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REVIEW ARTICLE

The Role of Nutrition and Functional Foods in Pre-Diabetes Management: A Comprehensive Review

Reema Goyal[1*], Sukriti Singh[2], Rekha Kaushik[3] Shiv Kumar[3]
[1-3*] Department of Food Science and Technology,
MMICT & BM (HM), MM(DU), Mullana, Ambala Haryana, India
*Corresponding Author

ABSTRACT
Pre-diabetes is a condition where blood glucose levels are higher than normal but not high enough to be classified as type 2 diabetes (T2DM). It often lacks severe symptoms but signifies a disturbed metabolic state, including insulin resistance, and increases the risk for cardiovascular diseases (CVD) and other comorbidities. With urbanization, sedentary lifestyles, and poor dietary habits, pre-diabetes is becoming a global health concern. In 2021, an estimated 541 million adults worldwide had pre-diabetes, with projections reaching 730 million by 2045. The prevalence is rising, particularly in urban areas of India, such as Delhi and Mumbai. Lifestyle changes, including dietary modifications, are critical for managing pre-diabetes. This review explores the potential of functional foods, specifically seeds like flax, cumin, carom (ajwain), and fenugreek (methi), which contain nutrients like omega-3 fatty acids, fiber, and antioxidants. These seeds have been shown to improve insulin sensitivity, regulate blood glucose, and reduce inflammation. As functional foods are affordable and accessible, they offer a viable alternative to pharmaceutical treatments, especially in low- and middle-income countries. Further research is needed to assess the real-life applicability of these interventions.
Keywords: *Pre-diabetes, insulin resistance, functional foods, flaxseed, cumin, fenugreek, glycemic control.*

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INTRODUCTION

Pre-diabetes can also be called impaired glucose tolerance or IFG, which separates normal glucose control and T2DM. Pre-diabetes is a condition that is characterized by high blood sugar results that are not high enough for the diagnosis of diabetes, which usually has no initial symptoms thus making it hard to diagnose one without a blood test [81]. Even though it does not exhibit definite signs, pre-diabetes is a severe condition that requires intervention because it represents a disorder in glucose homeostasis that suggests I.R and T2DM if not treated properly. The condition not only leads to the development of diabetes but is also a risk factor for CVD and other chronic conditions; it is therefore a public health concern [8].

The global rate of pre-diabetes has increased over the last few decades mainly because of the change in the life style, urbanization and diet. The IDF Diabetes Atlas (2021) approximated the number of adults with pre-diabetes in 2021 to be 541 million and projected it to climb to 730 million by 2045. This increasing tendency shows the severity of the situation and increased attention regarding the issue of pre-diabetes and the development of the preventive measures [50]. Such changes have played a role in the rise of pre-diabetes including increased rates in urbanization, transition to lifestyle that requires very little physical exertion and poor nutrition characterized by high consumption of processed foods, foods high in refined sugars and unhealthy fats [18]. For instance, the urban dwellers are almost five times likely to develop pre-diabetes and therefore T2DM due to westernaning diets and perceived healthy lifestyles [10].

India being amongst the developing country with a high and increasing population and rate of urbanization, it is not a surprise that pre-diabetes incidence is on the rise as well. Prevalence of pre-diabetes is also estimated to stand at 14% of the population of India and it has been identified that Delhi

and Mumbai have the highest rate of cases. This statistic is additionally worsened by inequitable distribution of health care, heightening the need to address culturally appropriate and effective dietary intervention for pre-diabetes populace [61, 75]. Continuing increase in the burden of pre-diabetic individuals in India and other development countries makes it imperative to consider affordable and sustainable interventions in preventing or controlling the progression of diabetes.

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The global rate of pre-diabetes has increased over the last few decades mainly because of the change in the life style, urbanization and diet. The IDF Diabetes Atlas (2021) approximated the number of adults with pre-diabetes in 2021 to be 541 million and projected it to climb to 730 million by 2045. This increasing tendency shows the severity of the situation and increased attention regarding the issue of pre-diabetes and the development of the preventive measures [50]. Such changes have played a role in the rise of pre-diabetes including increased rates in urbanization, transition to lifestyle that requires very little physical exertion and poor nutrition characterized by high consumption of processed foods, foods high in refined sugars and unhealthy fats. For instance, the urban dwellers are almost five times likely to develop pre-diabetes and therefore T2DM due to westernaning diets and perceived healthy lifestyles [10]. India being amongst the developing country with a high and increasing population and rate of urbanization, it is not a surprise that pre-diabetes incidence is on the rise as well. Prevalence of pre-diabetes is also estimated to stand at 14% of the population of India and it has been identified that Delhi and Mumbai have the highest rate of cases. This statistic is additionally worsened by inequitable distribution of health care, heightening the need to address culturally appropriate and effective dietary intervention for pre-diabetes populace [61, 75]. Continuing increase in the burden of pre-diabetic individuals in India and other development countries makes it imperative to consider affordable and sustainable interventions in preventing or controlling the progression of diabetes.

In this paper, the importance of take functional foods, mainly seeds, by persons with pre-diabetes lies in the natural, economical, and environmentally friendly solution. Compared to pharmaceuticals that may take its toll on the body and pocket and also may not be easily accessible especially in the low income and middle-income countries, the functional foods are more advisable for them in managing the pre-diabetes [68, 79]. Furthermore, most of these seeds are available locally and can easily be included in the everyday diet, making it logical to recommend foods with such seeds in any population, which is likely to have the danger of developing pre-diabetes. Nevertheless, systematic and long-term studies of functional foods for managing pre-diabetes poorly since experimental studies demonstrated the potential use of functional foods among such population [21]. Previous research works done are mostly primarily clinical trials and are short-term; a majority of these studies should be properly controlled, long term human trials on individual kernels and the possibilities of synergistic effects of multiple seeds on prevention of development of pre-diabetes to T2DM [70]. Besides, while there is evidence that functional products can increase metabolism of glucose and reduce inflammation, it is unknown if such foods can act instead of pharmaceuticals or if they can be used as supplement [44, 73].

With renewed interest in the management of pre-diabetes especially among the developing countries like India, and using functional foods as needed in the management of the condition, this study aims at filling this gap. In detail, it will discuss on flaxseed, cumin, carom and fenugreek in pre-diabetes intervention and their possible role on glucose homeostasis, insulin sensitivity and inflammation. These insights of the current review may be useful to healthcare practitioners as well as policymakers to design and implement valid strategies tailored to prevent and address pre-diabetes, their presentation and management.

Aim of the Study

The primary aim of this research is to investigate the nutritional benefits of flaxseed, cumin, carom, and fenugreek seeds in the management of pre-diabetes. Specifically, this study seeks to:

1. Evaluate the impact of these seeds on glycemic control, insulin sensitivity, and inflammatory markers.
2. Assess the potential synergistic effects of incorporating these seeds into daily diets.

3. Provide evidence-based recommendations for incorporating these functional foods into dietary strategies for pre-diabetic individuals.

MATERIAL AND METHODS

This paper is based on an analysis of existing data and studies related to the role of functional foods, particularly flaxseed, cumin, carom (ajwain), and fenugreek, in the management of pre-diabetes. It does not involve original data collection but instead synthesizes information from secondary sources. The analysis was focused on reviewing peer-reviewed literature, including clinical trials, cohort studies, and randomized controlled trials, to assess the effects of these seeds on glycemic control, insulin sensitivity, and inflammation in individuals with pre-diabetes. The methodology employed involved a thorough examination of relevant studies retrieved from databases like PubMed, Google Scholar, and ScienceDirect, published within the last decade. Only human studies that provided detailed intervention protocols and outcome measurements related to blood glucose levels, insulin resistance, and inflammation markers were considered for inclusion. The study aimed to extract data on the effectiveness of seed-based interventions and understand the variations in outcomes due to factors like dosage, seed preparation methods, and study durations. Data analysis in this review involved summarizing the results from the selected studies, focusing on key clinical outcomes such as fasting blood glucose, HbA1c levels, and insulin sensitivity. The findings were presented to identify patterns and effectiveness in managing pre-diabetes, highlighting any discrepancies or gaps in the existing literature. The review did not involve the collection of new data or participant involvement, as it solely relied on the available published studies.

GLOBAL AND NATIONAL BURDEN OF PRE-DIABETES

Global Statistics and Trends:

Pre-diabetes commonly known as diabetic state II or intermediate hyperglycemia is a condition between normal glycemic control and diabetes mellitus Type II. This has become a problem that has extended to various parts of the world, thus pointing towards a serious public health concern. The IDF Diabetes Atlas (2021) estimated that global pre-diabetes prevalence rate was 7.9 % in the year 2021 and with this about 541 million adults globally were with pre-diabetes. This figure is anticipated to rise steadily, where the forecasts reveal that 730 million people will be impacted by the year 2045. The root cause of this has been attributed to the various demographic, life style and dietary changes that have common in the recent past decades [77, 83]. With increase in urbanization, change in nutritional habits and high levels of physical inactivity, the global population of pre-diabetes has been on the rise.

The causes of this surge in the cases of pre- diabetes are as follows: Among the most significant factors, there is the increased level of urbanization on both the developed and developing countries' population [30]. An index diet that is common in Urban settings includes high calorie foods which are low in nutrients and are usually packed with refined sugars, trans fats and processed carbs all of which are prominent contributors to insulin resistance and dysregulation of metabolism [35]. Such kinds of calorie rich diet coupled with little or no activity level due to nature of jobs and social indulgence lay the basic platform for this increasing disease burden of pre- diabetes [10, 45, 65]. Urban dwellers are the most affected owing to a higher propensity to embrace the westernized diet through taking more fast foods and processed foods that affect the glucose metabolism and insulin sensitivity of the body [40].

Besides, the increase in pre-diabetes is influenced by the socioeconomic factors which are so essential to people's lives. Authors stated that low-income consumers could hardly access fresh fruits and whole foods as they opted to consume processed foods, which are rich in calories [46]. Such a change in diet has been associated with an increase in the incidence of obesity, which is one of the most significant and convincing risk factors for the development of pre-diabetes [41]. In addition, there is limited health care access and lack of proper education on prevention of pre-diabetes, especially in LMICs was also found to be responsible for underdiagnosed and undertreated pre-diabetes.

According to the future predictions, the population group with pre-diabetes will increase even more in the future, especially in LMICs, where urbanization and changes in life are progressing rapidly [9]. For example, it is anticipated that china and india two of the largest continent's population will have one of the biggest rise in pre-diabetes population due to their rapidly changing lifestyle by adopting western's diet habits and lifeless working plans [15]. These projections provide indications of an impending public health disaster; it is therefore incumbent upon different levels of governments and other relevant public health institutions to rise up to the challenge of pre-diabetes on a large scale [29].

Factors Influencing the Increase in Pre-Diabetes:

The following are determinants of the increasing global incidence of pre-diabetes. Such factors as change of lifestyle, increased population density, poor diet, and inheritances are other factors [22]. Whereas the

rural people are willingly or otherwise shifted to urban settings, they are exposed to really unfavorable settings that make them adopt unhealthy diets and low physical activity. Unfortunately, the very elements that make living in cities convenient mean that processed foods and drinks including sugary commodities and fast foods are easily accessible thus leading to excessive calorie intake and low-quality diet [27].

These and other factors have also taken root in the modern society where people take a lot of time sitting at workplaces and other areas, thus contributing to the problem of pre-diabetes. This kind of a life has seen a drastic reduction in the physical activity due to enhance screen time, sedentary working and transport relying on cars [34]. Pre-diabetes is characterized by insulin insensitivity, and physical inactivity impairs the body's capacity to control blood glucose as well [56].

These foods include processed foods and those packed with calories and carbohydrates from refined sugars, and unhealthy fats, contribute to the exacerbation of impaired glucose tolerance to full-fledged Type 2 Diabetes [41]. Sucrose is used in a variety of foods like sugary drinks and candy which makes it to pass through the bloodstream quickly thus raising the level of glucose in the body. The body gradually becomes less sensitive to these peaks and this results to insulin resistance. This cycle further exacerbates by poor dietary practice, lack of quality fiber, essential nutrients and micronutrient that are necessary for optimal glucose metabolism [9].

National Statistics and Regional Differences:

In India, pre diabetes has become one of the most troubling health issues experienced by the population. Out of the total population, National Diabetes and Diabetic Retinopathy Survey has shown that 14% of total people in India were suffering from pre-diabetes in 2017, whereas, this ratio is higher in the urban zones like Delhi-Mumbai. This statistic a problem towards health implication as India continues to undergo urbanization and go through the growth of its economy [52]. In urban facilities, there is increased consumption of foods with refined sugars, unhealthy fats and processed foods similar to the western cuisine hence the high prevalence of insulin resistance and pre-diabetes [28].

Though the incident of pre-diabetes is not that high when compared to the studies conducted on urban communities in India, the rural populace is also turning a prey to this disease due to their change in diet and sedentary lifestyle [67]. One of the primary reasons that are leading to this pre-diabetes prevalence is the evolution to refined diets from the traditional diets that were rich in fruits, vegetables, and whole grains. Moreover, there is a limited access to cardiovascular healthcare services and therefore early diagnosing especially in the rural regions [12].

Regarding pre-diabetes, the situation is quite similar in the United States as well. CDC also explains that 88 out of every 100 adults in the United States has pre-diabetes, but only 84 of them do not know it [18]. Such an outlook and the failure to implement the appropriate early intervention approaches explain why pre-diabetes transitions to T2DM [72]. According to Huang (2023) [31] Huang & Kien (2009) [36], pre-diabetes is more common in people with a BMI more than 25, and inhabitants of America who are in this category bear a higher load than the Whites; this is because the load is higher among the African Americans, Hispanic Americans, and Native Americans. The high incidence of pre diabetes is also therefore attributable to the poor eating habits that are prevalent among the populace where people take a lot of calorie, sugar products and fast foods frequently. Additionally, the sedentary nature of many jobs and lifestyles exacerbates the risk of pre-diabetes [43, 69].

It must also be pointed out that there are disparities in the occurrence of the Pre diabetes where there is relative elevation in high density area because they have better access to health facilities and there is always increased awareness of the health check programs around the country. However, such patients from rural areas experience healthcare constraint and inadequate knowledge regarding the disease status which results in a higher chance of evolving into T2DM.

The burden and implications of pre-diabetes both at the international and national level are on the rise and this seems to be attributed by a number of factors; some of these factors include urbanization, poor food choices and physical inactivity as well as disparity in the socio-economic status of the populations. Probability of pre-diabetes is expected to increase in LMCBC as well as in the developed countries including the U.S., it is imperative to respond to this public health problem at global, national, and regional level with a particular emphasis on prevention, screening, and proper management [31]. There is a need to enhance the awareness, nutrition quality, and heath care facilities to have an influence of reducing the severity of pre diabetes.

PATHOPHYSIOLOGY AND MECHANISMS OF PRE-DIABETES

Pre-diabetes is a condition different from the Diabetes, meaning that the levels of glucose in the bloodstream are higher than normal and vary from those that are high as in diabetes. This state, marked pathology by two mechanisms whereby patients progress to Type 2 Diabetes Mellitus (T2DM) – insulin

resistance and beta-cell dysfunction. In this part of the article, the author shall expound on these mechanisms to include how they contribute to the metabolism of glucose, relationship with chronic inflammation, and effects of lifestyle factors such as diet and exercise [5].

Insulin Resistance:

Diabetes mellitus type two is a result of insulin resistance where cells in the human body including muscles, the liver and fat tissues, don't respond to insulin appropriately. Thereby, glucose transport into the cells is inhibited, which leads to increase in blood glucose concentration. In the long run, the pancreas is forced to secrete more insulin so that high glucose concentration is balanced in the bloodstream. As observed in other groups in this study, it is not sufficient enough to conquer insulin resistance to keep normal levels of blood glucose and later develop pre-diabetes, and T2DM [10] [56].

There are various causes of insulin resistance whereby the most important being the visceral fat. The visceral fat is arranged around the organs and tissues and is associated with elevated secretion of cytokines and FFA that enters the liver and impairs insulin signaling. This sort of fat is especially dangerous because it causes a higher level of insulin resistance than subcutaneous fat, known as the fat deposited in the subcutaneous tissue located underneath the skin [41]. Often this fat is stored in the abdomen and is related to obesity which is known to be a determinant of insulin resistance [61]. In patients with pre-diabetes, such high fat levels add onto insulin resistance, as they increase the secretion of enemies of insulin, molecules that make cellular tissues less receptive to this hormone [7].

Dietary factors are also important in the promotion of insulin resistance.The Administration's budget of year two involves the funding of activities and projects that are directly linked to the general objective of the paper, which focuses on the causes of insulin resistance. A review mainly on carbohydrates indicated that the intake of foods with high glycemic index including refined carbohydrates leads to insulin resistance uniquely [12]. Complex carbohydrates include some breads also labeled as 'white', and other foods that have been considered as processed foods such as sugary drinks [19]. These result in insulin demanding the pancreas to produce more insulin so as to stabilize the blood sugar further stressing the insulin producing beta-cells [25]. Such persistent call on the organism to produce insulin will eventually prove too much for its pancreas, thus lead to a decrease in production of insulin and worsening of insulin sensitivity [17].

It is worthy to acknowledge that genetics also have a significant obligation in insulin resistance as well. Contrary to this, several studies conducted in different years have established that genetic predispositions to diabetes in the family makes a person more vulnerable to insulin resistance and pre-diabetes [15]. Some types of inherited traits could damage insulin receptors or change metabolism of glucose in cells such that it becomes very hard to manage insulin properly. However, current life styles including sedentary behavior and low intake of fruits and vegetables could intensify these genetic susceptibilities and therefore put one at a higher risk of developing insulin resistance [29].

Beta-Cell Dysfunction and Inflammation:

Dysfunction of endocrine cells, particularly beta-cells of pancreas, is another crucial factor contributing to the development of pre-diabetes. Beta-cells which is one of the types of cells found in the pancreas is responsible for synthesizing insulin when blood glucose concentration rises. Moreover, in the beginning, there is increased production of insulin by the beta-cells in the body in response to this reduced receptiveness [32]. However, over the long run, it becomes difficult for the pancreas to compensate for the problem with an increase in the production of insulin. Due to the constant production of insulin, beta-cells will tend to be stressed and impaired to the extent of being depleted [76]. It leads to pre-diabetes to T2DM since the pancreas cannot secrete a sufficient amount of insulin to regulate glucose in the bloodstream.

There are strong relations with chronic low-grade inflammation pathology and beta-cell dysfunction in patients with PRI. It explained that in individuals with insulin resistance the visceral fat and the free fatty acids are released which induce inflammation. Such pathways produce cytokines such as TNF-α (tumor necrosis factor-alpha) and interleukins that impair insulin signaling and toxicity to beta-cells [38]. Apart from this, oxidative stress, which is resulting from production of free radicals in the body beyond their neutralization ability, also impacts negatively on beta-cells and worsens the situation of insulin resistance [56].

Pre-diabetes state cannot be considered to be harmless as oxidative stress plays a crucial role in the development of further complications. ROS may have toxic effects on the pancreatic beta-cells hence reducing their efficiency when it comes to insulin secretion in response to high glucose levels. ACCORDINGLY, this damage results into irreversible beta-cell dysfunction, which characterizes T2DM [33, 82]. These cytokines also causatively play a role in this strategy by interfering with insulin signaling

pathways and enhancing the development of a pro-inflammatory state, which further worsens the actual mitochondrial derangement in T2DM and pre-diabetic populations.

Furthermore, it was also found that beta-cell dysfunction and inflammation are interrelated [51]. This paper argues that not only does insulin resistance lead to inflammation and stress of the beta cells, inflammation also independently contributes to insulin resistance; therefore, inflammation acts in a virtuous cycle that moves from pre-diabetes directly to diabetes [56, 76]

Impact of Lifestyle Factors on Pre-Diabetes:

However, it should be understood that along with genetic and metabolic factors, the lifestyle is the key determinant of pre-diabetes development and progression. Activity, nutrition, and weight loss are some of the aspects that are known to either slow down or aggravate the onset of pre-diabetes [56]. As it has been discussed in the previous section, increased consumption of foods containing refined carbohydrates and unhealthy fats is the root cause of insulin resistance and beta-cell dysfunction [62]. On the other hand, the diet which is considered good and healthy consisting of fiber, healthy fats and lean protein has been found out to have positive effects on the body insulin sensitivity and decrease inflammation as discussed by [6].

Lack of exercise is another important risk factor of insulin resistance and the development of pre-diabetes. Modern day cultures typified by prolonged sitting have been linked to the development of obesity and mainly the visceral sub-type of obesity which further leads to insulin resistance [66]. It also reduces the insulin resistance, promotes muscular uptake of glucose and keeps an individual free from obesity. It has also been revealed that physical activities decrease inflammation and oxidative stress, thus decreasing risk of Beta cell impairment in addition [29, 56].

Lifestyle changes, especially weight loss have been found to be one of the best approaches that can be taken for preventing the development of T2DM from pre- diabetics [71]. Lowering body weight and abdominal obesity is well known to enhance insulin response and correct abnormalities regarding glucose homeostasis. This means that it may require change in diet and working on a number of exercises, both of which are the fundamental principles of managing Type II diabetes, pre-diabetes [13, 24, 4].

The pathophysiology of pre-DM involves insulin resistance, beta-cell dysfunction, inflammation, as well as oxidative stress [74]. Poor diet (eating excessive calories and especially developing abdominal obesity, high consumption of processed carbohydrates), and genetics are major causes of insulin resistance that cause pre-diabetes. Over time, insulin resistance causes increasing stress and impairment of beta-cells, which decreases insulin secretion [78]. They also explained that chronic inflammation aggravates the underlying processes that lead from prediabetes to T2DM [80]. This paper examines these mechanisms and concludes that early intervention and prevention mostly through diet, physical activity, and weight management are essential in tackling pre-diabetes and preventing its transformation into diabetes.

DIETARY INTERVENTIONS AND MANAGEMENT STRATEGIES

Pre-diabetes is characterized as a negligent or borderline diabetes and is treatable by means of life changes and diet. The most effective approaches that are recommended to prevent the transition of non-diabetic hyperglycemia to T2DM include dietary intervention and functional foods that can effectively increase insulin sensitivity and maintain the levels of blood glucose and inflammation [11].

Role of Nutrition in Pre-Diabetes Prevention:

Condition of pre-diabetes is closely link with nutrition and therefore, nutrition has a major factor for the prevention and control of pre-diabetes. Fiber and protein are important macronutrients that are crucial in managing blood sugar and supporting metabolic health in the body. These macronutrients should be consumed in the right proportions so that they aid in regulating glucose levels and insulin in the body.

- **Macronutrient Balance:** Carbohydrate, protein, and fats are among the basic food nutrients that are recommended by nutritionist for anyone with prediabetes. The particular type of fiber referred to as soluble fiber has an impact on glucose control since it slows down the rate at which sugar is absorbed into the blood. Some such eating habits include consumption of grains and beans, fruits and vegetables, which may help in preventing or managing T2DM [64]. Also, proteins play a crucial role in regulating glucose in the blood since it does not have a significant effect on the blood sugar if taken in moderate proportions. Research has shown that adequate intake of protein is useful in supporting the muscles; metabolism; and regulating insulin action [13]. Monounsaturated and polyunsaturated fats, found in olive oil, nuts, seeds, and avocados are beneficial for metabolism and weight regulation, which is a key factor that is considered in pre diabetes diagnosis [29].
- **Low Glycemic Index Foods:** A glycemic index is a measure of the extent to which a particular food raises the blood sugar level: low GI foods have a slow effect on blood glucose level than high-

GI foods; thus, they can be recommended as a part of the pre-diabetic diet. The GI ranks how fast foods containing carbohydrates spike the blood glucose level. On the other hand, low glycaemic index foods are mostly composed of nutritious foods such as whole grains, legumes, non-starchy vegetables and certain fruits that release glucose gradually into the blood circulation system. If low-GI foods are incorporated into the diet, the blood glucose level of people with pre-diabetes will be regulated, consequently avoiding the development of T2DM [17]. On the other hand, low GI foods like refined white bread, sugary soft drinks and snacks raise the blood sugar level quickly and worsen pre-diabetic emerged-condition [10].

- **Effectiveness of Lifestyle Changes:** The modification of life style such as diet, exercise and weight loss has been identified to be of great impact in preventing the conversion of pre-diabetes to T2DM [39]. It has been found out that the benefits of adopting Mediterranean, DASH or plant-based diets include improved insulin sensitivity and reduction in blood glucose levels [42]. The amount and type of food also: the Mediterranean diet with their fats from olive oil, nuts and seeds, whole grains, vegetables and lean proteins is recommended for improvement of metabolic profile and decrease of type 2 diabetes in people [6]. The same way, the DASH diet that consists of high consumption of fruits, vegetables, whole grains and lean protein, low intake of saturated fats and sugars is regarded useful in reducing BP levels and blood glucose among the pre-diabetes subjects [20]. Other dietary approaches such as plant based diet have also been advocated for use in managing pre-diabetes due to their positive effects on insulin sensitivity and inflammation [36].

Focus on Functional Foods:

Functional foods are defined as the foods that can be consumed to contribute to the specific health purposes apart from their nutritional value. It has some beneficial substances which include vitamins, complex carbohydrates, antioxidants and healthy fats that can have an overall effect in enhancing one's health, particularly for those having clinical afflictions including pre-diabetes. Amongst these functional foods, few have been evaluated for their therapeutic value in managing diabetes, overweight and obesity and inflammation and include seeds such as flaxseed, cumin, carom seed (ajwain) and fenugreek seeds [37, 50].

- **Flaxseed (Alsi):** Flaxseed is one of the most effective functional foods that can be recommended for consumption in case of pre-diabetes. Beneficial to humans in its omega 3 fatty acid content, fiber, and lignan levels, flaxseed is effective in enhancing insulin index and regulating blood glucose content [47]. The above research shows that flaxseed has beneficial effects on fasting blood glucose level, insulin sensitivity, and lipid profiles in persons without diabetes mellitus. In the light of these metabolic effects of flaxseed, high soluble fiber content facilitates the delay of glucose absorption to minimize a high surge of blood glucose [16]. Also, lignans present in flaxseed possess antioxidant properties that assist in tackling oxidative stress and that is without forgetting the fact that stress leads to the development of insulin Resistance and inflammation [15, 48].
- **Cumin (Zeera):** There are so many health benefits that have been ascertained about cumin, a spice common in most recipes for culinary purposes and of prime importance to the digestion process being the enhancement in glucose metabolism. Volatile oils, flavonoids, and alkaloids are present in cumin that possesses antioxidant activity [24]. Some previous researches shows that the supplementation of cumin helps to decrease the oxidative stress, has a positive impact on insulin sensitivity and lipid metabolism rate which are critical for effective blood glucose management in people with pre-diabetes [64]. This review highlights that cumin has the potential of increasing insulin secretion and sensitivity and thus should be incorporated into diabetes functional food particularly with other complementary dietary changes [3].
- **Carom (Ajwain):** Carom seeds which are also famously known as ajwain are well known to have such health benefits [20]. Ajwain is also known to possess qualities that help in reducing the inflammation of the intestine and hence, helpful for one suffering from pre-diabetic condition. The elements present in ajwain including thymol and flavonoids promotes digestion, increases nutrient absorption rate, lowers blood sugar level [57]. Ajwain prevents the symptoms of chronic inflammation which plays an important role for progression of pre- diabetes as per the study made [70]. Carom seeds can be also consumed in herbal teas and herbal supplements, which makes it easy for individuals to increase their consumption of carom seeds in the diet to avoid the development of diabetes.
- **Fenugreek (Methi):** Fenugreek is another functional food that has been known to help in the management of pre-diabetes. The seeds of the fenugreek have soluble fiber, and also contain

saponins that help regulate the blood glucose level because reduces the rate at which glucose is absorbed and also enhances the function of insulin [64]. There are clinical trials showing that fenugreek can decrease fasting blood glucose concentration, increase insulin sensitivity and decrease HbA1c which is used to assess the overall mean blood glucose concentration in people with diabetes [22]. With such features; interacting with blood glucose levels, antioxidants and anti-inflammation, fenugreek supplement can be recommended for the people with pre-diabetic symptoms [11].

Consumption of these functional foods can be readily adopted as a nutritional intervention for pre-diabetes by following them in addition to the individual's normal diet. Due to the fact that flax seed, cumin, carom and fenugreek have complementary actions on glucose and inflammatory metabolism pathways, the synergistic effects of these spices on metabolic health are postulated. That is why those seeds are accessible, cheap and can be integrated in many dishes, and therefore appropriate for pre-diabetes people especially in developing countries [49].

Pre and post-diabetes can be managed efficiently with dietary approach and weight management strategies besides functional food. Minerals, fats, and protein determine the ability of the body to control blood sugar and enhance the body's efficiency to utilize insulin. Moreover, one cannot forget the fact that low glycemic index foods like the whole grain and vegetables should also be included in the diet so as to reduce undue stress on the blood sugar levels. Some of the functional foods such as flaxseed, cumin, carom and fenugreek have also proven useful in the management of pre-diabetes mainly because of their blood glucose regulating, anti-inflammatory and metabolic functions. Thus, the integration of these functional foods in diet could be a more economical and feasible approach to manage this increasing epidemic of pre-diabetes and progress it to T2DM.

CLINICAL EVIDENCE ON FUNCTIONAL FOODS FOR PRE-DIABETES MANAGEMENT

Thus, functional foods are becoming a point of interest in the treatment of PIE due to their potential to deliver other than nutritional value benefits. All these foods have qualities that are disease-fighting which include being effective in managing blood glucose levels, increasing the sensitivity of insulin, and preventing inflammation [58, 60]. The anti-diabetic functional foods extensively researched in new pre-diabetes management are flaxseed, cumin, carom or Ajwain, fenugreek.

Flaxseed (Alsi):

Flaxseed has received considerable attention in regard to healthy nourishment to control pre-diabetes outcome mainly because of omega-3 fatty acids and high fiber, and lignans. Such compounds are effective in improving insulin sensitivity as well as glycaemia regulation.

- **Omega-3 Fatty Acids:** Flaxseed is an excellent source of omega-3 fatty acid position especially the alpha-linolenic acids and it was revealed that may have an anti-inflammatory and insulin sensitizing properties [53]. Another beneficial effect of Omega-3 fatty acids is that the substance has been found to decrease inflammation levels that is common in pre-diabetes and insulin resistance. Afrooz Javidi et al. (2016) [2] showed that flaxseed oil positively influenced insulin sensitivity and lowering fasting blood glucose in the pre-diabetic patients.
- **Fiber Content:** A study has found that, flax seed soluble fiber delays the rate of glucose uptake in the bloodstream hence stabilizing blood sugar levels [49]. Also, the consumption of fiber results to weight loss through controlling hunger thus can be very useful to people with pre-diabetes. Research shows that flax seed intervention lowers the postprandial glucose levels and ameliorates glycemic profile [25].
- **Lignans:** Flaxseed phytoestrogens called lignans regulate oxidative stress, which is one of the causes of insulin resistance and inflammation. These bioactive components produce oranges make flax seed a suitable functional food in preventing pre-diabetes and promoting non development to T2DM [15, 63].

Cumin (Zeera):

Cumin is a spice commonly used in cuisines globally and has been documented to have medicinal values in the traditional medication usage. Various studies conducted in the past years have revealed that cumin is an antioxidant and thereby it may benefit pre-diabetes subjects in a way that how lipid profile and glucose levels are managed.

- **Antioxidant Properties:** This spice is also rich in such compounds as terpenoids, flavonoids and alkaloids which have antioxidant values [13]. These antioxidants assist neutralize toxins that trigger or exacerbate oxidative stress and inflammation in prediabetes [18]. It has been concluded in several investigations that cumin supplementation affects oxidative stress and insulin resistance [55, 64].

- **Lipid Metabolism and Glucose Homeostasis:** According to Brand-Miller at al., 2003 [17] cumin lowered the total cholesterol, triglycerides and the LDL cholesterol but increased the HDL cholesterol. They lead to improved cardiovascular health, which plays a vital role on individuals with pre-diabetes since Statistics show that most pre-diabetic patients face a huge potential of getting cardiovascular diseases [3]. In the same vain, cumin has regulation effects on glucose homeostasis through stimulation of insulin release and increased sensitivity to insulin, [6, 54].
- **Clinical Evidence:** Studied conducted on different clinical trials have revealed that cumin has the ability to reduce the blood glucose level and also improve insulin sensitivity of patients with pre-diabetes [26]. Another research was conducted to determine the effect of cumin powder supplement to high-fat diet on fasting blood glucose and insulin resistance in prediabetes; the study recorder a decrease in both factors [66]. Such findings could open avenues in the direction of considering cumin as an additional component to the therapeutic plan when dealing with pre-diabetes [29].

Carom (Ajwain):

Carom seeds that are also referred to as ajwain have been used in the traditional medicine practice because of their properties that help in digestion and reduction of inflammation. There has been a shift of interest towards its use in enhancing gut health and managing glucose homeostasis; therefore, they can be considered as functional foods for those with pre-diabetes.

- **Gut Health and Digestion:** Carom seeds are known to enhance the functionality of the digestive system, which may pose as a problem to the pre-diabetes patient. Ajwain comprises thymol and flavond which acts as stomachic that help in stimulation of secretion of digestive enzymes that in return aids digestion ans assimilation of nutrients [69]. Enhanced digestion is useful in regulating fluctuations of blood sugar by assuring that the nutrients you consume are effectively utilized in the body instead of being stored and converted to glucose.
- **Anti-inflammatory Effects:** The low-grade inflammation remains chronic in pre-diabetic individuals and plays a huge role in worsening the process of insulin resistance. Ajwain has been known to possess good anti-inflammatory attributes in treatment based on the bioactive compounds. Research has established that ajwain has great potential to lower the CRP level which is widely used to predict cases of insulin resistance [24]. In essence, since ajwain has properties that counteracts inflammation, which is one of the main pre-diabetes promoters as noted in the AJE article by Bhardwaj, Verma, Trivedi, & Bhardwaj (2015) [15], it is useful in managing the condition.
- **Regulation of Blood Glucose:** Some of the indexes are that according to the preliminary studies ajwain has the ability to modulate blood glycemia metabolism [30]. There was one study were taking ajwain enhanced glucose tolerance and insulin level among participants with pre-diabetic disorders in clinical trials [69]. Taking into consideration the positive effects of compounds in ajwain on blood glucose control outlined in this research, one can conclude that ajwain may be a natural, dietary solution for pre-diabetics [4].

Fenugreek (Methi):

Methi is an aromatic herb that is widely used in all arenas – culinary as well as medicinal ones. It becomes as a source of soluble fiber and also contains saponins that have been proven to work positively on blood glucose and insulin.

- **Soluble Fiber:** The soluble fibers which is present in fenugreek seeds become viscous in nature once they come in contact with water in the intestine and this hinders the rate of diffusion of glucose from the intestine to the blood stream. This leads to better glycemic control and reduce sharp increase in blood glucose after consuming food [27]. Some clinical investigations have established that fenugreek has the ability to reduce the fasting blood glucose and postprandial blood glucose levels [22].
- **Saponins:** Another compound that is present in the fenugreek includes saponin which has been proved to enhance the functionality of insulin receptor hence increasing the insulin sensitivity. They also act as free radical scavengers, reduce cholesterol level and metabolism; features that are useful for people with pre-diabetes, given their elevated tendency to cardiovascular diseases [61]. This shows that incorporation of fiber together with saponins makes fenugreek to be one of the rich functional foods for control of blood glucose and improving the metabolic health [1].
- **Clinical Evidence:** In this context, multiple clinical studies about fenugreek have been presented and all of them pointed out that this plant is very useful in regulating blood sugar levels. A work that appeared in the Journal of Diabetes & Metabolic Disorders established that the use of

fenugreek positively affected the insulin function, and also decreases the level of HbA1c for people with pre-diabetes [23]. In another study, it was observed that taking fenugreek could reduce the blood glucose concentrations and enhance the receptor sensitivity to insulin therefore can be used to manage pre-diabetes [42, 59].

In regards to the pre-diabetes management, the evidence derived from the clinical trials using functional foods such as flaxseed, cumin, carom, and fenugreek are rather encouraging. Es otros alimentos metabolizados que al contener bioactivos no sólo facilitan el control de la glucemia, sino que inhiben la inflamación y mejora la sensibilidad a la insulina [6]. Due to their inherent characteristics, the functional foods provide a natural and cost-effective approach to diets in a bid to managing pre-diabetes especially in areas where individuals have no access to drugs. As a result, more additional studies should be performed, mainly of an observational nature and for an extended period, to explain the efficiency of these foods in stabilizing pre-diabetes and halting its further development into type 2 Diabetes Mellitus.

CONCLUSION

This paper brings focus on the increasing trends of Pre-diabetes globally and focuses more on the benefits of diet intervention as well as the functional foods for the same. Undiagnosed and mostly latent, pre-diabetic condition is an essential predictor for T2DM, and it exerts a considerable impact on public health. Even though the development of pre-diabetes varies greatly from one country to another, the issue of pre-diabetes is alarming due to the fact that the population is getting more urbanized, and people leading a sitting culture. Pre-diabetes often needs intervention and diet change is fundamental in the management of the condition to avoid the development of T2DM. Nutraceutical seeds functional foods including flaxseed, cumin, carom, and fenugreek, available in the market are highly beneficial as they contain bio-active compounds that help in improving insulin sensitivity, managing blood glucose levels and has anti-inflammatory properties. These foods are pure, meaning that more research is needed, especially concerning the long-term outcome of a diet's implementation and its applicability in daily practice. Consumption of these foods in the dietary interventions makes them inexpensive and easy o implement especially in the disadvantaged places. It is suggested that public health interventions should aim at improving the awareness, availability and durability of interventions for pre-Diabetes in order to provide support to the increasing population that is at risk of developing the disease.

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