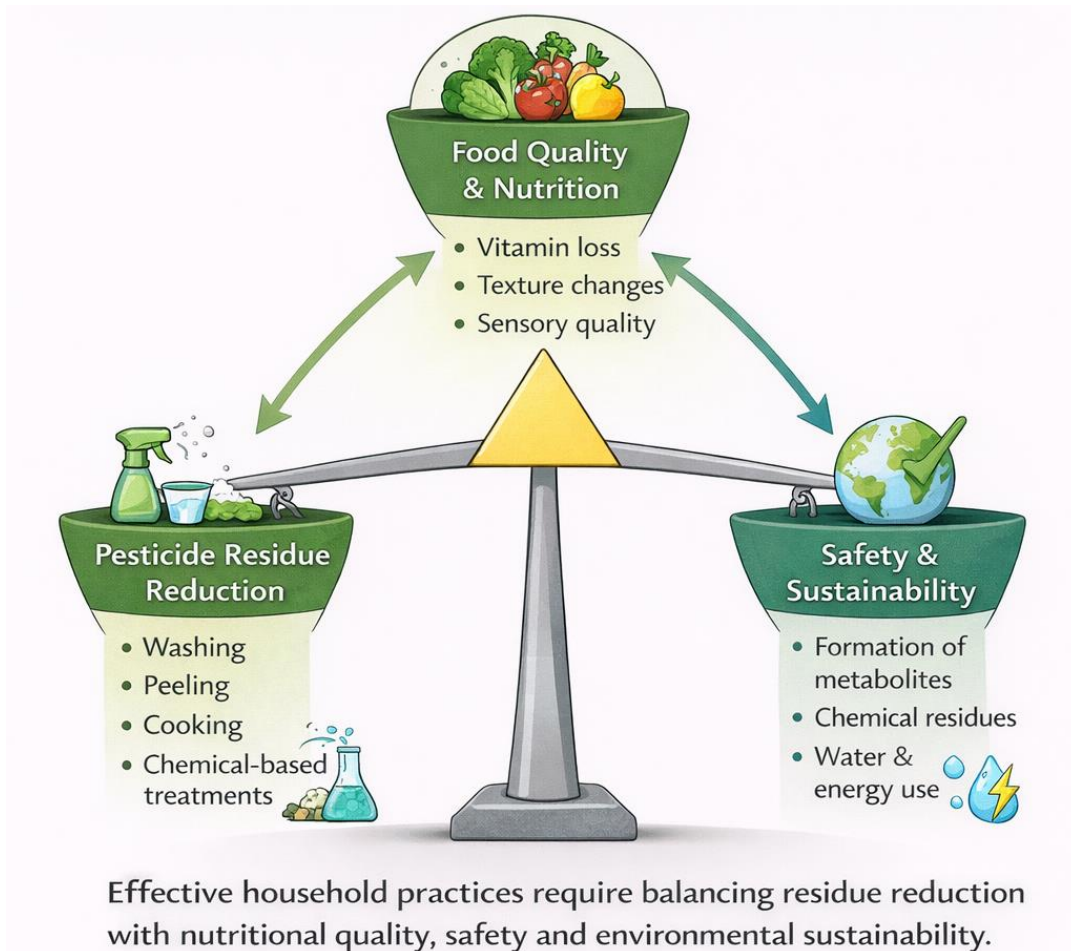


Figure 8.1. Balancing pesticide residue reduction, food quality and safety at the household level. Source: Generated with ChatGPT (DALL•E) and modified by the author using Microsoft PowerPoint (2026)

Transformation of pesticides into metabolites is particularly relevant for compounds known to degrade into other biologically active substances. A well-documented example is thiophanate-methyl, which can convert into carbendazim. In a study examining household-style tomato processing, Liu et al. tracked both thiophanate-methyl and carbendazim through washing, peeling and heat treatment. Their results demonstrated that household processing affected the distribution and levels of both the parent pesticide and its metabolite, underlining the importance of considering residue profiles rather than single compounds alone [62].

The formation of transformation products may also occur during the use of strong oxidizing treatments. Reviews of ozone-based residue reduction methods indicate that while oxidation can effectively degrade pesticides, it may also induce chemical changes whose outcomes depend strongly on treatment conditions such as dose, exposure time and food matrix. These studies emphasize that oxidizing treatments require careful control, as excessive or poorly managed conditions may lead to unpredictable transformations rather than simple residue removal [50].

From a consumer perspective, the potential formation of metabolites does not imply that household processing is unsafe, but it reinforces the need for realistic and proportionate practices. Simple methods that rely primarily on physical removal, such as thorough washing under running water, peeling when appropriate and discarding cooking water after boiling, are generally associated with fewer uncertainties related to chemical transformation. Consequently, household pesticide reduction strategies should prioritize effectiveness while avoiding unnecessarily aggressive treatments that may increase the likelihood of unintended chemical changes [3].

8.2. Nutrient Loss vs Residue Reduction

Household steps that help reduce pesticide residues can sometimes also reduce the nutritional value of fruits and vegetables, so it is important to balance both goals. In general, washing under clean running water is a low-risk approach: it can lower surface residues while having minimal impact on nutrients inside the food, because most vitamins, minerals and fibre are not removed simply by brief rinsing [3]. By contrast, practices that remove or strongly affect the outer layers—such as peeling, prolonged soaking, or intense heat treatments—may offer greater residue reduction for some pesticide–produce combinations but can also lead to nutrient losses [9].

Peeling is a clear example of this trade-off. Many pesticide residues are concentrated on or near the surface, so removing the peel can substantially reduce residues. However, peels also contain valuable dietary components, including fiber and various phytochemicals, and in some fruits and vegetables a meaningful fraction of vitamins and antioxidants can be located close to the skin. For consumers, this means peeling can be a sensible option when residue concerns are high or when preparing food for sensitive groups, but it should not be used automatically for all produce—especially when thorough washing and trimming may be sufficient [3, 9].

Thermal processing (blanching, boiling, and cooking) can further reduce residues through leaching into cooking water and partial breakdown of heat-sensitive pesticides, but it may also decrease certain nutrients. Water-soluble and heat-sensitive nutrients—particularly vitamin C and some B vitamins—are among the most vulnerable during heating and boiling because they can degrade and/or leach into water [21, 63]. At the same time, nutrient changes are not uniform: the extent of loss depends on the food type, cooking method, and duration. Studies examining blanching and freezing of vegetables show that nutrient and bioactive compound changes can be highly vegetable-specific, with some compounds relatively stable and others more sensitive to processing conditions [53].

For practical household decision-making, the key message is “use the mildest effective method.” Start with thorough washing and only add stronger steps (peeling, cooking) when they fit the food and the situation. When boiling is used, keeping cooking times reasonable and avoiding unnecessary soaking can help limit nutrient losses; discarding cooking water may reduce pesticide exposure but can also remove leached nutrients, so the choice should reflect the meal purpose and the consumer’s priorities [9, 64]. Overall, the best household strategy is not the most aggressive one, but the one that achieves meaningful residue reduction while preserving food quality and nutrition as much as possible.

8.3. Towards Environmentally Friendly and Safe Household Practices

In addition to effectiveness, household practices aimed at reducing pesticide residues should also be evaluated in terms of environmental impact and consumer safety. Many commonly recommended residue reduction methods—such as washing, peeling, and cooking—are simple, low-cost and rely primarily on physical removal processes. These approaches generally pose

minimal risks to consumers and the environment when used appropriately, making them suitable as first-line household practices [3, 9].

In contrast, the use of chemical-based treatments at the household level may raise concerns related to sustainability and safety. Excessive use of detergents, strong acids, or oxidizing agents can lead to unnecessary chemical discharge into wastewater and may introduce residues of cleaning agents onto food if rinsing is inadequate. Reviews emphasize that many of these treatments offer only modest improvements over water alone, while increasing the risk of misuse or over-application, particularly in non-professional settings [3, 9].

From an environmental perspective, water use and waste generation should also be considered. Prolonged soaking or repeated washing steps increase water consumption without always providing proportional benefits in residue reduction. Similarly, aggressive processing methods that require high energy input or generate contaminated wastewater may conflict with sustainability goals. Studies reviewing household and small-scale processing consistently recommend prioritizing efficient, targeted practices that minimize resource use while achieving acceptable reductions in residues [5].

Promoting environmentally friendly and safe household practices ultimately depends on consumer awareness and informed decision-making. Rather than encouraging complex or chemical-intensive treatments, public guidance should emphasize practical strategies such as washing under running water, peeling when appropriate, and cooking according to customary dietary habits. By understanding the strengths and limitations of different methods, consumers can make choices that protect food safety while also supporting environmental sustainability and long-term public health [3, 64]. Overall, Figure 8.1 highlights the importance of a balanced approach, in which household practices aim to reduce pesticide residues while preserving nutritional quality and minimizing safety and environmental risks.

9. Conclusions and Recommendations

Household practices can play a meaningful role in reducing pesticide residues on fruits and vegetables when applied correctly and with realistic expectations. As demonstrated throughout this digital textbook, no single household method provides complete or universal residue removal. Instead, the effectiveness of residue reduction depends on multiple factors, including the

type of food, the pesticide involved, and the specific preparation method used. Understanding these interactions is essential for making informed and safe household decisions.

Simple practices based on physical removal, such as washing under running water, trimming outer parts, peeling when appropriate, and discarding cooking water after boiling, consistently emerge as the most reliable and low-risk strategies. These methods can significantly reduce surface residues while minimizing unintended consequences related to chemical transformation, nutrient loss or environmental burden. More aggressive approaches, including prolonged soaking, chemical-based solutions or oxidizing agents, may offer additional reduction in specific situations but also introduce greater uncertainty and potential risks if misused.

An important theme highlighted in this guide is the need to balance pesticide residue reduction with food quality and nutritional value. Excessive processing can reduce beneficial nutrients and negatively affect texture, flavor and overall acceptability. Therefore, the goal of household preparation should not be to maximize residue removal at all costs, but to apply the mildest effective method that aligns with the type of produce and its intended use. This balanced approach supports both food safety and healthy dietary practices.

From a sustainability perspective, environmentally responsible household practices should be prioritized. Methods that require minimal water, energy and chemical inputs are generally preferable, as they reduce environmental impact while still providing meaningful residue reduction. Promoting simple, resource-efficient practices also supports long-term sustainability goals and reduces unnecessary chemical discharge into wastewater systems.

Ultimately, consumer awareness and education are central to improving household food safety. By understanding what household methods can and cannot achieve, consumers can avoid unrealistic expectations and unnecessary risks. Clear guidance that emphasizes practical, evidence-based strategies empowers households to make informed choices that protect health, preserve nutritional quality and support environmental sustainability. In this way, household practices become not only a tool for reducing pesticide exposure, but also part of a broader approach to safe, sustainable and responsible food preparation.

10. References

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