Review Article

Potential Health Benefits and Problems Associated with Phytochemicals in Food Legumes

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Abstract: Phytochemicals are a naturally occurring group of chemicals in plants and plant-derived foods. Presence of phytochemical components such as phytohemagglutinins, tannins, phytic acid, saponins, protease inhibitors, oligosaccharides and phytoestrogens in food legumes has both health benefits and adverse effects. These have been associated with numerous health benefits, including reduced cardiovascular and renal disease risks, health care treatments including anti-aging, enhancement of brain function, lower glycemic index for persons with diabetes, increased satiation and cancer prevention. Health benefits resulting from ingestion of oligosaccharides which have been developed in the past few years to use as physiologically functional foods consist of proliferation of bifidobacteria and reduction of detrimental bacteria, diminution of toxic metabolites, anti-cancer effect and protection of liver function. These biologically active compounds in food legumes also have immense potential in biomedical application. On the other hand, phytochemicals have adverse effects as they limit the digestibility of proteins and carbohydrates or reduce the bioavailability of certain nutrients, interfere with normal growth, reproduction and flatulence production. Moreover, phytoestrogens have been linked with infertility problems. The synergistic or antagonistic effects of mixtures of these phytochemicals from food legumes, their interaction with other components of the diet and the mechanism of their action have remained a challenge with regard to understanding the role of phytochemicals in health and diseases. Current researches in phytochemicals are exploring various potentials and utilization in foods and drugs which could be used as front-line defences against numerous life threatening diseases including HIV/AIDS. Because of the potential health benefits of phytochemicals in food legumes, it is probably inappropriate to refer to these substances as natural toxins. The time has come for us to re-evaluate their presence in our diet. Their mitigating effects and the mechanism of their action need to be further addressed if we are to understand the role of phytochemicals in health and diseases.

Keywords: Adverse Effects; Food Legumes; Health Benefits; Phytochemicals; Natural Toxins

1. Introduction

Food legumes are major sources of dietary protein in the East and Great Lakes Region of Africa where legume utilization in traditional dishes is enormous. Food legumes synthesize several chemical substances termed as phytochemicals. Phytochemicals are a naturally occurring group of chemicals in plants and plant-derived foods. Many phytochemicals function as crucial components in the natural defence system of their host plants, defending against infections and microbial invasions. Other phytochemicals give plants their flavours, aromas and pigments (Lee *et al*., 2000a). These phytochemicals from food legumes such as raffinose family sugars, phytohemagglutinins (lectins), phytic acid (phytate), phenolic compounds, saponins, trypsin inhibitors and phytoestrogens are attracting considerable interest as a result of their diverse properties, both deleterious and beneficial (Ali and Muzquiz, 1998; Lila and Raskin, 2005).

Phytochemicals may provide health benefits which prevent or delay the onset or continuation of chronic diseases in humans and animals beyond the nutrients they contain (Guhr and LaChance, 1997; Hasler, 1998). The healing power of foods is a popular concept that focuses on how legume source foods can have health-protecting properties. Most of the phytochemicals are characterized by anti-oxidant properties (Geil and Anderson, 1994; Arkadiusz *et al.,* 2002). Animal foods contain a similar group of disease-preventing nutrients-the term zoochemical has been suggested for them.

Phytochemicals and zoochemicals-unlike carbohydrates, fats, proteins, vitamins and minerals-are not considered essential for life and have therefore been assigned quasi-nutrient status (Frias *et al*., 2000). Several disease-preventive benefits have been proposed for phytochemicals and zoochemicals. Research shows individual nutrients can facilitate cell-to-cell communication (Kelly, 1999), modify cellular receptor uptake of hormones (Potter, 1995) , convert to vitamin A (Shils *et al.,* 1994), repair DNA damage from toxic exposure (Jenkinson *et al.,* 1999), detoxify carcinogens through the activation of the cytochrome P450, and Phase II liver enzyme systems (Persky and Van Horn, 1995), serve as anti-oxidants to help prevent various forms of cancer (Steinmetz and Potter, 1996), cause apoptosis (cell death) in cancer cells (Mo and Elson, 1999), enhance immune response (Zhang *et al.,* 1997) and help to prevent cardiovascular disease (Gaziano *et al.,* 1995), osteoporosis (Head, 1999), muscular degeneration and cataracts (Seddon *et al.,* 1994).

Additionally, phytochemicals from food legumes carry out a variety of functions, acting as anti-oxidants, protective (immune-boosting), therapeutic effects, anti-aging and other health-promoting properties of active compounds (Mary and Ilya, 2005). With the shift towards a more plant-based diet, food legumes will be potent tools

ISSN 1992-0407

in the treatment and prevention of chronic diseases (James *et al.,* 1999).

The physiological effects of different legumes vary significantly. These differences may result from polysaccharide composition, in particular quantity and variety of dietary fibre and starch, protein make-up, and variability in phytochemicals content (Enneking and Wink, 2000). Fenugreek (*Trigonella foenum graecum*) and isolated fenugreek fractions have been shown to act as hypoglycaemic and hypocholesterolaemic agents in both animal and human studies. The unique dietary fiber composition and high saponin content in fenugreek appears to be responsible for these therapeutic properties. Faba beans (*Vicia faba*) have lipid-lowering effects and may also be a good source of anti-oxidants and chemopreventive factors. Mung beans (*Phaseolus aureus, Vigna radiatus*) are thought to be beneficial as an anti-diabetic, low glycaemic index food, rich in anti-oxidants. Evidence suggests that these novel sources of legumes may provide health benefits when included in the daily diet (Zecharia and Aliza, 2002a).

Though the mechanism is not completely clear, the actions of phytochemicals may protect us from a host of diseases (Mary and Ilya, 2005). Some of these beneficial chemicals block various hormone actions and metabolic pathways that are associated with the development of cardiovascular disease and cancer, and other chemicals stimulate protective enzymes. The phytochemicals appear to work alone and in combination, and perhaps in conjunction with vitamins and other nutrients in food, to prevent, halt or lessen disease.

Research is currently very active in exploring the potential of phytochemicals for biomedical applications. Investigators are constantly striving and deciphering the many ways of utilization of phytochemicals (plant chemicals) in foods and drugs which might be used as front-line defences against many life-threatening diseases, including HIV/AIDS, cancer, heart disease (heart attacks), osteoporosis (bone disease), improving brain function, cardiovascular disease and diabetes**.** As scientists continue to identify individual constituents in plants, they are discovering more human health benefits. Several studies have explored the many uses of botanical-derived chemicals-everything from powerful anti-oxidants to potential cancer cures (Asanaka *et al.,* 1988; Kabir *et al.,* 1998; Kabir *et al.,* 2000; Marcia, 2000; Zecharia and Aliza, 2002b). Some of the phytochemicals are already available on the market, such as flava soy capsule for the relief of menopausal symptoms.

Phytochemiclas have always been associated with a number of substances which inhibit specific physiological functions of animals including digestion, enzyme activity, metabolism and absorption of nutrients. These factors negatively affect the nutritive value of beans through direct and indirect reactions (Shimelis and Rakshit, 2005a). They inhibit protein and carbohydrate digestibility, interfere with mineral bio-availability, induce pathological changes in intestine and liver tissues thus affecting metabolism, inhibit a number of enzymes and bind nutrients making them unavailable (Bressani, 1993). They also produce gas and cause much discomfort to individuals who consume beans (Ologhobo and Fetuga, 1984). A number of these phytochemicals are under study for their potential health benefits. Different food processing methods are used for the reduction/removal of these bioactive compounds for consumption (Binyam *et al.*, 1995; Shimelis and Rakshit, 2007).

The review of literature reveals that a considerable amount of work has been generated over the years on the effectiveness of different processing methods to reduce/remove phytochemical compounds using plant breeding, biotechnological techniques, and chemical and physical treatments. However, conclusions are often reached that no one method is superior to another and it is perfectly feasible to achieve removal/reduction of phytochemicals for the benefits of consumers with similar quality using different methods. Lack of threshold levels makes a choice difficult (Shimelis, 2005). Currently, determination of the threshold level is under study using experimental animals (Zecharia and Aliza, 2002a). The threshold levels at which undesirable components may exert adverse effects need to be established.

The aim of this paper is to describe some of the benefits and problems associated with the phytochemicals in food legumes. A number of phytochemicals are present in foods but this paper will describe only a few of those in which health benefits have also been reported.

2. The Adverse Effects

2.1. Phytohaemagglutinins

Phytohaemagglutinins (lectins) are proteins or glycoprotein substances, usually of plant origin, that bind to sugar moieties in cell walls or membranes and thereby change the physiology of the membrane to cause agglutination, mitosis or other biochemical changes in the animal red blood cells (Liener, 1983; Gupta, 1987). Generally, lectins are classified into animal, plant, bacterial, fungal and virus lectins. Legumes' lectins are one of the largest lectin families with more than 70 types have been reported. Lectins are found in most plant foods including those that may be eaten without heat treatment or processing (Nachbar and Oppenheim, 1980). Lectins are specific not only in the sugars that they bind to the cell membranes but also in their toxicity. The lectins from legumes are all toxic when taken orally (Liener, 1989b).

The seeds of many edible legumes have long been known to contain proteins which agglutinate erythrocytes. Some of these phytohaemagglutinins have been suggested to contribute to the poor nutritive quality of raw legumes (Jaffe, 1980). Phytohaemagglutinins are the main toxic components in food legumes, sugar-binding proteins that bind to and agglutinate animal red blood cells. The toxicity of phytohaemagglutinins is characterized by growth depression (inhibition) in experimental animals and diarrhea, nausea, bloating and vomiting in humans (Liener, 1983). Several outbreaks in England after the intake of improperly cooked beans have been related to the presence of lectins in the beans (Noah *et al.,* 1980). Heat processing can reduce the toxicity of lectins as it can be denatured by heat, but low temperature of slow cooking may not be enough to completely eliminate its toxicity (Thompson *et al.,* 1983).

The toxic effects of lectins relate to their binding with the specific receptor sites on the epithelial cell of the intestinal mucosa which then causes lesion, disruption and abnormal development of the microvillae (Liener, 1989b). Consequently, absorption of nutrients is impaired. The intake of raw beans or purified lectins from beans has been shown to decrease the absorption of sugars (Donatucci *et al.,* 1987), amino acids (Kawatra and Bhatia, 1979), lipid, nitrogen and vitamins B_{12} (Dobbins *et al.,* 1986). Lectins can also impair the nutrient absorption by reducing the activity of brush border enzymes, e.g. peptidases, disaccharides, alkaline phosphatase, glutamyl transferase (Rouanet *et al.,* 1988; Liener, 1989a), pancreatic and salivary amylase (Fish and Thompson, 1991). The increased secretion of mucin and the increased weight and number of intestinal mucosal cells in the presence of lectins (Pusztai, 1986) have also been thought to lead to endogenous loss of nitrogen and aggravated toxic effects of lectins with respect to protein utilization. The carbohydrates or proteins, those that are undigested and unabsorbed in the small intestines, reach the colon where they are fermented by the bacterial flora to short-chain fatty-acids and gases. This increased fermentation contributes to some of the gastrointestinal symptoms associated with the intake of raw beans or purified lectins. Bacterial overgrowth or colonization of coliform bacteria in the small intestine has been observed upon feeding raw beans or purified lectins and this has also been suggested to contribute to lectin toxicity (Liener, 1989b). How lectins increase bacterial colonization is unclear but it may be related to the polyvalent nature of lectins; this allows lectins to bind to both the mucosal cells and bacteria at the same time and fix the bacteria close to the intestinal mucosa. The lectin-induced disruption of the intestinal mucosa may allow entrance of the bacteria and their endotoxins to the blood stream and cause a toxic response (Banwell *et al.,* 1985). Lectins, themselves, may also be internalized and cause systemic effects such as increased protein catabolism and breakdown of stored fat and glycogen, and disturbance in mineral metabolism (Pusztai, 1986; Liener, 1989b). No recognizable patterns exist between the chemical and biological properties of the lectins and their taxonomic distribution in the leguminous family (Liener, 1983).

2.2. Saponins

Saponins are widely distributed in many plant species and have complex chemical structures consisting of a variety of tri-terpenoidal or steroidal aglycons and various carbohydrate moieties (Park *et al.*, 2000). They are bitter tasting, foam producing tri-terpene glycosides and serve as natural anti-biotics for plants. Saponins are a diverse group of compounds commonly found in cereals and legumes, e.g. chick peas, soya beans, lentils, peanuts, *Phaseolus* beans and alfalfa sprouts; and in some plants commonly used as flavorings, herbs or spices, e.g. ginseng, fenugreek, sage, thyme and nutmeg (Oakenful and Sidhu, 1990). Saponins are composed of a steroidal or tri-terpene aglycone (sapogenin) linked to one or three saccharide chains of variable size and complexity *via* ester and ether linkages (Price and Fenwick, 1984) (Figure 1). The presence of both polar (sugar) and non-polar (steroid or tri-terpene) groups provide saponins with strong surface-active properties which then are responsible for many of its adverse and beneficial biological effects (Duhan *et al.,* 2001). Saponins in food legumes especially in beans are with varying degree of haemolytic and foam producing activity.

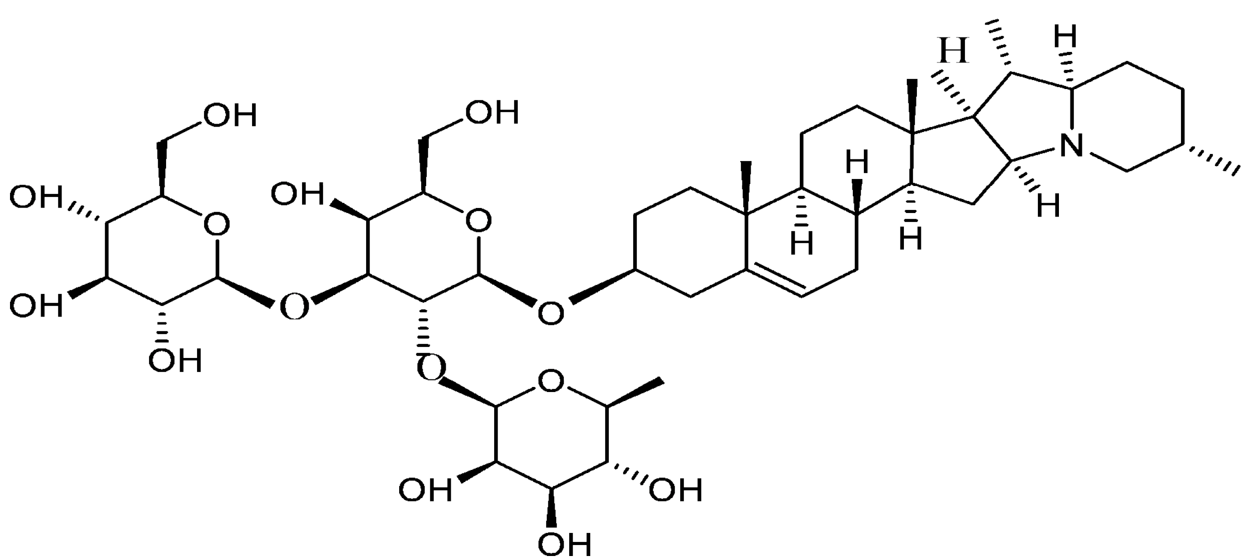

Figure 1. Chemical structure of soyasaponin (Price and Fenwick, 1984)

Among the better-known biological toxic effects of saponins is their capacity to cause lysis of erythrocytes (Kahlil and El-Adawy, 1994), this, in general, being due to its interaction with the cholesterol in the erythrocyte membrane (Birk and Peri, 1980) and make the intestinal mucosa permeable (Johnson *et al.,* 1986). Scott *et al.* (1985)

reported that intravenous injection of saponins to mammals can cause local inflammation, and in large doses, can result in death due to massive release of erythrocyte debris and reduction in the oxygen-carrying capacity of the blood. Saponins can also lyse other cells such as those found in the intestinal mucosa and consequently affect nutrient absorption. Decreased weight gain has been observed with high saponin intake due to a number of reasons including reduced food intake attributable to the bitter taste of saponins (Birk and Peri, 1980), or decreased absorption and utilization of nutrients caused either by the inhibition of metabolic or digestive enzymes (Cheeke, 1976). Saponins also decrease re-absorption of bile cholesterol into the body.

2.3. Trypsin Inhibitors or Protease Inhibitors

Trypsin is an enzyme involved in protein digestion and trypsin inhibitors that can result in a decreased level of bioavailability of protein. Trypsin inhibitors are abundant in raw cereals and legumes seeds and are capable of binding to the trypsin enzyme. These have been associated with growth inhibition, thus inhibiting its activity, interfering with the digestion of proteins and resulting in an increased pancreatic secretion and hypertrophy of the pancreas (Birk, 1989; Shimelis and Rakshit, 2005b). Dry beans are quite rich in cystine containing trypsin inhibitors. About 30-40% of the total cystine content of the food comes from beans, although the inhibitor makes the cystine unavailable. Generally, all legumes studied to date have been found to contain trypsin inhibitors in varying amounts. When beans are ingested by humans and mono-gastric animals in significant amounts, they disrupt the digestive process and may lead to undesirable physiological reactions (Collins and Beaty, 1980). The adverse effect of protease inhibitors have been observed primarily in animals with a high weight of pancreas, expressed as a percentage of body weight (0.29-0.80), such as rats, mice, chicken, hamsters and young guinea pigs. The effect of protease inhibitors on the pancreas of humans remains unclear and needs further elucidation (Mary and Ilya, 2005).

2.4. Phytoestrogens

Phytoestrogens are plant-derived substances that are structurally and functionally similar to endogenous estrogens of humans and other members of the animal kingdom. Principally, there are three main classes of phytoestrogens-isoflavones, coumestans, and lignans which are found in many food legumes (Murkies *et al.*, 1998) (Figure 2).

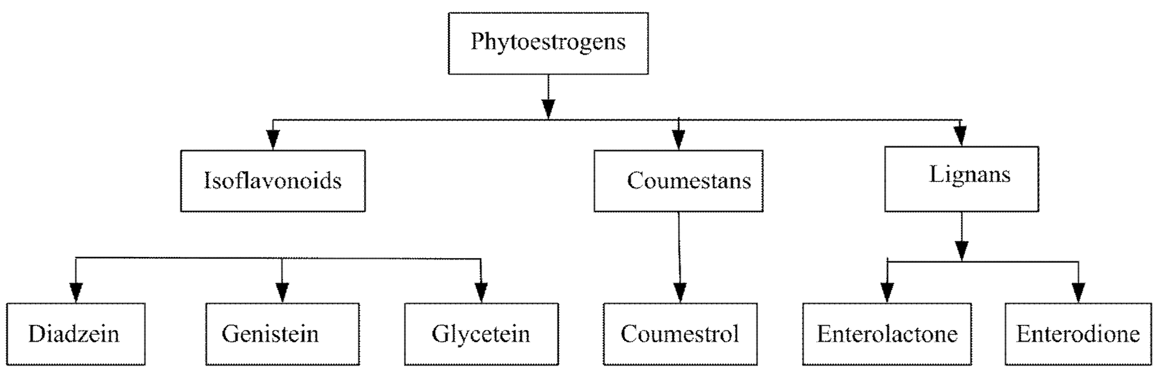

Figure 2. Classification of phytoestrogens

Phytoestrogens are widely distributed in the plant kingdom including legumes, cereals, oilseeds, fruits and vegetables. Lignans are a group of diphenolic compounds with dibenzylbutane skeleton structures and similar characteristics to the phytoestrogens (Setchell and Adlercreutz, 1988). Many different plant lignans have been identified and/or isolated but recently the mammalian lignans enterolactone [(*trans*-2, 3-bis-(3-hydroxybenzylyl)-butyrolactone)] and enterodiol [(2, 3-bis (3-hydroxybenzylyl) butan-1, 4-diol)] have gained much attention. They are produced by the bacterial flora in the colon from the plant lignans matairesinol and secoisolariciresinol, respectively, and have been detected in the biological fluids of man and animals. The two main classes of phytoestrogens are the isoflavones and the coumestans, the former having attracted greater attention (Setchell and Adlercreutz, 1988). The phytoestrogens, plant lignans, and their bacterial products undergo enterohepatic circulation and some have been detected in the urine. The structures of the main phytoestrogens are shown in Figure 3.

Phytoestrogens have been linked with infertility problems (Setchell *et al.,* 1987). Reports of infertility in sheep in Western Australia indicated that, the infertility syndrome, characterized by a cystic condition of the ovaries, an irreversible endometriosis and failure to conceive, appear to have been caused by grazing in pasture having a high content of clover (*Trifolium subterraneum*) which is rich in dietary phytoestrogens. In addition, there are concerns that phytoestrogens may enhance tumor growth since oestrogens have growth-stimulatory effects (Miller, 1990; Allred *et al.,* 2001). Some purified lignans are toxic when taken in high doses and resulted in renal impairment, nausea, vomiting, delirium, stupor and coma (Ayres, 1990). Women who consume more soya products containing phytoestrogens and protease inhibitors might have lower cancer risks but seem to have reproductive problems (Messina and Barnes, 1991; Rishi, 2002).

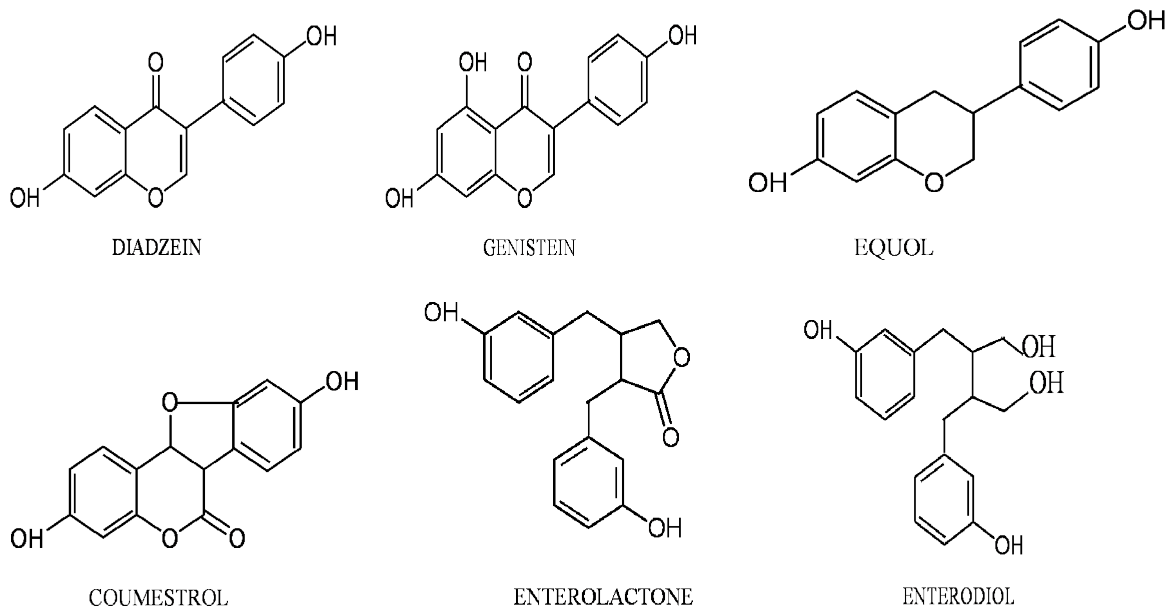

Figure 3. Structure of important phytoestrogens (Bingham *et al.*, 1998; Setchell, 1998)

2.5. Tannins

Tannins are polyphenolic compounds which has the ability to precipitate proteins from aqueous solution (Swain, 1985). Tannins consist mainly of gallic acid residues that are linked to glucose *via* glycosidic bonds as shown in Figure 4. It is generally agreed that tannins precipitate proteins because they contain a number of functional groups which complex strongly with two or more protein molecules, building up a large cross-linked protein-tannin complex. Tannins are present in food legumes, though generally not in such high amounts in some cereals such as brown sorghum and finger millet. They are known to inhibit the activities of trypsin, chymotrypsin, amylase and lipase, decrease the protein quality of foods and interfere with dietary iron absorption (De Lumen and Salamat, 1980).

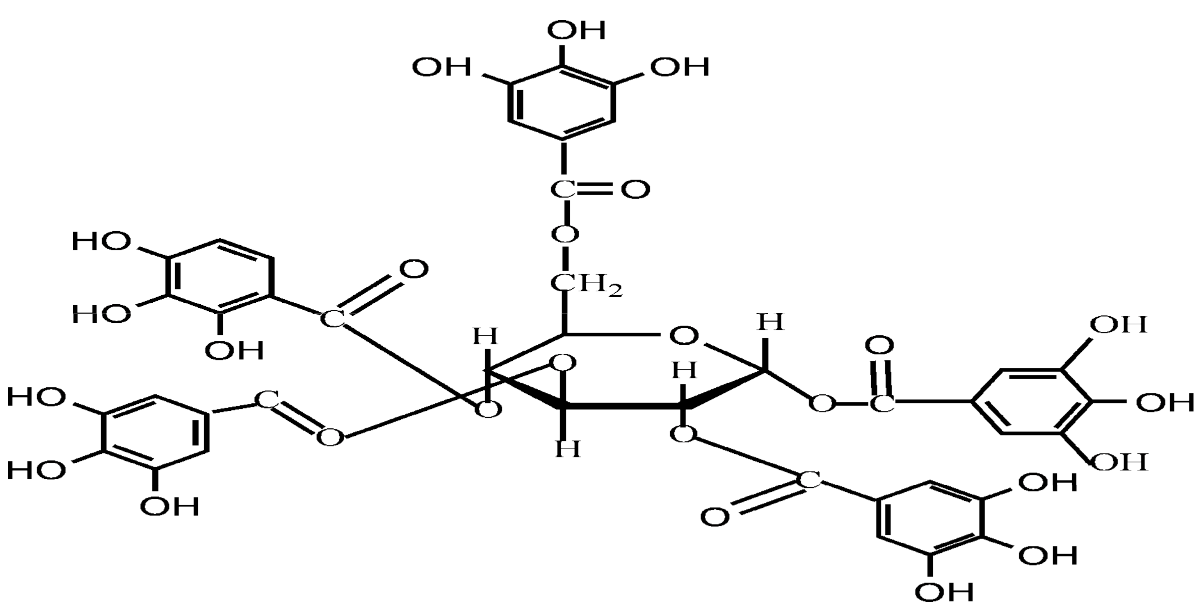

Figure 4. Basic structure of tannin (Peter, 2003)

Tannins form insoluble complexes with protein and inhibit several enzymes (Bressani *et al.,* 1983). Poor digestibility and biological utilization of bean protein from cooked beans of the colored cultivars have been directly related to the tannins' content of these beans. Tannins (particularly the condensed types) inhibit several enzymes and they are located mainly in the seed coat of grains (Elias *et al.,* 1979). Many investigators observed that tannins and related polyphenols can react with proteins, decrease protein digestibility and therefore reduce protein quality (Bressani *et al.,* 1983; Shimelis and Rakshit, 2008).

The nutritional effects of tannins on poultry feed, egg production, rats, swine, ruminants and insects have been investigated (Awika and Rooney, 2004). Toxic effects of tannins have been categorized as causing depression in food/feed intake, decreased nitrogen retention (increased nitrogen excretion and/or reduced protein digestibility) by allowing tannin complexes with dietary protein or other dietary components (formation of the less digestible tannin-dietary protein complexes). Tannin complexes with digestive enzymes (interfering with normal digestion), inhibition of digestive enzymes, increased excretion of endogenous protein, malfunctions in the digestive tract, tannin effect on the digestive tract (alimentary canal) and toxicity of absorbed tannin or its metabolites (Salunkhe *et al.*, 1990; Deshpande *et al.,* 2000). The biochemical nature of how the food tannins bind to food proteins is difficult to discern, primarily due to the complexity of tannin chemistry as well as the number of tannin species present in food (Sathe and Salunkhe, 1984).

In conclusion, the presence of tannins in food can therefore lower feed efficiency, depress growth, decrease iron absorption, damage the mucosal lining of the gastrointestinal tract, alter excretion of cations, and increase excretion of proteins and essential amino acids (Reddy and Pierson, 1994).

2.6. Oligosaccharides

Flatulence-causing α-galactosides are oligosaccharides of the raffinose-series, which are considered as unwanted components due to their role in flatus production and accumulation of gas in the intestinal tract which results in discomfort, abdominal rumblings, cramps, pain and diarrhea. Oligosaccharides of the raffinose family of sugars (raffinose, stachyose and verbascose) (Figure 5) are known to produce flatus in human and other monogastric animals, pigs and poultry (Vidal-Valverde *et al.,* 1992). This is due to the lack of the necessary α-galactosidase enzyme which helps to break down raffinose-series oligosaccharides during consumption of food legumes (Salunkhe and Kadam, 1989). These sugars pass to the large intestine where they get fermented by colon bacteria giving CO_2, H_2 and CH_4 as the main components of flatus gases (Rao and Belavady, 1978; Shimelis and Rakshit, 2008).

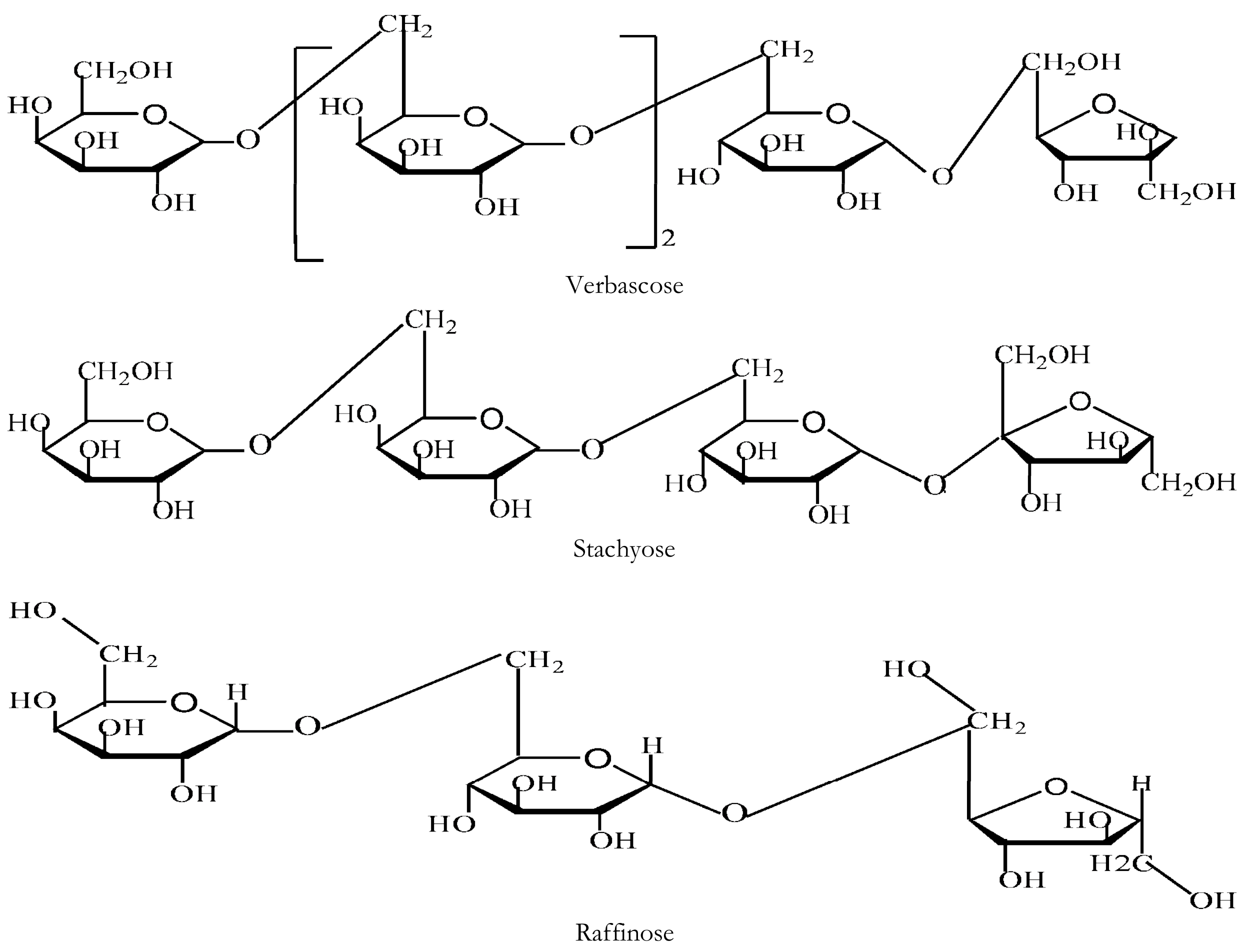

Figure 5. Structure of raffinose family sugars (Nakakuki, 1993; Yasushi *et al.*, 1993)

Sucrose, stachyose and raffinose are the major sugars in haricot beans when ingested by mammalian digestive systems. Sucrose is hydrolyzed and absorbed, but the raffinose family of sugars remains unhydrolyzed due to the absence of α-galactosidase enzyme activity in the small intestine, which is capable of hydrolyzing the α-D-1-6 galactosidic linkage, and hence they are not absorbed. A number of investigators have demonstrated that the oligosaccharides; raffinose and stachyose, are the principal causes of flatulence in human and animals (Rackis *et al.,* 1970; Reddy *et al.,* 1980; Fleming, 1981).

Oligosaccharides are associated with a low food intake in animal experiments (Frias *et al.,* 2000). The phytochemicals activity of food legumes is also frequently associated with the presence of these oligosaccharides, which are not hydrolyzed in the upper gut. Therefore, raffinose family oligosaccharides are a limiting factor in the use of kidney beans in monogastric diets. Consequently, the presence of these sugars in food legume seeds is one of the major constraints in their full utilization as human food.

2.7. Phytic Acid

It is now generally believed that the compound phytic acid can be commonly called *myo*-inositol hexaphosphoric acid (IP6) or, scientifically, 1,2,3,4,5,6-hexakis (di-hydrogen phosphate) *myo*-inositol is composed of an insitol sugar (John *et al*., 2004) (Figure 6), similar in structure to D-glucose, with six phosphate groups attached to each hydroxy (Wodzinski and Ullah, 1996).

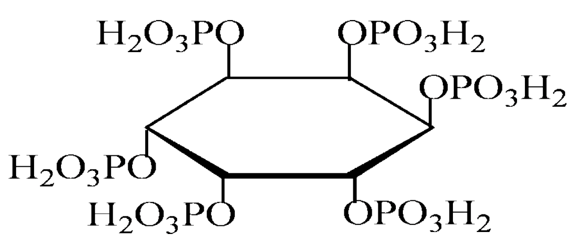

Figure 6. Molecular structure of phytic acid (John *et al*., 2004)

Phytic acid has been considered as an anti-nutritional component in cereals, seeds and beans. Phytates represent a complex class of naturally occurring compounds that can significantly influence the functional and nutritional properties of foods. Research has traditionally focused on its structure that gives it the ability to bind minerals, proteins and starch, and the resulting lower absorption of these elements. However, recent researches have shown that phytic acid has many health benefits. Phytic acid has anti-oxidant, anti-cancer, hypocholesterolemic and hypolipidemic effects. Phytic acid may have health benefits for diabetes patients. It lowers blood glucose response by reducing the rate of starch digestion and slowing the gastric emptying. Studies also show that phytic acid may reduce inflammation (Shamsuddin, 2002; Catherine, 2007).

Phytic acid is the principal storage form of phosphorus in many plant tissues, especially in most grains, seeds and beans. Rich sources of phytic acid are bran and flaxseed (3% phytic acid). Phosphorus in this form is generally not bioavailable to non-ruminant animals because they lack the digestive enzyme, phytase, required to separate phosphorus from the phytate molecule. On the other hand, ruminants readily utilize phytate because of the phytase produced by rumen microorganisms (Yoon *et al*., 1983; Flanagan, 1984).

Food legumes contain significant amounts of inositol hexaphosphates (IP6). Phytate is a strong chelator of important minerals such as calcium, magnesium, iron and zinc and can therefore contribute to mineral deficiencies in developing countries (Habtamu and Kelbessa, 1997; Hurrell, 2003). For people with a particularly low intake of essential minerals, especially young children and those in developing countries, this effect can be undesirable. Phytate has long been recognized as phytochemical, affecting the bioavailability of minerals (Ca^{2+}, Mg^{2+}) and trace elements such as Zn^{2+}, Fe^{2+}, Cu^{2+}, Mn^{2+}, Se^{4+}, Mo^{3+} and B^{3+} (Reddy *et al.,* 1982) through formation of insoluble complexes at intestinal pH (Erdman, 1979) and inhibits several proteolytic enzymes and amylases (Singh and Krikorian, 1982). Zinc appears to bind phytic acid in physiological pH range more tightly than other minerals (Lönnerdal, 2002).

Phytate in food legumes complexes with proteins by forming phytate-protein compound which may result in reduced solubility of proteins which can affect the functional properties of proteins (Laurena *et al.,* 1994). The reduction or removal of phytic acid to increase mineral bioavailability is essential while processing weaning foods in the African context where zinc is a serious limiting factor (Shimelis, 2008). In formulation of baby foods at industry or household level; phytic acid needs to be properly inactivated to ensure the bioavailability of minerals in the final product.

3. The Health Benefits

Human consumption of biologically active natural products is not limited to pharmaceutical products. A much greater number is ingested as foods or dietary supplements (nutraceuticals) just as likely to exert biological effects that go far beyond providing calories and essential nutrients. Health-related phytochemicals interactions lead to a more holistic approach to disease prevention and treatment (Sur *et al.,* 2001; Lila and Raskin, 2005; Shimelis and Rakshit, 2005a).

Phytochemicals present in food legumes have health benefits which appear to be similar to those suggested for the dietary fibers in fruits, vegetables and other crops. Studies in phytochemiclas indicate that they have a capacity to lower blood glucose and hormonal responses to starchy foods (legumes), decrease blood lipids, and decrease cancer risks (Lila and Raskin, 2005). New research on phytochemicals is underway, including impact of food processing on bioavailability of phytochemicals, developing an *in vitro* bioavailability estimation method for bioactive compounds, application of phytochemicals as nutraceuticals, functional foods and cosmetics (Craig, 1997). Additionally, studies are being undertaken to indicate the main groups of bioactive compounds, giving a description of their localization, chemical properties and biological actions.

3.1. Phytic Acid

Phytin is a complex salt of phytic acid, inorganic cations and proteins; isolated from plants and belongs to the group of organic phosphates. It is a mixture of calcium-magnesium salt of inositol hexaphosphoric acid. Phytin as salts is found in plants (predominately in seeds) as well as in animal tissues and organs. Phytic acid contents were found to be higher in the outer coverings of seeds than in the whole seeds (Mukhamedova and Akramov, 1977). Like the other phosphorous-containing preparations, phytin stimulates hemopoiesis (production of red blood cells by bone marrow) and increases the haemoglobin oxygen transportation capacity, inhibits lipid peroxidase and concomitant injuries of the intestinal and liver cells, potentiates bone growth and development and improves the functions of the nervous system. The raw material for phytin production is food legumes (especially of the bean species), cereal grains, rice bran, as well as oil plant cakes obtained as by-products of the food processing and oil producing industries. Currently, Sopharma AD manufactures phytin from food legumes. Phytin and its finished dosage form can be used for therapeutic and prophylactic effects; such as the relief of physical and mental overloading (enhancement of brain function). It can also be used as a food supplement to various diets, depending on the condition of the organism. Phytin also helps peel away dry surface cells and supports anti-aging and skin care treatments.

The inhibitory effect of phytic acid on the proliferation of human immune deficiency viruses (HIV), implicated as causative agents of the acquired immune deficiency syndrome (AIDS), has been tested *in vitro* (Lin *et al.,* 1996). They reported that phytic acid at a concentration of 1.67 mg ml^{-1} inhibits the cytotoxic effect of the immune deficiency virus and the specific anti-genic reaction in the affected cells.

Starchy foods which are slowly digested and result in lower blood glucose response have been suggested to be more beneficial to health, and in the management of diabetes and hyperlipidaemia (Wolever, 1990). Besides its well-known negative properties, phytate has been found to form chelates *in vitro*, inhibiting the formation of iron-catalyzed hydroxyl radicals (Fenton reaction) and lipid per-oxidation. As a result, phytic acid has gained in significance as a naturally occurring anti-oxidant (Empson *et al.,* 1991). The potential beneficial effects of phytic acid, such as a delayed postprandial glucose absorption (Yoon *et al.,* 1983), a decrease in plasma cholesterol and triglycerides (Katayama, 1995), reduction of proliferation in different cell lines, including erythroleukaemia human mammary cancer cells (Shamsuddin, 1995) and anti-cancer function of phytic acid (Shamsuddin, 2002) have been recently discussed in the literature. Hirose *et al.* (1991) demonstrated, using a rat wide-spectrum organ carcinogenesis model, that dietary phytate inhibited development of hepatocellular carcinomas and putative preneoplasmatic lesion in the pancreas. Protective effects of phytic acid were also observed in azoxymethane (Shamsuddin and Ullah, 1989) and dimethylhydrazine (Shamsuddin *et al.,* 1989) induced colon carcinogenesis, and in the case of transplanted fibrosarcoma, in mice and rats. The basic mechanism of the anti-carcinogenic effect of phytic acid is still unclear. However, it is thought that its anti-carcinogenic benefits may be in part attributable to its anti-oxidant capability.

3.1.1. Anti-oxidant Properties of Phytic Acid

A function of phytic acid as a natural anti-oxidant was first postulated by Graf *et al.* (1984). In molar ratios of 0.25 phytate-to-iron and above, the generation of hydroxyl radicals *via* the Fenton reaction was almost completely blocked (Graf *et al.,* 1987) with hydroxyl radical formation measured spectrophotome trically by the formation of formaldehyde in the presence of dimethyl sulphoxide. In a further *in vitro* experiment, electron spin resonance spectroscopy (ESR) was applied in combination with spin trapping to study the anti-oxidant properties of phytic acid (Rimbach and Pallauf, 1998). Spin trapping provides an opportunity not only to detect radicals, but also to characterize partially the type of radicals formed. The ESR studies indicated that the anti-radical effect of phytic acid occurs by chelating iron required for the generation of hydroxyl radicals *via* the Fenton reaction, due to the phosphorus moieties of the phytic acid molecule. Midorikawa *et al.* (2001) conclude that phytic acid acts as an anti-oxidant to inhibit the generation of reactive oxygen species from H_2O_2 by chelating transition metals, such as copper and iron, thereby possibly mediating anti-carcinogenic properties. Several studies also provide evidence for anti-oxidant properties of phytic acid *in vivo* (Shan and Davis, 1994; Rimbach and Pallauf, 1998; Porres *et al.,* 1999).

Anti-oxidant effects of phytic acid are mainly mediated through its iron chelating and copper properties, although the molecular mechanisms are not fully understood. However, under *in vivo* conditions, phytic acid has not always been demonstrated to have a significance effect on the oxidant or anti-oxidant status (Lee *et al.,* 2000b). Ultimately, phytic acid as a major component food legume is considered an important anti-oxidant and is increasingly used in various therapeutic diets for its protective effect on cancer of the colon and rectum (Reddy *et al.,* 1982; Shamsuddin, 1995; Shamsuddin, 2002; Tran *et al.,* 2003).

3.1.2. Anti-cancer Function of Phytic Acid

Experiments of *in vivo* and *in vitro* have demonstrated striking anti-cancer (preventive as well as therapeutic) effects of phytic acid (Fournier and Gordon, 2000). Phytic acid can prevent the formation and incidence of several cancers in experimental animals in soft tissue, colon, metastatic lung cancer and mammary cancers (Shamsuddin *et al.,* 1989; Vucenik *et al.,* 1992, 1995, 1997;

Sun and Liu, 2006). Researches on the anti-cancer function of phytic acid conclude that inclusion of phytic acid (IP_6) for prevention and therapy of various ailments, cancer in particular, is warranted (Shamsuddin, 2002; Singh *et al.,* 2004). Phytic acid has been also suggested to have a role in the prevention of dental caries (John *et al.*, 2004) and platelet aggregation, in the treatment of hypercalciuria and kidney stones, and as anti-dote against acute lead poisoning, primarily due to its mineral-binding ability (Lila and Raskin, 2005). Thus, utilization of physiologically functional foods which are botanical sources can reduce risks of many life-threatening diseases in Africa, such as breast cancer risk.

3.2. Protease Inhibitors

Legumes contain protease inhibitors which are being studied as anti-cancer agents. Recently, the US National Cancer Institute identified a number of foods, including legume based, which are thought to be protective against cancer (Troll and Kennedy, 1989; Messina and Barnes, 1991; Caragay, 1992). Several substances which are responsible for the cancer protective effect have been suggested and many of them are phytochemicals including trypsin inhibitors, phytic acid, phytoestrogens and lignans, saponins and tannins.

While the protease inhibitors have been linked with pancreatic cancer in animal studies, they may also act as anti-carcinogenic agents as suggested by animal studies, *in vitro* cell culture work, and epidemiological data which show low cancer mortality rate in human population with high dietary intake of protease inhibitors. These were discussed in studies (Messina and Barnes, 1991; Messina and Messina, 1991). Of the protease inhibitors, the most effective are those with chymotrypsin inhibitor activity found in soy bean, haricot bean and chick pea.

Several mechanisms whereby protease inhibitors inhibit carcinogenesis have been hypothesized (Kennedy and Billings, 1987; Troll, 1989). The inhibitor may reduce the digestion of proteins and thus the amino acids available to the growing cancer cells; deprivation of amino acids particularly leucine, phenylalanine and tyrosine has been shown to prevent the growth of mouse hepatoma and mammary adenocarcinoma (Troll *et al.,* 1987). The inhibitors may stop the ongoing cellular process begun by carcinogen exposure by reversing the carcinogen-induced change in oncogene expression. They may inhibit the formation of super oxide anion radicals (O_2^-) and hydrogen peroxide (H_2O_2) by neutrophils induced through tumour promoters; these oxygen-reactive species can damage or modify cellular DNA. The inhibitors may inhibit the oxygen radical-induced DNA polymerase, the enzyme involved in the formation of poly (ADP-ribose).

3.3. Saponins

Saponins are a group of plant glycosides consisting of a steroid or tri-terpenoid aglycone to which one or more sugar chains are attached. They exhibit cell membrane-permeabilizing properties and, thus, have been investigated for their therapeutic potential (Bachran *et al.*, 2006). Saponins are found primarily in legumes, with the greatest concentration occurring in soybeans. Saponins have been shown to have diverse biological properties including fungistatic, haemolytic, insecticidal and diverse pharmacological activities. Results of recent investigations suggest that saponins have cholesterol-lowering, anti-cancer and immuno-stimulatory properties (Oakenfull *et al.,* 1979; Gurfinkel and Rao, 2003), and important in human diets to reduce the risk of heart disease (Potter *et al.,* 1980). Anti-cancer properties of saponins appear to be the result of anti-oxidant effects; immune modulation and regulation of cell proliferation (Rao, 1996).

Soyasaponins are bioactive compounds found in many legumes. Although crude soyasaponins have been shown to have anti-colon carcinogenic activity, purified soyasaponins and soyasapogenins were tested for their ability to suppress the growth of HT-29 colon cancer cells, as determined by the WST-1 assay, over a concentration range of 0-50 ppm. Soyasaponin I and III, soyasapogenol B monoglucuronide, soyasapogenol B, soyasaponin A_1, soyasaponin A_2, and soyasapogenol A were evaluated. Consequently, results from *in vitro* fermentation suggested that colonic microflora readily hydrolyzed the soyasaponins to aglycones. These observations suggest that the soyasaponins may be an important dietary chemopreventive agent against colon cancer, after alteration by microflora (Gurfinkel and Rao, 2003). Recently, a non-permeabilizing concentration saponinum album from *Gypsophila paniculata* L. has been described to enhance the cytotoxicity of a chimeric toxin in a cell culture model. The saponin-mediated enhanced uptake of targeted saporin-based drugs is strongly dependent on the saponin structure (Bachran *et al.*, 2006). Furthermore, saponins nowadays are used for health care treatments (Duhan *et al.,* 2001).

3.4. Phytoestrogens

Epidemiological data and biological properties of phytoestrogens suggest that they may also be important in the prevention and control of cancer, particularly the hormone-dependent ones. The urinary excretion of lignans and the isoflavonic phytoestrogens was significantly lower in breast cancer patients and omnivores than in the vegetarians with a lower risk of cancer (Adlercreutz *et al.,* 1986, Harris *et al.*, 2005). How phytoestrogens may influence carcinogenesis is still unclear but several mechanisms have been postulated in several reviews (Adlercreutz, 1991; Adlercreutz *et al.,* 1991).

Generally, phytoestrogens may be protective against various types of cancers, menstrual irregularities, osteoporosis, and cardiovascular disorders (Rishi, 2002). Within the past few years, phytoestrogens have attracted considerable attention for their potential anti-cancer activity. Since almost all anti-cancer drugs have serious side effects, the search is underway for "natural" alternatives or complements to traditional therapy. Further, the increased enthusiasm towards phytoestrogens as potential anti-cancer agents is shown by the published data. The population-based studies show that the mortality due to breast, ovarian, prostate, and colon cancer has a negative correlation with the phytoestrogens and cereal intake in the diet (Rose *et al*., 1986)). There are hundreds of *in vitro* studies, which show that phytoestrogens can inhibit a wide range of both hormone-dependent and hormone-independent cancer cells (Anderson *et al*., 1999; Safe *et al.,* 2001).

The elevated cholesterol levels accompanied by loss of endogenous estrogen secretion increases the risk of developing coronary artery disease (CAD) in postmenopausal women (Dewell *et al*., 2002). Current evidence suggests that phytoestrogens have significant potential in reducing CAD *via* favorable effects on the lipid profile. The epidemiological data also suggests that phytoestrogen consumption contributes to the lower incidence of cardiovascular disease in Asian countries and in vegetarians and that phytoestrogens may be cardioprotective (Adlercreutz, 1990).

In postmenopausal women, estrogen deficiency is a major risk factor for osteoporosis (Dempster, and Lindsay, 1996). The incidence of hip fracture increases and may lead to immediate disability. It has been observed that osteoporosis and risk of hip fracture is lower in postmenopausal Japanese women than their Western counterparts (Cooper *et al*., 1992). Hormone replacement therapy (HRT) has been proven to lower the risk of cardiovascular disease and osteoporosis (Arjmandi, 2001). The consumption of phytoestrogens has been shown to be protective in the prevention of thyroid, lung, stomach, colon, and skin cancers (Messina *et al*., 1994; Horn-Ross *et al*., 2002), however, further research is warranted at this time. There is increasing evidence that phytoestrogens may be beneficial in chronic renal disease (Velasquez and Bhathena, 2001).

The global movement for consuming a phytoestrogen-rich diet is increasing and tabletized concentrated isoflavone extracts are being promoted heavily. This is because epidemiological data and animal, human and *in vitro* studies support the role of phytoestrogens in lowering the risk of various types of cancers (especially breast and prostate cancer) and cardiovascular disease. However, contradicting reports are also emerging simultaneously, which is creating confusion. Due to this, there is difficulty in making widespread recommendations about dietary intake of phytoestrogens. Thus, more research is required to establish the role of phytoestrogens in the above discussed conditions. Evaluation of benefits and risks of phytoestrogens is a complex task due to inter-individual variation and complexity in absorption and metabolism. Overall, it is naive to assume that consumption of phytoestrogens may be good. On the other hand, inappropriate or excessive use may be detrimental. Before making widespread recommendations for phytoestrogens intake, extensive data on specific intracellular effects, duration of exposure and disease, and results from prospective randomized studies in humans is essential. It is also necessary to determine the potential side effects of phytoestrogens. Out of various phytoestrogens, isoflavones (genistein and diadzein) have been studied in the greatest depth. Studies on lignans are few and for coumestans very few. This might be due to lack of industrial funding and problems in analytical techniques. Study of effects of individual compounds in various clinical conditions is essential at this time. Based on dietary phytoestrogens, structure activity relationship studies should be carried out and more synthetic and semisynthetic compounds (likeipriflavone) should be evaluated (Zhi-qiang *et al*., 2006). Genetic modification of food legumes and improvement in food technology/engineering to enhance phytoestrogen production is predictable.

3.5. Oligosaccharides

Oligosaccharides are one of the most popular functional food components in Japan and are exported to many countries including USA. The number of consumer products containing oligosaccharides includes soft drinks, cookies, cereals and candies. Physiologically functional oligosaccharides meet two specific requirements: (1) they are not digestible by human digestive juices and (2) they are preferentially consumed by beneficial intestinal bacteria, bifidobacteria, in the colon.

Ingestion of oligosaccharides increases the bifidobacteria population in the colon which, in turn, contributes to human health in many ways. The benefits of oligosaccharides ingestion arise from increased population of indigenous bifidobacteria in the colon which by their antagonistic effect, suppress the activity of putrefactive bacteria and reduce the formation of toxic fermentation products. *Lactobacilli* show similar effects, mainly in the upper gut. The toxic metabolites formed during fermentation of foods in the colon include ammonia (liver toxin), amines (liver toxin), nitrosoamines (carcinogens), phenols and cresols (cancer promoters), indole and skatole (carcinogens), estrogens (suspected carcinogens or breast cancer promoters), secondary bile acids (carcinogens or active colon cancer promoters), aglycones (often mutagenic), and others (Hespell and Jeffrey-Smith, 1983; Hylemon and Glass, 1983; Kanbe, 1988; Mitsuoka, 1990; Hideo, 1994). Additionally, a number of adverse consequences result from toxic metabolites formed during fermentation of legume foods in the colon which are possible causes of aging, immunity decreases, and adult diseases as a result of diminishing secretion of gastrointestinal juices in old age and adult diseases such as cancer and arthritis (Benno and Mitsuoka, 1986; Mitsuoka, 1990; Mizutani, 1992). Mental stresses, which are already known to affect human health through hormonal disturbance, also change the intestinal microflora profile, drastically decreasing bifidobacteria and increasing bacteria (Komai, 1990). Incorporation of bifidobacteria, instead of oligosaccharides, into processed foods is quite difficult because of their high susceptibilities to oxygen, shear, heat and acids (Hideo, 1994).

Health benefits resulting from ingestion of oligosaccharides are proliferation of bifidobactria and reduction of detrimental bacteria (Wada *et al.,* 1991), reduction of toxic metabolites and detrimental enzymes (Saito *et al.,* 1992), prevention of pathogenic and autogenous diarrhea (Kurmann and Rasic, 1991), prevention of constipation (Matsunami *et al.,* 1992), protection of liver function (Takasoye *et al.,* 1990), reduction of serum cholesterol and blood pressure (Hidaka *et al.,* 1986; Masai *et al.,* 1987), anti-cancer effect (Hirota, 1990) and production of nutrients (Hughes and Hoover, 1991). Bifidobacteria produce the vitamins B-1, B-2, B-6, B-12, nicotinic acid, and folic acid. Bifidobacteria, however, cannot produce vitamin K (Hughes and Hoover, 1991).

Human studies have shown an increase in bifidobacteria resulting from oligosaccharide ingestion and a reduction in detrimental bacteria such as *Clostridium perfringens* (Masai *et al.,* 1987; Wada *et al.,* 1991). Ingestion of 2-10 g/day for several weeks effectively increased bifidobacteria population in the human intestine by an average of 7.5 times and decreased *C. perfringens by* an average of 81%. With some oligosaccharides, *lactobacilli* also increased 2-3 times and C. *perfringens* decreased by 0.50-0.06 times (Hideo, 1994).

Bifidobacteria prevent the growth of exogenous pathogenic microbes and the excessive growth of indigenous detrimental microflora through production of short-chain fatty acids (mainly acetic acid and lactic acid at a 3:2 mole ratio) and an ability to produce some anti-biotic materials. The growth-inhibiting and destructive effects of acetic and lactic acids on undesirable bacteria are known (Rasic and Kurmann, 1983). The suppressive effects of these acids against *Salmonella* (Chung and Goepfert, 1970) and *E.coli* (Tamura, 1983) were reported. Reduction of toxic metabolites and detrimental enzymes by oligosaccharides ingestion has been shown in human tests and *in-vitro* human-faeces culture tests (Kato *et al.,* 1992; Saito *et al.,* 1992).

The reductions of toxic metabolites by the ingestion of oligosaccharides or bifidobacteria alleviate the detoxifying load of the liver (Takasoye *et al.,* 1990). The advantages oligosaccharides have over dietary fiber are that they have a smaller daily requirement (usually 3 g/day), do not cause diarrhea in recommended doses, are slightly sweet, have neither bad texture nor bad taste, are completely water soluble, do not build viscosity, do not bind minerals, are physically stable, and are easier to incorporate into processed foods and drinks.

4. Other Benefits

Lignan-rich plant products are components of many Chinese and Japanese folk medicines (Ayres, 1990). Rheumatoid arthritis, gastric and duodenal ulcers, scrofula (tuberculosis-like disease of the lymph glands, generally localized in the neck), venereal wart, nasal papillomas and psoriasis are diseases reported to be treated by lignan-rich plant products (Ayres, 1990) although more studies are needed to confirm that lignan is the active ingredient in these products. Phytic acid has been suggested to have a role in the prevention of dental caries and platelet aggregation, in the treatment of hypercalciuria and kidney stones, and as anti-dote against acute lead poisoning, primarily due to its mineral-binding ability (Graf, 1986; Graf and Eaton, 1990).

Tannins occur in a wide variety of plants, where they often provide a natural protective system against attack by microorganisms or against being eaten by animals. Presumably, the effectiveness of tannins in protecting plants against invasion by microorganisms is a result of the strong affinity of tannins for either digestive enzymes secreted by the microorganisms (Jones *et al.,* 1976) or proteins on its surface. Many gastrointestinal microbiologists postulate that the excessive formation of secondary bile acids and steroids is related to the high incidence of colon cancer after use of animal sources of high-dietary fat (Gorbach and Goldin, 1990; Lambert *et al*., 2005). Thus, utilization of physiologically functional foods which are botanical foods can reduce the causes of high breast cancer risk.

Saponins are present in a number of herbal remedies, e.g. ginseng, liquorice and sarsaparilla, which appear to have expectorant and anti-flammatory effects (Shibata, 1977). Several phenolic compounds, e.g. monomeric hydrolysable tannins, oligomeric ellagitannins and condensed tannins, having galloyl groups or hexahydroxydiphenoyl groups, have potent inhibitory effect on herpes simplex virus types 1 and 2 (HSV-1, HSV-2) infection (Fukuchi *et al.,* 1989). These viruses are linked to several human diseases including gingivostomatitis, stomatitis, meningitis and venereal transmitted genital disease. Three hydroxyl groups in the benzene ring and high molecular weight of the phenolic compounds are needed for the inhibition of the virus to take place. Interestingly, protein binding and anti-tumour activities also are related to molecular weight, and dimeric ellagitannins with high molecular weight also have strong anti-HIV activity (Asanaka *et al.,* 1988; Fukuchi *et al.,* 1989).

5. Conclusions

Recent investigations have demonstrated that both adverse effects and health benefits could be attributed to phytochemicals in food legumes. Different food processing methods are used for the reduction/removal of the adverse effects of these bioactive compounds for consumption. However, threshold levels at which undesirable components may exert adverse effects need to be established. It is evident that, in many cases, the same interactions that make them adverse are also responsible for their beneficial effects. However, health benefits are possible at a certain level of phytochemicals' intake without causing many adverse effects. Based on the data available in literature, it appears that source of legumes have a wide variety of health-promoting activities and may have potential as functional foods. In addition, it should be noted that different food legumes have greater potential to act as therapeutic agents. Ultimately, the greatest promise of phytochemicals investigation might be its ability to spark a dramatic and widespread shift in the understanding and appreciation of plant foods.

Indeed, the physiological effects of phytochemicals are related to their level of intake and the conditions in which they are taken, e.g. presence of other dietary constituents, health and nutritional status of the individual.

Consequently, to balance their risks with benefits, there is a need to obtain more information on the concentration of phytochemicals in food legumes and their level of intake. More work is required on dose-response studies to determine the minimum amount needed to have a specific beneficial health effect without causing any adverse effect. After their intensive study, phytochemicals could be used as potential health bodyguards for the 21st century. Owing to the potential health benefits of phytochemicals in food legumes, it is perhaps incorrect to refer to these plants and plant-derived group of chemicals as natural toxins. The time has come for us to reconsider their presence in our diet. The mitigating effects and the mechanism of their action need to be further addressed *via* investigation of the main groups of bioactive compounds which can give a description of their localization, chemical properties and biological actions.

In conclusion, their true properties and biomedical applications, in fact, have not yet been fully explored. However, with the availability of crucial research outputs from African agricultural research centers and higher learning institutions, a number of new applications in the future are likely. Research and development studies on indigenous and improved varieties of African food legumes and other plants will help to explore new demands on phytochemicals for health benefits in the region. Improvement in food process technology and food engineering to enhance phytochemicals production is inevitable.

6. Acknowledgment

The author would like to express heartfelt gratitude to the Melkassa Agricultural Research Center for the support in gathering materials for this article. He also wishes to thank Adane Tilahun and Ashenafi Geletu of Addis Ababa University, Food Science and Nutrition Program for their valuable assistance in phytochemicals structure arrangement with professional ChemDraw software, Chemoffice, 2004. Special thanks are due to Tizazu Habtie and Fantaye Kifle for their valuable support during manuscript preparation.

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Determinants and Dimensions of Household Food Insecurity in Dire Dawa Town, Ethiopia

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Abstract: Based on primary data collected from 200 household in 2005, this study scrutinizes determinants and the extent of food insecurity in Dire Dawa town. A binary logit model has identified household size, daily income and proportion of expenditure on food, education of household head, sex of household head, access to credit and marital status of the household as significant determinants of food insecurity in the study area. The FGT index result has revealed that 43% of the sampled households cannot meet the daily recommended caloric requirement with a food insecurity gap of 13%. The findings call for action-based advocacy on family planning to curb population growth, provision of technical training to the unemployed that enhances job creativity and competitiveness on the market, access to credit for the needy with proper targeting criterion and expansion of both formal and informal education.

Keywords: Food Security; FGT Index; Logit Model; Dire Dawa

1. Introduction

No developing country can afford to ignore the phenomenon of urbanization which will be one of the strongest social forces in coming years especially in developing countries. High rates of urbanization mean that urban food insecurity and malnutrition are concerns even for regions like Africa and Asia where current levels of urbanization are relatively low (Engle *et al*., 1998).

The level of urbanization in Ethiopia reached 17% in 2002. However, this level is expected to reach nearly 30% by the year 2020 as the urban areas are currently growing at around 6% per year. Slow economic growth and the low level of investments in urban centers combined with high population growth have resulted in high rates of unemployment and the inaccessibility and inadequacy of existing services for low income groups which further exacerbated urban poverty (FDRE, 2002).

Welfare monitoring based poverty analysis of Ethiopia showed that the depth and severity of consumption poverty showed an improvement between 1995/96 and 1999/2000 in rural areas while a slight deterioration was observed in urban areas (MoFED, 2002). The same study revealed that, during the same period, the calorie intake per adult per day in urban Dire Dawa was 1831 and 1929 kilocalories (kcal), respectively, which is below the minimum requirement of 2100 kcal. Considering an intake of 2100 kcal per person per day and the minimum cost prevailing in each location, households with insufficient purchasing power in Dire Dawa were estimated to constitute 47% of the total population (MoPED, 1994).

The CSA (1999) report indicated that the population growth rate in urban Dire Dawa with the medium variant was about 4.1 for the period between 2005 and 2010. With regard to urban unemployment, CSA (2004) report revealed that the unemployment rate of urban Ethiopia in 2004 was 22.9% and the rate was highest in the urban areas of Dire Dawa (33.5%) followed by Addis Ababa (22.1%).

The increase in urban population outstrips the capacity of the city to provide employment opportunities because it cannot absorb all the additional supply of labor coming from other areas. Although 74% of the regional population resides in urban Dire Dawa, the ear-tagged food security budget which was allocated for the Dire Dawa Administration Council has never been allocated for the urban areas employment generation activity. The perception of policy makers and other development agents that rural conditions are much worse than urban ones does not mean that resources should not be directed to the urban poor. The preparation and implementation of different policies to improve the livelihood and food security situation based only on past research findings might ultimately lead to erroneous outcomes because of the fact that socio-cultural, political and economic features can change over time, especially in the urban setting. In view of the above background, the specific objectives of this study were (1) to scrutinize the food insecurity situation and identify its determinants and (2) to examine the extent and severity of the food insecurity gap and its severity in Dire Dawa town.

1.1. Measurement and Indicators of Food Security

Measurement is necessary at the outset of any development project to identify the food insecure, to assess the severity of their food shortfall, and to characterize the nature of their insecurity (Hoddinott, 2001). There is no single indicator that best measures household food security, so several indicators are being used. One common indicator is caloric adequacy (Habicht and Pelletier, 1990; Payne, 1990; Maxwell and Frankenberger, 1992; Kennedy *et al*., 1994; Maxwell, 1996; Chung *et al.,* 1997). This measure captures food sufficiency in terms of quantity but does not address the quality of the diet or issue of vulnerability or sustainable access. The traditional approach of measuring food security using dietary intakes has been to select an optimal caloric intake based on a recommended daily allowance for the equivalent of a moderately active adult and compare it to observed household caloric intake per adult equivalent (Maxwell *et al*., 2000).

Comparison of methods to measure the state of food insecurity at household level in terms of costs, time requirement, skill and susceptibility to misreporting among four outcome indicators namely individual intake,

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ISSN 1992-0407

household calorie requisition, dietary diversity and index of coping strategies and household caloric acquisition is found to be a better measurement (Hoddinott, 2001).

Household food security in urban areas primarily depends on the level of income, the prices of food and other consumer goods on which the households allocate outlay. Households with larger family size, less literate and older household heads are more likely to fall into poverty than those with smaller family size, more literate and younger household heads (MoPED, 1994; MoFED, 2002).

Dire Dawa is located in a food deficit region of Ethiopia, the result of which means prices of food grains and other food items are high almost throughout the year. The gap between the low income and other income groups with respect to percent of expenditure on food is narrow, probably reflecting the unsatisfied food demand by the urban community in Dire Dawa. The relative prices of food items are higher compared to other towns such as Jimma, Bahir Dar and Awassa. It may, therefore, be expected that the real income of households in Dire Dawa is lower, the result of which is the affordability by households to purchase food reduced (MoPED, 1994).

2. Materials and Methods

2.1. Description of the Study Area

Dire Dawa town, located in the eastern part of the country, has an estimated total land area of 39.54 km^2. It is located 515 km east of Addis Ababa between Addis Ababa and Djibouti. Its altitude is about 1200 meters above sea level. Dire Dawa has bimodal rainfall pattern with short rain season from March to April and main rain season from August to mid September. Dire Dawa has an annual rainfall of about 604 mm and mean annual temperature of 24.8 ^{0}C.

Dire Dawa town has an estimated population of 204,244 of which the female population comprises 52.3%. The average household size and sex ratio, defined as number of males per 100 females, is 4.5 and 91.4, respectively. Other demographic indicators revealed an economic activity rate of 48.2, economic dependency ratio of 1.34 and unemployment rate of 33.5 (CSA, 2004).

2.2. Sampling and Data Collection

The primary data source for this research was the Dire Dawa urban households' socio economic data collected by undertaking a survey of 200 households. Three stages stratified random sampling technique with probability proportional to size sampling was employed to draw a total of five *kebeles* and 200 households. At the first stage, Dire Dawa *kebeles* were stratified into two strata based on wealth ranking of the urban *kebeles*, each having ten and fifteen *kebeles*. At the second stage, probability sampling was employed to draw two *kebeles* from one strata and three from the remaining one. Finally, a total of 200 households were randomly selected from representative *kebeles* by using probability proportional to size sampling procedure. The sample frame used was a registered household list collected through census by Population and Vital Statistics Office of the Administration Council.

2.3. Methods of Data Analysis

Quantities of food commodity consumed by the household during the past seven consecutive days were collected by survey questionnaire and then converted to their kilocalorie equivalent using Food Composition Table for Use in Ethiopia (ENHRI, 1998). Moreover, variations in energy requirements in terms of age and sex of household members were counterbalanced by converting all household members into their adult equivalent employing standard conversion table.

The methodology of classifying a given household as food secure or food insecure depends on the minimum acceptable weighted average food requirement of 2100 kcal per adult equivalent per day which is estimated to be 225 kg of food (grain equivalent per person per year) set by the Ethiopian government. As a result, total kcal consumed by a given household during the past seven days were computed for daily consumption and finally divided by total household adult equivalent to reach a kcal per adult equivalent per day.

Having identified the food insecure and food secure groups of households, the next step was to identify the socio-economic characteristics that are correlated with food insecurity. In light of this, it was hypothesized that household characteristics such as sex of household head, household size, access to credit, daily income per adult equivalent, proportion of household food expenditure, household head education status, dependency ratio, owning savings account and marital status of household head have relative importance in determining the state of food security at household level.

In order to test the hypothesis, a probabilistic model is specified with food security as a function of series of household characteristics as explanatory variables. The dependent variable in this case is dummy variable, which takes a value of zero or one depending on whether or not a household is food insecure.

Thus, a logistic model was specified to identify the determinants of food insecurity and to assess their relative importance in determining the probability of being in a food insecure situation at household level. Pertinent to the above statements and following Gujarati (1995), the functional form of logit model can be specified as:

$$P_i(Y=1|X) = \frac{1}{1+e^{-(\beta X)}} \text{ ---------- (1)}$$

For ease of exposition, we write (1) as:

$$P_i = \frac{1}{1+e^{-Z_i}} \text{ -------------------------------------- (2)}$$

The probability that a given household is food insecure is expressed by (2) while the probability for not food insecure is:

$$1-P_i = \frac{1}{1+e^{Z_i}} \text{ --------------------------------------- (3)}$$

Therefore, we can write:

$$\frac{P_i}{1-P_i} = \frac{1+e^{Z_i}}{1+e^{-Z_i}} \text{ ---------------------------------- (4)}$$

Now, (Pi/1-Pi) is the ratio of the probability that a household will be food insecure to the probability of that it will not be food insecure. More specifically, it represents simply the odds ratio in favor of food insecurity.

Finally, taking the natural log of equation (4), we obtain:

$$L_i = \ln\left[\frac{P_i}{1-P_i}\right] = Z_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_n X_n \quad \text{---- (5)}$$

where, *Pi* is a probability that household i of being food insecure and ranges from 0 to 1; *Zi* is a function of n explanatory variables (X) which can also be expressed as:

$$Z_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_n X_n \quad \text{---- (6)}$$

where, β_0 is an intercept, $\beta_1, \beta_2, \dots, \beta_n$ are slopes of the equation in the model, *Li* is log of the odds ratio, which is not only linear in X_i but also linear in the parameters, and *Xi* is vector of relevant household characteristics.

If the disturbance term (U_i) is introduced, the logit model becomes:

$$Z_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_n X_n + U_i \quad \text{--- (7)}$$

To scrutinize the dimensions of food insecurity, head count ratio, food insecurity gap and severity of household food insecurity have been estimated employing the Foster, Greer and Thorbecke (FGT) index (Foster, Greer and Thorbecke, 1984). This model was recently used by the International Food Policy Research Institute (IFPRI) for the analysis of household food insecurity (Hoddinott, 2001).

The FGT model can be expressed as follows:

$$P(\alpha) = \frac{1}{n}\sum_{i=1}^{q}\left[\frac{(m - y_i)}{m}\right]^{\alpha} \quad \text{--------------- (8)}$$

where, n is the number of sample households, y_i is the measure of per adult equivalent food calorie intake of the i^{th} household, m represents the cutoff between food security and insecurity (expressed in caloric requirement), q is the number of food insecure households, and α is the weight attached to the severity of food insecurity. In equation (8), $m - y_i = 0$ if $y_i > m$.

Attaching no weight to the severity of food insecurity is equivalent to assuming that $\alpha = 0$. So then, the formula reduces to P(0) = q/n, this is called the head count ratio and measures the proportion of sample households which are deemed to be food insecure. Giving equal weight to the severity of food insecurity among all food insecure households is equivalent to assuming that $\alpha = 1$. Summing the numerator gives the food insecurity gap; dividing this by m expresses this figure as a ratio. This index P(1) will provide the opportunity to estimate resources required to eliminate food insecurity through proper targeting. That is, the product (n*m*P1) gives the total calorie commitment required to bring the food insecure households to the given daily calorie requirement level.

In addition, giving weight to the severity of food insecurity among the most food insecure households is equivalent to assuming that $\alpha > 1$. The most common approach in poverty literature is to set $\alpha = 2$, yielding:

$$P(2) = \frac{1}{n}\sum_{i=1}^{q}\left[\frac{(m - y_i)}{m}\right]^{2} \quad \text{-------------------- (9)}$$

Hence, P(0) measures percentage of food insecure households, P(1) is food insecurity gap and P(2) is the severity of food insecurity.

3. Results and Discussion

3.1. Household Food Security Status and Adult Equivalent

Family size in terms of adult equivalent (AE) and food insecurity are related positively. The number of adult equivalents within the household does not necessarily imply job opportunities or access to income and the same was reflected in the survey result.

Households with less than 3.51 adult equivalents constituted 54.4% of food secure and 29% of food insecure households. Similarly, 55.8% of food insecure and 34.2% of food secure households have AE within a range of 3.51–6.00. A significant mean difference of adult equivalent was revealed in the survey results between the two groups at probability level of less than 1% (Table 1).

Table 1. Household food security and adult equivalent.

Adult equivalent group	Food secure (N = 114)	Food insecure (N = 86)	Total (N = 200)
	Percent		
≤ 3.50	54.40	29.00	43.50
3.51 - 6.00	34.20	55.80	43.50
6.01 - 8.50	11.40	10.50	11.00
≥ 8.51	0.00	4.70	2.00
Mean (AE)	3.77	4.51	4.09
Std. Deviation	1.68	1.89	1.81
t-value		2.880***	

**** = Significant at P < 0.01*

3.2. Household Food Security and Occupation Categories

Out of 86 food insecure households, those household heads involved in informal activity, government and unemployed contribute 23.30, 30.20 and 30.20% of food insecure households, respectively, whereas those involved in formal activity comprised about a quarter of food secure households.

Those household heads classified as unemployed but which are food secure obtain their income from relatives as gift and remittance and some from house rent. Not surprisingly, households whose household heads were employed in NGOs were found to be food secure. The result of the survey revealed a significant difference in terms of occupation of household head among the food secure and food insecure groups at less than 1% probability level (Table 2).

Table 2. Household food security status by occupation categories.

Occupation category	Food secure (N = 114)	Food insecure (N = 86)	Total (N = 200)	χ^2
	Percent			
Formal	27.20	14.00	21.50	27.56***
Informal	8.80	23.30	15.00	
Government	38.60	30.20	35.00	
NGOs	6.10	0.00	3.50	
Unemployed	16.70	30.20	22.50	
Others	2.60	2.30	2.50	

*** = *Significant at P < 0.01*

3.3. Household Food Security and Education of Household Head

In societies such as Ethiopia, where household heads are the major breadwinners of the households, the household head's educational status could determine the food security status of the entire household. The survey results showed an insignificant relationship at 10% probability level when household educational level was categorized into illiterate, write and read, primary, secondary etc and became significant while categorized as literate and illiterate at less than 5%. Categorization of the household head as literate and illiterate exhibited that 77% of household heads were literate. Among the literate households, 61.7% were found to be food secure and out of 46 illiterate households, 58.7% were food insecure (Table 3).

Table 3. Household food security by educational status of household head.

Level of education	Food secure (N = 114)	Food insecure (N = 86)	Total (N = 200)	χ^2
	Percent			
Illiterate	16.70	31.40	23.00	12.51
Write and read	7.90	6.98	7.50	
Primary, 1st cycle	5.30	6.98	6.00	
Primary, 2nd cycle	14.00	19.77	16.50	
Secondary, 1st cycle	8.80	4.65	7.00	
Secondary, 2nd cycle	31.60	22.00	27.50	
Certificate	1.70	1.16	1.50	
Diploma	10.50	6.98	9.00	
BSc/BA and above	3.50	0.00	2.00	
Literate	61.70	38.30	77.00	6.005**
Illiterate	41.30	58.70	23.00	
Total	57.00	43.00	100.00	

** = *Significant at P < 0.05*

The possible implication is that, in addition to other factors, while some level of education is important to household food security, its marginal contribution beyond primary education is small unless continued further or supported by vocational training that enable households to be self employed or competent to be employed.

3.4. Household Food Security Status by Number of Income Sources

The sampled households reported that 64% of them had engaged in one to two income-generating activities. Diversifying income sources is important to reduce risk in the urban economic environment, especially for low income groups. The average number of income generating activities or sources per household for the whole sample was found to be 2.3. The corresponding figures for food secure and food insecure were found to be 2.16 and 2.5, respectively. The reasons for higher mean of income sources for food insecure households might be associated with the type of activity households had been engaged in and the insufficiency of income to cover household's food and non-food expenditure.

It was hypothesized that number of income sources and food insecurity were related negatively. Within the food insecure group, the higher the number of income sources, the lower the percentage of food insecure households. The number of income sources exhibited a significant mean difference at less than 5% probability level between the two groups (Table 4).

Table 4. Household food security by number of income sources.

Number of income sources	Food secure (N = 114)	Food insecure (N = 86)	Total (N = 200)
		Percent	
1 – 2	71.00	54.70	64.00
3 – 4	24.60	37.20	30.00
5 – 6	4.40	8.10	6.00
Mean	2.16	2.50	2.30
Standard deviation	1.07	1.22	1.15
t-value		2.096***	

*** = *Significant at P < 0.01*

3.5. Household food security and daily income per adult equivalent

Household income is of paramount importance in achieving household food security, especially in the urban situation where people largely depend on earning capacity rather than on natural resources as in rural areas.

Daily income per adult equivalent was hypothesized to have a negative relationship with household food insecurity. About 16% of food secure and 38.4% of food insecure households were found to earn a daily income per adult equivalent of *Birr* 4 or less. Hence, as daily income per AE increases, the percentage of food insecure households exhibits a declining tendency. The mean daily income per adult equivalent of food secure and food insecure households were found to be *Birr* 16.73 and 6.93, respectively. The survey results depicted a significant mean difference in daily income per adult equivalent at probability level of less than 1% between food secure and food insecure household groups (Table 5).

Table 5. Household food security status by daily income per adult equivalent (*Birr*).

Daily income per adult equivalent	Food secure (N = 114)	Food insecure (N = 86)	Total (N = 200)
		Percent	
≤ 4.00	15.79	38.37	25.50
4.01 - 8	18.42	29.07	23.00
8.01 - 12	21.93	19.77	21.00
12.01 - 16	11.40	5.81	9.00
16.01 - 20	7.89	4.65	6.50
> 20	24.56	2.33	15.00
Mean	16.73	6.93	12.51
Standard deviation	18.80	6.30	15.54
t-value		-5.188***	

*** = *Significant at P < 0.01*

3.6. Household Food Security and Daily Food Expenditure per Adult Equivalent

Urban food expenditure in the Dire Dawa sample households was characterized by heavy reliance on purchased food commodities such as cereals, pulses, vegetables and livestock products. Food commodity from own production was almost non-existent. The mean daily food expenditure per AE of the whole sample was *Bir*r 4.04 and for food secure and food insecure households, the figures were 5.12 and 2.60, respectively. As the amount of daily food expenditure per AE increased, significant level of difference was observed between the two groups. The results of the survey suggested a significant mean difference in daily food expenditure per AE at less than 1% significant level ($P < 0.01$) between the two groups (Table 6).

Table 6. Household food security status by daily food expenditure (Birr).

Daily income per adult equivalent	Food secure (N = 114)	Food insecure (N = 86)	Total (N = 200)
		Percent	
≤ 4.50	47.37	88.37	65.00
4.51 - 8.00	40.35	10.47	27.50
8.01 - 11.50	8.77	1.16	5.50
11.51 - 15.00	2.63	0.00	1.50
≥ 15.01	0.88	0.00	0.50
Mean	5.12	2.60	4.04
Standard deviation	2.61	1.53	2.54
t-value		-8.53***	

*** = *Significant at P < 0.01*

4. Determinants of Food Insecurity

Nine independent variables that were hypothesized to have influence on household food insecurity in the study area were included in the model, of which seven were found to be statistically significant. The likelihood ratio has a chi–square distribution and it can be used for assessing the significance of logistic regression. It is used to test the null hypothesis that none of the independents are linearly related to the log odds of the dependent. It is an overall model test which does not, however, assure every independent variable is significant. The estimated result was found to be significant at less than 1% probability level revealing the null hypothesis that none of the independents are linearly related to the log odds of the dependent is rejected. Additionally, goodness of fit in logistic regression analysis is measured by count R^2 which works on the principle that, if the predicted probability of the event is greater than 0.50, the event will occur otherwise the event will not occur (Table 7).

Table 7. The maximum likelihood estimates of the logit model.

Variable code	Variable type and definition	Coefficient	Wald statistics	Odds ratio
HSZE	Household size in number	0.413	15.528***	1.512
HHSX	Dummy: 1 if household head is male; 0 otherwise	1.797	4.572**	6.033
MRTSTHH	Dummy: 1 if household head is married; 0 otherwise	-1.472	3.327*	0.229
EDUSTHH	Dummy: 1 if household head is literate; 0 otherwise	-1.161	5.992**	0.313
DYINCAE	Daily income per adult equivalent	-0.147	18.625***	0.863
PRPNFDEX	Proportion of expenditure on food	-0.008	3.276*	0.992
HGTCRDT	Dummy: 1 if household has got credit; 0 otherwise	-0.862	3.248*	0.422
HSAVACC	Dummy: 1 if household has saving account; 0 otherwise	-0.296	0.527	0.744
DEPNDRTO	Dependency ratio	-0.156	0.262	0.855
Constant		0.563		
Pearson Chi-square			66.67***	
-2 Log likelihood			206.65	
Sensitivity			69.80	
Specificity			78.90	
Percent correctly predicted (Count R^2)			75	
Sample size			200	

**** = Significant at P < 0.0l; ** = Significant at P < 0.05; * = Significant at P < 0.l0.*

Overall, the estimated model correctly predicted 75% of households to fall into the actual category. The sensitivity, correctly predicted food insecure is 69.8% and that of specificity, correctly predicted food secure is 78.9%. This indicates that the model has estimated the food insecure and food secure correctly. In light of the above summarized model results, a possible explanation for each significant independent variable is given consecutively as follows:

4.1. Household Size (HSZE)

Given the strong positive relationship between household size and food insecurity already noted in the descriptive part, it is not surprising that the estimated parameters are positive and highly significant. This positive relationship shows that the odds ratio in favor of the probability of being food insecure increase with increase in household size. Other things remaining equal, the odds ratio in favor of food insecurity increases by a factor of 1.512 as household size increases by one. The possible reason is that with the existing high rate of unemployment and fewer employment opportunities coupled with low rate of payment, an additional household member shares the limited available resources that lead the household to become food insecure.

4.2. Sex of Household Head (HHSX)

Sex of household head is represented by a dummy variable taking the value equal to one if the sample household is headed by male, zero otherwise. The estimated coefficient of the variable is found to be significant at less than 5% probability level and positively related with household food insecurity. That implies, assuming other variables are kept constant at their mean values; a household headed by a male is more likely to be food insecure compared to female headed households. A possible reason may be that female household heads are more responsible and pay due attention to their family. Therefore, having a woman as head of household implies higher caloric availability due to differences in spending priorities between males and females.

4.3. Marital Status of Household Head (MRTSTHH)

It is dummy variable taking a value of one if the household head is married and 0 otherwise The negative relationship with dependent variable is related to the economic scale of consumption items purchased and pooling available resources in one way or another and, possibly, married households reduce expenditure that would have been spent separately. The results of marital status and sex of household seems to be contradictory but headship is not only gifted to male as observed from sampled households. There were female household heads in the presence of male (husband) either due to economic reasons or absence of male household head in the area for any reasons. In general, being married in itself is not an assurance of escape from the risk of food insecurity. Rather, it is mainly because of the fact that household size, level of income and other factors of household affect food security status in relation to marital status.

4.4. Educational Status of Household Head (EDUSTHH)

Although the educational status of other income earner household members is of great importance, that of the household head plays a significant role in shaping household members by being exemplary and willing to invest in education. The negative coefficient for education can be explained in terms of contribution to education on working efficiency, competency, diversifying income, adopting technologies and becoming visionary in creating a conducive environment to educate dependants with the long term target of ensuring better living conditions than illiterate ones. Thus, being literate reduces the chance of becoming food insecure in the sample households.

4.5. Daily Income per Adult Equivalent (DYINCPAE)

The survey results showed a negative relation between daily income per adult equivalent and food insecurity and the coefficient is highly significant at less than 1% probability level. It corresponds with the prior expectation and the explanation is that income determines purchasing power of the household with the prevailing price so that those households with higher daily income per adult equivalent are less likely to become food insecure than low income households.

4.6. Proportion of Food Expenditure (PRPNFDEX)

Proportion of food expenditure spent by the household is significant at less than 10% probability level and related negatively with food insecurity. Given that other variables are held constant, as the proportion of expenditure on food increases, access to food by household also increases to the amount needed for household consumption. In the situation where some covariant shocks, happen, for instance rise in price of food commodity increasing the proportion on food expenditure helps to overcome the change and keep households accessing needed food and it also leads to the consumption of better quality food.

4.7. Household Access to Credit (HGTCRDT)

The results of the survey revealed that the variable under consideration is negatively related to food insecurity and significant at less than 10% probability level. The possible explanation is that credit gives the household an opportunity to be involved in income generating activities so that derived revenue increases financial capacity and purchasing power of the household to escape from the risk of food insecurity. Access to credit also supports consumption when households face hard times.

5. Extent and Severity of Food Insecurity

The results of the survey revealed that the head count ratio or incidence of food insecurity is 0.43 which implies that 43% of the sampled households cannot meet the daily recommended caloric requirement. The food insecurity gap was computed to discover how far the food insecure households are below the recommended daily caloric requirement and also provides the opportunity of to estimating resources required to eliminate food insecurity through proper targeting. The food insecurity gap was found to be 0.13 which indicates that, if the city administration mobilizes and distributes resources that can meet 13% of the caloric needs of every food insecure household and distribute to each household to bring it up to the recommended daily caloric requirement level, then theoretically, food insecurity could be eliminated. Finally, the severity of food insecurity, for the most food insecure households was found to be 0.059.

6. Summary and Policy Implications

The sample households were classified into food secure and food insecure groups based on kcal actually consumed by the households during the previous seven days of survey date compared with the recommended daily kcal per adult equivalent. Total daily food energy per adult equivalent of less than 2100 kcal was considered as food insecure and food secure otherwise.

The descriptive statistics showed the existence of a significant mean difference in daily income per AE and daily food expenditure per AE at less than 1% probability level between food secure and insecure households. The t-test for household adult equivalent showed a mean difference between the two groups at less than 1% probability level, but less than 5% significance level for number of income sources. Education status and occupation of household head were found to be significant at less than 5 and 1% significance levels, respectively.

Binary logit model output showed that seven out of nine variables, namely household size, sex of household head, marital status of household head, education of household head, daily income per adult equivalent, proportion of food expenditure and access to credit were found to be statistically significant with the hypothesized sign as determinants of household food insecurity in the study area.

The head count ratio revealed that 43% of sampled households were found to be food insecure. The gap and severity of food insecurity were estimated to be 13 and 5.9%, respectively.

Even if limited in scope and with a lot of questions remaining unanswered, this study has come up with results which have important policy implications. The relatively stagnant business condition coupled with poor investment performance in the study area has contributed to the deterioration of income generation capacity for food insecure households. In this situation, household size aggravates the problem of meeting food requirements. Therefore, action-based awareness creation on the impacts of population growth at the family, community and national levels should be strongly advocated in an attempt to reduce fertility and lengthen birth spacing. Moreover, development actors involved in the population issue should encourage households to have an acceptable number of children through provision of support such as covering schooling costs, providing training and other related incentives.

Furthermore, as income and food insecurity are negatively related, searching for and providing productive technical skills to make trainees competitive on the current labor market and able to generate income should be sought and promoted. Moreover, the administrative council should also consider the reallocation and utilization of food security program budgets for the purpose of employment generation schemes in urban Dire Dawa. Access to credit could also create an opportunity to be involved in economic activity that generates revenue to households. Development partners operating in the study area should provide credit to eligible households using targeting criterion that reflects actual characteristics of food insecure households. The other pressing issue related to provision of credit is the requirement of collateral and group lending procedures, which discourages so many households. People are afraid of holding accountability for others so individual lending should be considered as another option and collateral requirement should be avoided since there is a need to lift food insecure households out of their current situation. Simultaneously, borrowers should be encouraged to save or contribute as matching fund to reach the limited resources for a large number of needy people.

The effect of education on household food security reveals the significant role of the variable in consideration for betterment of living conditions. The more the household head is educated, the higher will be the probability of educating other family members too, so that they become familiar with modern technology, which the twenty first century badly demands. Therefore, strengthening both formal and informal education and vocational or skills training should be promoted to reduce food insecurity in Dire Dawa town.

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Determinants of the Adoption of Physical Soil Bund Conservation Structures in Adama District, Oromia Region, Ethiopia

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Abstract: This study emphasizes the adoption of physical soil bund structures including the major factors influencing the adoption process. The study is based on the data collected from 120 households. Two analytical techniques, descriptive statistics and logistic regression function were employed in analyzing the data. The findings indicate that a host of factors, most of which are policy related, were responsible for poor technology adoption. In this regard, adoptions of technologies are predominantly influenced by economic variables such as land size, livestock holdings and income of the households. Furthermore, institutional factors, such as access to credit, mass media, and extension services as well as the educational level of the farmers are primarily influencing the adoption decision. The results of the study confirm that past extension approaches have been biased against natural resource management. With the exception of physical soil bund structures, other components of soil conservation packages were found to be marginalized. Overall, survey results reveal that integrated natural resource oriented approaches were not adopted. Based on the findings, it is strongly recommended that policy makers and technical institutions should readdress the policy-related issues to facilitate extension systems that will ensure environmentally sustainable development.

Keywords: Adoption; Conservation; Physical Structures; Small Scale Farmers

1. Introduction

The agriculture sector in Ethiopia must nearly double its yields on existing farm land to meet food needs, which are increasing due to the high growth rate of the population. In Ethiopia, agriculture contributes a significant share of family food self-sufficiency and national food security, playing an important role in the development of the national economy. In this regard, the Ethiopian Economic Association contends that agriculture is the mainstay of the national economy, where has accounted for about half (47%) of the Gross Domestic Product (GDP) in recent years and more than 80% of the economically active rural population earning their livelihood from crop and livestock production (EEA, 2005). However, despite its importance for national development and food security, agricultural land productivity is declining as time progresses while the population is increasing at a fast growth rate. The main reason behind the low productivity of farm land is attributed to land degradation which is commonly concerned with soil degradation of the arable land. In Ethiopia in general and in East Shewa Zone in particular, agricultural land has been under continuous cultivation for the past several decades and it is physically and chemically degraded. The Central Rift Valley, (the study area), is among the severely degraded areas, where the severity of the problem is aggravated by erosive agricultural practices.

In this regard, the fundamental attempts for agricultural and rural development necessitate the extension of intervention to promote improved agricultural technologies and appropriate natural resources management. To this end, the Ethiopian government has initiated a massive program of soil and water conservation with the support of international organizations. In addition to these efforts made through conservation related projects, considerable attention has been put in place for the promotion of soil and water conservation practices through national extension package programs as a part of the agricultural development strategy. However, from experiences over the past years it appears to have not made progress with respect to bringing major impacts on the adoption of modern technologies (Wagayehu, 2003). On the other hand, despite widespread soil degradation and a low level of technology adoption, the limited efforts have been made to identify the nature of physical soil bund conservation structures adoption and have not been sufficient to summarize defined conclusions. Therefore, this study examines the adoption of physical soil bund conservation structures and determines the influencing factors in the study community.

2. The Study Methodology

This study was conducted in Adama District in East Shewa Zone, Oromia Regional State, Ethiopia. The target population was farmers who are living in the peasant associations (PAs) of the district who have participated in the extension package program and soil conservation projects. The sampling procedure adopted was stratified cross-sectional sampling method. The district was divided into three sub-groups based on the agro-ecology, and then two PAs were selected from the peasant associations of each agro-ecology. A sampling frame was prepared from a list of farmers on a membership registration book. For data collection purposes, six PAs were included in the study group and 120 farmers (20 from each PA) were selected by random sampling procedure. The selection of sample PAs was also conducted by random sampling procedure within each sub-category of peasant association. Therefore, based on a suggestion made by

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ISSN 1992-0407

Poate and Daplyn (1993) in the first stage of sampling, six PAs were selected by random sampling techniques in each category and, in the second stage, twenty farmers were selected from each selected PA using simple random sampling technique. In order to maximize the reliability of the results, relevant information was collected from primary and secondary data sources for analytical purposes, as well as for crosschecking of the information. The primary information was collected from sampled farmers by enumerators who administered the structured interview schedule. Finally, data collected from different primary and secondary sources were summarized and transferred into Statistical Package for Social Sciences (SPSS) computer program. Using SPSS sub programs, the descriptive statistical techniques were employed to determine the nature of data for final decisions and recommendations.

In the meantime, Logit statistical model was selected for further data analysis and interpretation. According to Karki and Bauer (2004), this is the most commonly used econometric model with limited dependent variables and is used to examine the relationship between adoption and determinants of adoption. Based on Gujarati (1988) and Bohrnstedt and Knoke (1994), the following Logistic distribution model was selected and employed to determine the odds (probability) of physical soil bund structure adoption decision of the farmers.

[illegible]

(Probability of technology adoption)

[illegible]

(Probability of technology non-adoption)

[illegible]

Thus, the logit (L_i) multiple regression model (logistic distribution) containing 12 predictors (binary and continuous variable) was specified and regressed against dependent binary of soil bund technology adoption. In order to estimate the probability of adoption of the physical soil bund conservation structure, the above model (equation 3) was employed considering that technology adoption is a dichotomous dependent variable and independent variables are socio-economic factors that can influence the adoption process.

3. Results and Discussion

3.1. Demographic Variables and Physical Soil Bund Structures Adoption

The demographic variables considered in this study are age of the family head, educational level, family size, sex and marital status of the respondent. To determine the influence of the age characteristics of the sample households on the adoption of physical soil bund structure, a comparison was made between different age categories of the respondents and was tested using frequency of each category. Results showed that about 78.3% of the respondents were within the age range of 30 to 60 years which is considered to be the effective age group to produce food, whereas 10 and 11.7% were below 30 and above 60 years, respectively (Table 1). These findings are consistent with other findings in Arsi zone (Haji, 2002) which indicated that the proportions of young and older farmers are lower compared to other age categories and the same source contends that the low proportion of this age group is due to lack of access to land resources.

Table 1. Adoption of soil bund in relation to age of the respondents.

Age category	Adopters		Non-adopters		Total	
	Number	Percent	Number	Percent	Number	Percent
< 30 years	10	8.3	2	1.7	12	10.0
30-40 years	35	29.2	7	5.8	42	35.0
41-50 years	22	18.3	6	5.0	28	23.3
51-60 years	22	18.3	2	1.7	24	20.0
> 60 years	9	7.5	5	4.2	14	11.7
Total	98	81.7	22	18.3	120	100.0

More specifically, about 68% of physical soil bund structure adopters were found to be within the age range of 50 and below years, while the remaining 32% of the adopters were found to be above the age of 50 years. These findings are consistent with literature, which confirms that younger farmers are more likely to be adopters of technology. When a comparison is made between the different categories, the farmers within age category of 30 to 40 years were found to be high adopters (of total respondent, 29.2%) of the physical soil bund structures, while only 5.8% of this group had not adopted the technology. On the contrary, out of the total respondents, only 8.3% of the farmers within the age category below 30 years were found to be adopters. The proportion of the older farmers (above 60 years) in the whole sample was about 12% and, within this age category, 9.2% were found to be adopters of soil bund structure technology (Table 1). These findings were also consistent with the findings from North Shewa Zone reported by Mulugeta (2000) which stated that, as the age increases, the decision to invest on land conservation decreases.

Family members are considered to be all persons related to the particular farmer and dependent on family farm land (Mulugeta, 2000). The survey results show that the average family size of the respondents was found to be 6.54 persons which, according to CSA (1995) cited by Mulugeta (2000), is above the national average of 5.17 persons per family and also greater than the regional average of 5.4 persons reported in the CACC (2003). When the adoption situation of the respondent is considered, about 67% of soil bund technology adopters were found to be those respondents with 3 to 8 family size out of the total sample farmers, whereas this group of farmers constitutes about 82% when considered only among the adopters category (Table 2). The proportion of non-adopters in such categories of family size (3 to 8 family members) was found to be 68.2%, whereas the remaining 31.8% are within the family size categories of below three and above eight when considering the non-adopters category only.

Table 2. Adoption of soil bund in relation to family size.

Category of family size	Adopters		Non-adopters		Total	
	Number	Percent	Number	Percent	Number	Percent
< 3 members	1	0.8	3	2.5	4	3.3
3-5 members	29	24.2	5	4.2	34	28.3
6-8 members	51	42.5	10	8.3	61	51.0
9 and above	17	14.2	4	3.3	21	17.5
Total	98	81.7	22	18.3	120	100.0

Based on the survey information, the results related to level of education of the respondent are summarized and presented in Table 3. According to these findings, out of the total sampled households, 80 respondents (about 67%) have formal education. Out of the total adopters, about 65% have formal education, whereas the remaining 35% are adopters with no formal education. Literature on soil conservation, for example, Tesfaye (2003) confirms that the better educated farmers show better positive response to soil conservation technology adoption and better decisions on soil bund retention on their farm land, which is adequately consistent with these findings.

Table 3. Adoption of soil bund with respect to level of education.

Level of education	Adopter		Non-adopter		Total	
	No.	%	No.	%	No.	%
No formal education	34	28.3	6	5.0	40	33.3
Adult education	6	5.0	3	2.5	9	7.5
Primary education	35	29.2	10	8.3	45	37.5
Junior-secondary	15	12.5	1	0.8	16	13.3
Secondary education	8	6.7	2	1.7	10	8.3
Total	98	81.7	22	18.3	120	100.0

More specifically, the numbers of those who have primary education were relatively high in both adopters and non-adopters with about 36 and 45% of each category, respectively. On the other hand, survey results show that, out of 71 respondents who have above adult education, nearly 82% adopted physical soil bund structures (Table 3) and this result is more or less closer to the findings of Mulugeta (2000) who reported that 89.7% of farmers who attend formal education were users of physical soil conservation structures. Moreover, Weir and Knight (2000) suggested, indicating that the more educated the farmers, the more rapidly adoption and diffusion would take place in that particular community.

Table 4 provides the sex composition of the respondents as related with farmer's adoption trends of physical soil bund structure in the sampled farmers. Based on the survey results, it was evident that, out of the total of 120 respondents, 78% were found to be male-headed households, while about 22% of respondents were female-headed households. The proportion of households headed by males is substantially higher than that of females, reflecting the fact that males in most Ethiopian societies assume execution of the major roles of the agricultural activities and the head is considered as the main bread winner in the household as well as the one who bears responsibility for the household. In general, the findings of the survey indicate that there is a strong relationship between technology adoption and sex of the respective farmer and this result is consistent with the results reported by Yisehak (2002), who indicated the existence of a significant relationship between sex of the respondents and use of improved seeds in the study community.

Table 4. Adoption of soil bund with respect to sex composition.

Sex category	Adopters		Non-adopters		Total	
	No.	%	No.	%	No.	%
Female	20	16.7	6	5.0	26	21.7
Male	78	65.0	16	13.3	94	78.3
Total	98	81.7	22	18.3	120	100.0

Regarding adoption rate, out of a total of 94 male respondents, about 83% were found to be adopters of physical soil bund structures, whereas the proportion of female adopters in the female category was nearly 77% (Table 4). In addition, about 80% of the adopters were male and 20% were female adopters in the adopters' category of respondents and, in the same manner, the proportion of male respondents was higher than female respondents in the category of non-adopters. Furthermore, the analysis of survey data shows that, among the total respondents, the majority (93.3%) were married, whereas the remaining 6.7% were found to be single household headed, due to either not being married, or being widowed or divorced, and among total non-adopters, the largest proportion (about 82%) of respondents were found to be married and only the remaining 18% of the non-adopters were single farmers. Concerning physical soil bund practices adoption, nearly 96% in the adopter category were married males and the remaining 4% were married female respondents.

3.2. Adoption Status and Comparison of Major Soil Conservation Practices

The overall analysis and comparisons for many introduced soil conservation practices were conducted and are presented in Table 5 in order to determine the status of adoption and make relative comparison between different practices with respect to farmers adoption of each practice which can help the researcher to generate conclusions concerning the attention and support of those particular practices and recommendations which is the ultimate goal of the study. Nearly 82% adoption rate for physical soil bund structures is found to be encouraging by ignoring the resources consumed with respect to the promotion of these practices in the past Food for Work Program (WFP) implementation years.

Contrary to the adoption of soil bunds, the adoption rates of conservation tillage (0.8%), fallowing (2.5%) and use of crop residue (7.5%) were found to be discouraging and they are first, second and third from the last, respectively. The other worst aspect of these practices is that 80.8%, 76.7 and 74.2% of the respondents are not aware of conservation tillage, fallowing and use of crop residue, respectively (Table 5). In these aspects, the findings show that past extension approaches were lacking appropriate packaging and integration of agricultural and natural resources oriented technologies to sustain land resource.

Table 5. Comparison of adoption of different soil conservation practices.

Conservation practices	Adopters		Non-adopters		No awareness	
	Number	Percent	Number	Percent	Number	Percent
Soil bund	98	81.7	22	18.3	Nil	Nil
Crop rotation	85	70.8	29	24.2	6	5.0
Intercropping	47	39.2	29	24.2	44	36.7
Conservation tillage	1	0.8	22	18.3	97	80.8
Reforestation	74	61.7	31	25.8	15	12.5
Use of crop residue	9	7.5	22	18.3	89	74.2
Contour farming	58	48.3	39	32.5	23	19.2
Area closure	81	67.5	33	27.5	6	5.0
Fallowing	3	2.5	23	19.2	92	76.7

From an agricultural point of view, land is an indispensable factor for crops and livestock production and the proper utilization of land under different components would contribute to the development of national agricultural production (CACC, 2003). However, the results of this study indicate that the attempt to promote proper land utilization to sustain agricultural land productivity looks minimal in the study community.

3.3. Socio-Economic Variables Associated with Soil Bund Adoption

Before moving on to look at the detailed analysis of the farmer's and farm characteristics effect on technology adoption, the usual procedure to test for means differences and tendency of association between variables were conducted using independent T-test and Chi-square test techniques, respectively. The results of these two test statistics are presented in Table 6 for continuous variables and in Table 7 for categorical variables. As shown in Table 6, except land holding, all selected variables were found to be statistically significant, indicating that physical soil conservation technology adoption decisions had significant association with the mentioned respective variables. In this aspect, characteristics of the household, such as age, education level attained by farmers and family size of the respondent, appeared highly significant ($P < 0.01$). Moreover, the remaining variables that are livestock holding and yearly income of the household also were found to be significant ($P < 0.05$) ensuring dependency of physical soil conservation technology adoption on these two variables.

Table 6. Summary of means' difference for discrete explanatory variables.

Continuous variable	Mean for different categories			T-Test	
	Adopters	Non-adopters	Mean difference	T-Value	P-Value
Age of respondent	43.35	54.10	-10.74	-2.829	0.009**
Education level	3.84	1.43	2.41	3.300	0.002**
Family size	6.53	6.05	0.48	0.804	0.003**
Land holding (ha)	2.51	2.66	-0.15	-0.505	0.614ns
Livestock (TLU)	3.81	2.75	1.06	1.278	0.025*
Yearly income (Birr)	3281.23	1905.67	1375.57	2.024	0.045*

*** and * = Significant at $P < 0.01$and $P < 0.05$, respectively; ns = Non-significant at $P < 0.05$.*

Age of the household head is negatively associated with adoption of physical soil bund structure (Table 6), which is similar to other study findings, while the result of the negative association of the landholding was unexpected and uncommon in most of the previous empirical studies. Federe *et al.* (1982) suggested relatively closer or similar results with these findings, stating that farm size is one of the factors on which empirical adoption study is focused but that farm size can have different effects on the rate of adoption depending on the characteristics of technologies and institutional setting of the service delivery system.

On the other hand, the relationships between adoption of physical soil bund structure and other variables, like education level of the household, family size, age, livestock holding and yearly income of the household were found, as expected, to have positive association to adoption. In the meantime, influence of landholding on adoption of physical soil conservation practices appeared to be insignificant in this particular study. According to Wegayehu (2006), age of household head can influence the availability of labor and that is one of the most important factors of production to farmers in rural areas. This, in turn, determines the decision of households as to which soil conservation type to adopt on their farm land and our results are consistent with his findings. In the meantime, it has been realized from literature reviews that many categorical variables practically affect the adoption of soil conservation technologies in the small scale farming systems of Ethiopia in general and in the study community in particular. Table 7 shows detailed investigations of these categorical variables in this study.

Table 7. Association between categorical variable and soil bund adoption.

Categorical variables	Adoption (%)		Chi-square	
	Non-adopters	Adopters	X^2-Value	P-Value
Gender (sex):				
Male	11.7	66.7	4.988	0.026*
Female	5.8	15.8		
Marital status:				
Married	15.0	78.3	57.408	0.000**
Single	2.5	4.2		
Responsibility in PAs:				
Yes, have	2.5	30.0	1.833	0.176ns
No, don't have	15.0	52.5		
Availability of credit:				
Yes, available	14.2	70.0	25.757	0.000**
Not available	3.3	12.5		
Access to mass media:				
Yes, accessible	15.0	69.2	0.007	0.933ns
Not accessible	2.5	13.3		
Sources of information:				
Extension staff	14.2	66.7	17.652	0.000**
Non-extension staff	3.3	15.8		
Main occupation:				
Crop farming	15.0	56.7	13.672	0.000**
Mixed farming	2.5	25.8		

*** and * = Significant at $P < 0.01$and $P < 0.05$, respectively; ns = Non-significant at $P < 0.05$.*

Regarding the effect of sex on technology adoption, Wegayehu (2006) suggested that sex of household determines access to soil conservation technological information provided by extension agents and soil conservation related projects operating in the area. Apparently, the marital status and social participation (responsibility in PAs) would also influence the adoption of any particular technology. The results of this survey indicate a strong association between social characteristics of the farmers and soil conservation technology adoption. The sex of the respondent with Chi-square of 4.99 and the marital status of the household with Chi-square value of 57.41 were found to be statistically significant, ($P < 0.05$) and ($P < 0.01$), respectively. In addition, the main farming system of the respondent also formed part of this study and it was found to be statistically significant with a Chi-square value of 13.67, indicating strong association between soil conservation technology adoptions and farming system. Among the many institutional variables, it was realized that credit facility, with Chi-square value of 25.76, and source of extension information, with Chi-square value of 17.65, were statistically significantly ($P < 0.01$) different (Table 7).

3.4. Economic Variables and Physical Soil Bund Structure Adoption

The economic variables include the estimated yearly income, land holding and main occupation of the farmers. Concerning family yearly income, the result shows that the minimum income of the respondents who reported was 300 *Birr* and the highest was found to be 23,260 *Birr,* indicating an average household income of

3,038.5 *Birr* with 2,863.0 *Birr* standard deviation and tossing coefficient of variation (CV) of about 94%. Furthermore, the results indicate that about half (45.8%) of the respondents earned a yearly income in the range of 1,000 to 3,000 *Birr*. Those in the yearly income categories of less than 1,000 *Birr* and those with greater than 7,000 *Birr* constitute nearly 15.8 and 7.0%, respectively (Table 8). In general, based on these results, it is possible to predict that the better the yearly income, the more such farmers would adopt the introduced conservation technology to alleviate the land degradation process.

Table 8. Adoption of soil bund with respect to yearly income of households.

Income category	Adopters		Non-adopters		Total	
(*Birr*)	Number	Percent	Number	Percent	Number	Percent
< 1000	8	6.7	11	9.2	19	15.8
1,000-3,000	40	33.3	15	12.5	55	45.8
3,001-5,000	22	18.3	6	5.0	28	23.3
5,001-7,000	6	5.0	4	3.3	10	8.3
7,001-10,000	5	4.2	1	0.8	6	5.0
> 10,000	2	1.7	0	0.0	2	1.7
Total	83	69.2	37	30.8	120	100.0

Coefficient of variation (CV) ≈ 94%

The discussion of this section is based on the results of household farm size summarized in Table 9, in which the overall average landholding of the households was found to be 2.54 ha with corresponding standard deviation of 1.2 ha, leading to about 47% coefficient of variation. The findings indicate that the average farm land holding of the study PAs is greater than one hectare of national average in the country, as reported by EEA (2000) cited in Haji (2002) and as well as the regional average of 1.36 ha per household. In the study group of the district, a total of 64 respondents (53.4%) are reported to be in the range of farm land holding category of 0.5 to 2.5 ha of land and these findings are closer to the 52.1% reported by the CACC (2003) and 39.2% of the respondents were land holders within the range of 2.5 to 4.0 ha (Table 9). The remaining 7.5% includes the holders of less than half and greater than four hectares.

Table 9. Adoption of soil bund structures in relation to land holding.

Land size category	Adopters		Non-adopters		Total	
(ha)	Number	Percent	Number	Percent	Number	Percent
< 0.50	2	1.7	1	0.8	3	2.5
0.50-1.50	27	22.5	5	4.2	32	26.7
1.51-2.50	25	20.8	7	5.8	32	26.7
2.51-4.00	41	34.2	6	5.0	47	39.1
> 4.00	3	2.5	3	2.5	6	5.0
Total	98	81.7	22	18.3	120	100.0

Coefficient of variation (CV) ≈ 47%

With respect to adoption of soil conservation structures, a total of 41 farmers (34.2%) in the land holding category of 2.5 to 4.0 ha were adopters of the introduced physical soil bund conservation practices in the study areas with the corresponding 5.0% of non-adopters. Furthermore, out of the group with farm land size in the range of 0.5-2.5 ha, the adopters and non-adopters constituted 43.2 and 10.0% of the total respondents, respectively (Table 9). The results showed that optimum land size ownership might be the major factor in promoting technology adoption in the small scale farming systems of Ethiopia in general and Adama District in particular.

Moreover, the results of the investigation on different occupational opportunities for farmers considered in the study revealed that crop farming and mixed crop-livestock farming are the two major occupations (Table 7) while livestock farming (pastoralist) is not commonly practiced in this particular farming community. In this respect, the results indicate that about 72% of the total respondents are engaged in crop farming out of which 56.7% were found to be adopters of physical soil bund structures, whereas the rest, 15% of the sample size, were not adopters. On the other hand, out of a total of 120 respondents, 34 (28.3%) were engaged in crop-livestock mixed farming and 30 farmers, 88.2% of this group or 25.8% of the total sample size (Table 7) were found to be adopters of physical soil bund structures.

3.5. Farm Land Related Variables and Adoption of Soil Bund Structures

In this study, farm land related variables include the physical conditions of particular farms, farm land distance from household residence and public facilities. Data of the respondents' farm land condition (erosion status) and farm land distance from the residence of the respondents are presented in Tables 10 and 11, respectively, and farm land distance from other public support providing facilities are also discussed in this section.

Table 10. Observed erosion problem on household farm land.

Category of soil erosion status	Adopters		Non-adopters		Total	
	Number	Percent	Number	Percent	Number	Percent
Very severe	65	54.2	7	5.8	72	60.0
Severe	32	26.7	10	8.3	42	35.0
Minor	1	0.8	3	2.5	4	3.3
No problem	0	0.0	2	1.7	2	1.7
Total	98	81.7	22	18.3	120	100.0

Basically, natural farm land characteristics and the erosive features of the soil represent major factors in dictating human intervention in small scale farming systems. With respect to biophysical condition of the farm land, the overwhelming majority of respondents (95%) reported very severe and severe soil erosion problems, including fertility decline and water logging, whereas only 5% of the total sample had only minor or no soil degradation problems on their farm lands (Table 10). Of the group with very severe and severe soil erosion problems, about 85% adopted physical soil bund conservation practices. On the contrary, only 16.7% of the group with minor or no soil degradation problem adopted the physical soil bund conservation structures, while the remaining 83.3% reported that they had no relevant reason to adopt physical soil bund structures.

Moreover, with respect to farm land distance, out of the total respondents, 63 farmers (53.4%) whose location of farm land is less than 2 km from their home were found to be physical soil bund structures adopters (Table 11). In addition, farmers constituting 24.6% of the total respondents in the 2 to 4 km distance category have adopted introduced technology. Five respondents (4.2%) of the category with farm land located at more than 4 km distance were found to be adopters of soil bunds. In the same manner, about 69% of the total respondents, whose farm land is within the near and medium distance (below 4 km) to development centers, category, were more likely to adopt physical soil conservation structures and, on the contrary, nearly 18% of the respondents in the same distance category to development center were non-adopters of conservation structures.

Table 11. Effect of farm land distance from residence on soil bund structure adoption.

Farm land distance category (km)	Adopters		Non-adopters		Total	
	Number	Percent	Number	Percent	Number	Percent
Not far (< 2 km)	63	53.4	16	13.6	79	67.0
Medium (2-4 km)	29	24.6	5	4.2	34	28.8
Far (above 4 km)	5	4.2	0	0.0	5	4.2
Total	97	82.2	21	17.8	118	100.0

With regards to road infrastructure facility, the results of this study indicate that 42% of the total sample who adopted the physical soil bund structures was those whose farm land distance from road facility were more than 6 km. This value is relatively higher than 39.5% of the total respondents whose farm land is within 4 km distance from primary roads and found to be adopters of the soil bunds. As argued by the EEA (2006), these findings also revealed that under development and poor infrastructure in the country in general and in the study area in particular are raising doubt about the economic feasibility of the technology adoption.

3.6. Institutional Support Related Variables Without Respect to Adoption

This section deals with the influences of institutional support related variables, mainly extension service, access to mass media and farmers' experience in physical soil conservation related projects including level of farmers' participation in the decision making process, on adoption rates of the conservation structures. With regard to extension services delivery, 36.4% of the respondents, confirmed that they were visited 1 to 2 times (days) per month by Development Agents (DAs), followed by 34.8% being visited 3 to 4 days per month. On the other hand, 6% of the total respondents reported no visit by DAs to their home or farm land. The investigation on DAs' visits to farmers shows that the farmers who were visited 3 to 4 days per month amounted to 41 out of whom 97.6% were found to be the adopters implying that the more visits received from development agents, the more likely farmers were to adopt physical soil bund structures to reduce soil degradation process on their farm lands. Out of the total respondents, only a few (2.5%) of non-visited farmers were found to be adopters of the promoted soil bund technology.

In the extension information delivery system, mass media are the most common extension channels to reach even the remotest areas and the majority of rural population in the country. As a result, the survey results reveal that 73.3% of the respondents had access to mass media (Radio, News Papers and Television) and were helped by it to adopt physical soil conservation practices, while the remaining 26.7% had no access to any kind of mass media in the past three to five years. Furthermore, about 82% of the total farmers who had access to radio were found to be adopters of physical soil bund structures to sustain agricultural land productivity.

In this study, farmers' experience of soil and water conservation related projects indirectly refers to any form of assistance rendered to the farmers in the area of soil conservation with the ultimate goal to promote adoption of soil conservation technology by avoiding resource limitation. Tables 12 and 13 present summary of survey data of farmers' experience in conservation related projects and level of farmers' participation in planning and evaluation processes, respectively. As indicated in Table 12, the majority (98.3%) of the total respondents were involved in different soil conservation related projects for 5 to 20 years and out of this group, about 83% were found to be adopters of physical soil and water conservation (soil bund) structures.

Table 12. Farmers' experience in soil conservation related projects.

Farmers' experience	Adopters		Non-adopters		Total	
	Number	Percent	Number	Percent	Number	Percent
No experience	1	0.9	1	0.9	2	1.7
< 5 years	4	3.4	2	1.7	6	5.2
5-10 years	39	33.6	14	12.0	53	45.7
11-15 years	13	11.2	0	0.0	13	11.2
16-20 years	17	14.7	1	0.9	18	15.5
> 20 years	22	19.0	2	1.7	24	20.7
Total	96	82.8	20	17.2	116	100.0

Table 13. Level of farmers' participation in planning and evaluation process.

Level of farmers' participation	Adopters		Non-adopters		Total	
	Number	Percent	Number	Percent	Number	Percent
Very good	1	0.8	Nil	Nil	1	0.8
Good	13	11.1	1	0.8	14	12.0
Satisfactory	23	19.7	2	1.7	25	21.4
Poor	37	31.6	5	4.3	42	35.9
Not at all	22	18.8	13	11.1	35	29.9
Total	96	82.1	21	17.9	117	100.0

Concerning participation in planning and evaluation processes of conservation projects, about 66% of the responding farmers reported their participation in same as poor and/or had no participation at all in the process of the development projects (Table 13). However, 76.6% of this particular group was found to be adopters of physical soil bund structures which might be due to the heavy promotion or publicity by the projects regardless of participation. The remaining 34.2% reported that their participation was very good to satisfactory and the adoption rate within this group which was about 93% is a very good indication of the influence of participation on technology adoption.

Furthermore, the survey related to level of farmers' participation went further and included assessment of their participation in problem identification, priority setting and decision making process. In this regard, about 24, 39 and 37% of the relevant respondents confirmed that they had poor participation in problem identification, priority setting and decision making process, respectively. The remaining proportion reported their participation in the mentioned project process as very good, good and satisfactory. In general, the results indicate that there is positive correlation between farmers' participation in the project process and technology adoption. In summary, the findings of the survey indicate that, in the past extension intervention, farmers' participation at different stages of the development project, including soil conservation related projects, was a neglected area.

3.7. Logistic Regression Summary and Discussion.

In this particular study, to look for a suitable model for selecting variables among total independent variables, different techniques and tools were employed to establish a relevant regression line to determine the relationship between dependent and independent variables. The dependent variable, which is adoption of physical soil bund structures, was taken as a categorical (dichotomous) variable with binary representation; while independent variables were a mixture of continuous and categorical variables, in which categorical variables were arranged in a binary manner as indicated in Table 14.

Table 14. Parameter estimate for adoption of physical soil bund structures.

Explanatory variables	Parameter estimates			
	Coefficient	Wald statistics	Exp (B)	P-Value
Constant	1.629	0.901	5.101	0.343 ns
Age of household head (years)	-0.084	7.180	0.919	0.007***
Sex of household head (1)	1.843	4.765	6.317	0.029**
Education level (years)	0.231	2.979	1.260	0.084*
Labor shortage (1)	-0.729	1.226	0.482	0.268 ns
Information source (1)	0.678	0.536	1.969	0.464 ns
Experience in projects (years)	0.043	0.740	1.044	0.390 ns
Farm land distance from development center (km)	0.479	3.713	1.615	0.054*
Land holding (ha)	0.458	1.871	1.580	0.171 ns
Access to mass media (1)	2.724	3.392	15.249	0.066*
Access to training (1)	0.260	0.147	1.297	0.701 ns
Land renting experience (1)	-1.462	3.050	0.232	0.081*
Livestock holding (TLU)	0.130	0.428	1.139	0.513 ns

****, ** and * = Significant at $P < 0.01$, $P < 0.05$ and $P < 0.10$, respectively; ns = Non-significant at $P < 0.10$.*

Regarding the fitness of the selected regression line, the model Chi-square (X^2) of 35.39 appeared statistically significant, indicating that including selected explanatory variables significantly reduced the log likelihood ratio of the model when compared with the model established using only intercept. The classification table classified and correctly predicted 95.7% of the adopters and 50% of the non-adopters, whereas the model's overall correct prediction was found to be 87.5%. From regression analysis, access to mass media was found to be the leading variable in influencing the change in odds ratio of the technology adoption. The observed 15.25 odds ratio for accessibility of farmers to mass media (Table 14) indicated that the odds of adoption were higher for each one point increase in respondent's accessibility to any kind of mass media. On the other hand, odds ratio of land renting was smallest of all, in the opposite direction, indicating that with a one point increase on the experience of land renting scale being associated with the odds of disapproving (non-adoption) the technology would increase by a multiplicative factor of about 0.25 point. For the sex (dummy variable), the 6.32 odds ratio means that the odds (probability) of approval of the technology adoption by the farmer would increase by this point as the binary dummy variable changed to one point.

Furthermore, seven explanatory variables (education level, source of information, farm land distance from development center, land size, farmers' experience in conservation related projects, livestock holding and farmer training) make a different contribution to odds ratio in the expanded model varying between greater than one and less than two, indicating positive association between predictors and technology adoption. On the other hand, three of the explanatory variables-age, labor shortage and experience of land renting-influence the odds ratio of technology adoption by less than one factor, indicating negative association between explanatory variables and binary technology adoption. In general, eleven explanatory variables, except farm land distance from development center, provided similar association as predicted and, out of the variables, farm land distance moved in the opposite direction to hypothetical assumption which suggests negative association with technology adoption. Overall, out of the selected twelve explanatory variables, 50% were found to be significant at different probability levels. In this regard, the age of respondents was statistically highly significant ($P < 0.01$), sex of household head was statistically significant ($P < 0.05$), and the remaining four explanatory predictors (farm land distance, education, access to mass media and land renting) were found to be statistically significant ($P < 0.1$) among the variables attaining significance at different statistical significance levels (Table 14). The model results confirm that the educated farmers are more likely to adopt physical soil bund structures compared to those who did not attain formal education due to the fact that educated farmers would have more access to information. This indicates that farmers with formal education are likely to be aware of soil degradation severity which motivates them to seek appropriate innovation in order to mitigate the degradation process.

4. Conclusion

The survey results indicated that a majority of respondents perceived soil erosion and soil fertility decline as the major threats to their farm land sustainability, since the problem of soil degradation is very serious on crop land. However, despite the widely prevailing problems of farm land degradation, adoption of most of the biological and physical soil conservation technologies appeared minimal. Basically, practices such as crop rotation, intercropping, fallowing, conservation tillage and crop residue management are essential components of soil conservation packages to enhance soil fertility of farm lands, but the adoption rate of those practices was found to be poor compared with soil bund structure indicating lack of appropriate packaging of the technologies in the farming system.

Due to lack of emphasis on extension service delivery systems in the past extension package program implementation, almost all soil conservation practices have been marginalized throughout the past many years, leading to non-sustainable farm land productivity. According to the findings of this study, participation of the farmers in extension package programs has improved the use of agricultural technologies among the farming community in previous years, but integration of agricultural technologies with environmentally-sound technologies and management is lower than the theoretical recommendations, leading to natural resources degradation and threats to environmental sustainability.

The study further revealed that almost all predicted socio-economic factors appeared to influence the adoption of soil bund structures in the small farming communities. In this regard, participation of farmers in soil conservation programs and adoption of introduced technologies are predominantly influenced by economic variables such as land size, livestock holdings and yearly income of the households. As confirmed by the findings of the study, farmers with greater resources are more likely to participate in the program and then adopt the introduced technologies compared to resource-poor farmers. Furthermore, institutional factors, which are mostly concerned with access to credit, mass media and extension services, primarily affect the physical soil bund structures adoption. Moreover, educational level of the farmers was also observed to facilitate the technology promotion process and the adoption decisions of the farmers. In this regard, farmers with a higher educational level were found to be greater technology adopters compared to non-educated farmers.

The survey findings further revealed that participation of farmers in the decision-making process of the development project was poor which is contrary to stated principles in national strategy. In reality, most of the approaches lacked elements of participation and were not encouraging the farmer's active participation in decision-making process. Overall, based on the evidence of this and other empirical studies, many policy-related issues need to be considered to promote economically and environmentally-sustainable development in the small-scale farming system. Generally, according to the study results, most of the major soil conservation practices that are important for packaging with physical soil bund conservation structures were found to be neglected. Hence, based on the findings of the present study, it is recommended that policy makers and technical departments should pay particular attention to those practices that have been marginalized in the past implementation years and follow an integrated intervention approach in order to mitigate soil resource degradation. Furthermore, appropriate policies and emphasis should be in place to facilitate farmers' accessibility to education, mass media and institutional support which ultimately influence technology adoption in the small-scale farming community.

5. Acknowledgement

The authors of this article are grateful to the Sasakawa Africa Fund for Extension Education (SAFE) project for financially supporting this study. In addition, the contributions of all stakeholders (especially Adama district farmers and extension field staff) are greatly appreciated and acknowledged by the authors.

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Combining Ability and Gene Action in Crosses among Asian and Ethiopian Genotypes of Hot Pepper (Capsicum annuum L. Var. Annuum)

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Abstract: Lack of availability/scarcity of genetic information has limited improvement work on hot pepper (*Capsicum annuum* L. var. *annuum*) in Ethiopia. However, information regarding the types and relative importance of gene actions can be generated using combining ability analysis and utilized in the selection of suitable genotypes for hybridization and for obtaining promising hybrids. This study aimed to generate useful information with respect to combining ability and gene action from p(p + 1)/2 half-diallel crossing pattern using twelve selected hot pepper genotypes of Ethiopian and Asian origins. Twelve parental lines and their 66 F_1s were tested in randomized complete block design with three replications at Melkasa Agricultural Research Center, Ethiopia, in 2004/2005 cropping season. Significant GCA and SCA effects were obtained for dry fruit yield per plant and related traits. The results showed the importance of both additive and non-additive gene actions with the predominance of the non-additive variances for dry fruit yield per plant and related traits, except for plant height and fruit length. An efficient breeding strategy for hot pepper could, therefore, be based on recurrent selection, inbred-derived hybrids or multiple crossing using genetically diverse hot pepper genotypes.

Keywords: Breeding Strategy; *Capsicum* spp.; Diallel Analysis; Fruit Yield; Genetic Diversity; Hybrids

1. Introduction

Hot pepper (*Capsicum annuum* L. var. *annuum*), 2n = 24, is a vegetable crop grown and consumed world-wide (Martelli and Quacqarelli, 1983). The first introduction of hot pepper to Ethiopia was by the Portuguese probably in the 17th century (Huffnagel, 1961). Nowadays, the crop is adapted to different agro-ecological zones and different local genotypes have evolved. Hot pepper fruits have a high nutritional value, particularly since they contain a considerable amount of vitamin C at green stage and are consumed as a fresh vegetable or, when dried or processed, as spice or condiment. The dried mature fruit of hot pepper is rich in Vitamin A (Poulos, 1993). The pungent types are preferred and have medicinal value; they stimulate saliva and the gastric juices that aid digestion.

In the past two decades, hot pepper genotypes of different origins have been introduced and local collections have also been made to address the problem pertaining to the narrow genetic base of the crop in Ethiopia. However, work on the genetic improvement of the crop is still at a low level and limited to selection of superior pure lines. Improved lines of hot pepper should be photosynthetically efficient with bigger canopy, earliness to mature, high fruit yield, less shrinkage of pericarp, good flavor, high pungency coupled with good aroma, a high number of seeds and larger fruit size.

The agronomic and environmental aspects for hot pepper improvement are well known, but there is a lack of genetic information on combining abilities for further improvement work. Thus, only a few superior genotypes have been produced and cultivated. Consequently, the dried fruit yield per hectare (ha) has remained very low (0.4 t/ha) with the quality of the marketable produce insufficient compared to a potential (2.5 t/ha dried fruit yield) of the crop in the country. Combining ability of inbred lines is the ultimate factor determining future usefulness of the lines for hybrids (Hallauer and Miranda, 1981). Sprague and Tatum (1942) were the first to partition total combining ability of the lines into general combining ability (GCA) and specific combining ability (SCA). They defined GCA as the average performance of a line in hybrid combinations and SCA as those instances in which certain hybrid combination is either better or poorer than would be expected on the average performance of the parent inbred lines included. General combining abilities are usually expressed as deviations from the overall mean (Kallo, 1988). This author described parent with zero GCA as having average GCA, and positive GCA as an indicator for a parent that produces above-average yield. He described negative GCA as an indicator for a parent that produces progeny with below average yield.

The concepts of GCA and SCA are useful for characterizing inbred lines in crosses and for enabling the interpretation of genetic variance and types of gene action operative in crosses of inbred lines (Hallauer and Miranda, 1981). Estimates of SCA describe those cases in which a certain hybrid combination does relatively better and is regarded as an estimate of non-additive gene action such as dominance and epistasis (Gowen, 1964). In the absence of epistasis, the additive variance (σ^2_A) equals the variance due to general combining ability (σ_g^2), and dominance variance (σ^2_D) equals the variance due to specific combining ability (σ_s^2) (Wricke and Weber, 1986). According to Jenkins (1940), a recurrent selection method that emphasizes GCA should be used if additive gene effect with partial dominance to complete dominance is important. However, recurrent selection method that emphasizes SCA would be appropriate if over-dominance is of primary importance (Hull, 1945). Comstock *et al.* (1949)

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ISSN 1992-0407

designed the recurrent reciprocal selection to enhance gene action related to both GCA and SCA.

Information on combining ability among and within gene pools is required to make inferences regarding additive or non-additive gene effects (Franco *et al.*, 2001) and enable a search for potentially superior parents and hybrids (Singh *et al.*, 1992). As a rule, diallel analysis using less than ten parents will have low precision (Singh and Chaudhary, 1985). The GCA of each parent (g_i) should be examined when the objective is the development of superior genotypes, while the SCA effects (s_{ij}) provide information about hybrid performance (Cruz and Regazzi, 1994). Such knowledge is important in choosing appropriate breeding procedures (Pixley and Frey 1991; Gonzalez and Cubero, 1993; Singh 1993). Thus, studies on the understanding of genetics of combining ability are needed to identify the types of gene actions and suitable breeding strategy of hot pepper. Hence, the objective of the present study was to obtain genetic information with respect to combining ability and gene action for dry fruit yield per plant and related traits in crosses involving hot pepper genotypes.

2. Materials and Methods

2.1. Genetic Materials, Crossing Techniques, and Planting

Hot pepper genotypes (Table 1) used as parental lines were selected based on results of evaluation for adaptability and yield during 1990 to 2003. In December 2003, crosses were made among the twelve parents in all possible combinations in a half-diallel fashion {p(p+1)/2} to fit Griffing's (1956) Method 2 Model I analysis. Hand emasculation and single flower caging were employed to achieve the required mating. The seeds obtained from the crosses were harvested at the end of the cropping season during April to May 2004 to obtain F_1 crosses.

Seeds of all the twelve selfed parental lines and their 66 F_1 crosses were sown on a seedbed at the end of August 2004. Seedlings were transplanted to the field in October 2004 at Melkasa Agricultural Research Center (8° 24' N latitude; 39° 12' E longitude; 1550 m above sea level altitude; sandy loam soil with pH of 6.9 to 7.9; 763 mm average annual rainfall with annual mean maximum of 26-29 ^{0}C and minimum of 11-16 ^{0}C temperatures for the past five years). The intra-row spacing was 0.3 m and the inter-row spacing was 1 m. The treatments were arranged in a randomized complete block design and replicated three times. Plot size was 4.2 m x 4.0 m with four rows. Fifty-six plants were accommodated in each plot. All cultural practices were used as recommended by Lemma (1998).

Table 1. Description of Asian and Ethiopian hot pepper (*Capsicum annuum* L. var. *annuum*) genotypes involved in half-diallel crossing.

Serial code	Genotype	Region of origin as genotype	Field evaluation period
P1	PBC 972	Malaysia	1995 – 2003
P2	PBC 602	Taiwan	1995 – 2003
P3	PBC 223	Korea	1994 – 2003
P4	ICPN10#5	Taiwan	1990 – 2003
P5	ICPN10#6	Taiwan	1990 – 2003
P6	ICPN9#16	Malaysia	1990 – 2003
P7	PBC 731	Korea	1994 – 2003
P8	PBC 535	Indonesia	1994 – 2003
P9	PBC 580	Sri Lanka	1995 – 2003
P10	Marekofana	Ethiopia	Cultivated variety
P11	Bakolocal	Ethiopia	Cultivated variety
P12	Marekoshote	Ethiopia	Cultivated variety

2.2. Data Collection and Statistical Analysis

Thirteen traits (Table 2) were recorded on 24 plants from two middle rows in each plot by excluding border rows and the first and last plants in each row. The results were expressed as mean values.

Analysis of variance was performed based on mean values of 78 genotypes for each trait studied as suggested by Singh and Chaudhary (1985). Combining ability was analyzed following Griffing's (1956) Method 2 and Model I. The usual restrictions such as $\Sigma g_i = 0$ and $\Sigma s_{ij}+s_{ji} = 0$ (for each i) were imposed on combining ability elements.

The estimates of GCA and SCA effects were obtained using the following formula (Dabholkar, 1992; Sharma, 1998): $\mu = 2x_{..}/p\ (p+1)$; $g_i = 1/(p+2)/[x_{i.}+x_{ii}-2x_{..}/p]$; $s_{ij} = x_{ij} - (x_{i.}+x_{ii}+x_{.j}+x_{jj})/(p+2)+2x_{..}/(p+1)\ (p+2)$, where μ = population mean or overall mean, p = number of parents, $x_{..} = \sum(s_{ii} + s_{ij})$, $x_{..}$ being total of all [p(p+1)]/2 items of the diallel table, $x_{ij} = \mu + g_i + g_i + s_{ij}$, x_{ij} being the hybrid performance of a given trait, g_i = estimate of GCA effect of ith inbred line, g_j = estimate of GCA effect of jth inbred line, s_{ij} = SCA effects of ijth cross or hybrid involved ith and jth parents, s_{ii} = SCA effects of iith parent with itself, $x_{i.}$ = total of array involving ith parent, x_{ii} = parental value of the ith parent, $x_{.j}$ = total of array involving jth parent and x_{jj} = parental value of the jth parent.

2.3. Estimates of Variance Components and Tests of Significance

The variance components due to GCA (σ^2g), SCA (σ^2s) and environment (σ^2e) were estimated as follows:

$\sigma^2g_i = (p-1)\ \sigma^2e/p(p+2) = (MSg - MSs)/(p+2)$,

$\sigma^2s_{ij} = (p^2+p+2)\ \sigma^2e/(p+1)\ (p+2) = (MSs - MSe)$,

$\sigma^2e = MSe$; $\sigma^2\ (g_i-g_j) = 2\sigma^2e/(p+2)$ and

$\sigma^2\ (s_{ij}-s_{ik}) = 2\sigma^2e(p+1)/(p+2)$.

Significance of GCA and SCA estimates were tested using the standard error of difference (SE_d) and 't' test based on the following formulas:

$SE_d(g_i) = [(p-1)/p^2+2p)MSe]^{1/2}$

$SE_d(s_{ii}) = [\{p^2+(p+2)/(p+1)(p+2)\}MSe]^{1/2}$

$SE_d(g_i- g_j) = [2MSe/(p+2)]^{1/2}$

t_i (computed) = $g_i/SE_d(g_i)$ compared at df of (p-1)

t_{ij} (computed) = $s_{ij}/SE_d(s_{ij})$ compared at df of p(p-1)/2.

3. Results

3.1. Estimates of Variance Components

Analysis of variance based upon means over replication showed significant differences among the genotypes for all the studied traits (Table 2). The genotypic variance was then partitioned into components due to general (GCA) and specific (SCA) combining ability effects. The mean squares of both GCA and SCA effects were highly significant ($P < 0.001$) for all the traits.

3.2. Estimates of General Combining Ability Effects

The estimates of GCA effects of the parents depicted in Table 3 indicated significant and useful as well as significant and undesirable directions depending on the trait under consideration. The Asian genotype PBC 223 exhibited significant and positive GCA effects coupled with high *per se* performance for number of branches per plant, stem diameter, number of fruits per plant and dry fruit yield per plant. The Ethiopian genotype 'Marekofana' showed significant GCA effects in the desired direction for plant height, length of internode on primary branch, number of nodes on primary branch, days to maturity, single fruit weight, canopy diameter and dry fruit yield per plant. Another Ethiopian genotype 'Marekoshote' followed a similar trend in showing significant GCA effects in the wanted direction for plant height, length of internode on main stem, canopy diameter, fruit length and single fruit weight in addition to preferred GCA effects coupled with high mean values for dry fruit yield per plant and earliness. Similarly, the Asian genotypes ICPN9#16 and PBC 535 showed positive GCA effects for dry fruit yield per plant coupled with significant and important GCA effect for days to maturity.

Significant and positive GCA effects in PBC 535 and 'Marekoshote' for length of internode on primary branch, fruit length and canopy diameter are in an encouraging direction coupled with positive GCA effects of dry fruit yield per plant. Nevertheless, the GCA effects of PBC 972 among Asian and 'Bakolocal' among Ethiopian genotypes were significant in an undesirable direction for dry fruit yield per plant and days to maturity. Likewise, Asian genotypes ICPN10#5 and ICPN10#6 showed significant and unwanted GCA effects for dry fruit yield per plant and number of fruits per plant.

3.3. Estimates of Specific Combining Ability Effects

Significant and desirable SCA effects (s_{ij}) of F_1s were observed at very high levels within the crosses of Ethiopian and Asian (E x A) group in respect of dry fruit yield per plant (51.9% of 27 F_1s), number of fruits per plant (48.1% of 27 F_1s), single fruit weight (29.6% of 27 F_1s), canopy diameter (37.6% of 27 F_1s), days to maturity (48.1% of 27 F_1s) and length of internode on main stem (22.2% of 27 F_1s). This is in contrast to an absence of similar results either in the corresponding F_1 crosses within Ethiopian (E x E) group or in SCA effects (s_{ii}) within parental lines (self's) for the same traits (Table 4). Likewise, a considerable proportion of F_1 crosses within Asian (A x A) group achieved significant and desirable SCA effects (s_{ij}) for dry fruit yield per plant and majority of related traits but with relatively lower shares compared to the proportions that were observed in F_1 crosses of Ethiopian and Asian (E x A) group (Table 4).

Significant and highest desirable SCA effects coupled with high dry fruit yield per plant were recorded from PBC 223 x 'Marekoshote', ICPN10#5 x 'Marekofana' and PBC 580 x 'Marekoshote' crosses, all of which were generated from crosses between Ethiopian and Asian genotypes. Similarly, the majority of the significant and high level of desirable SCA effects as well as the top *per se* performances for all other traits were obtained from F_1 crosses of Ethiopian and Asian group. In general, high proportions of F_1 crosses of Ethiopian to Asian group were with significant and desirable SCA effects for dry fruit yield per plant, single fruit weight and number of fruits per plant. Similarly, some F_1 crosses of Ethiopian and Asian group performed outstandingly for most of the traits but F_1 crosses with negative SCA effects for all the traits were observed in all the groups (E x E, E x A and A x A).

Parents PBC 223 and 'Marekofana' exhibited significant and high level of GCA effect (g_i) in addition to resulting in F_1 crosses with significant and positive SCA effect for dry fruit yield per plant. However, ICPN10#5 x 'Bakolocal', ICPN9#16 x 'Bakolocal' and PBC 602 x PBC 731 crosses with significant and desirable SCA effects (s_{ij}) for number of fruits per plant evolved from parents with either negative and positive or positive and positive GCA effects. Similarly, most crosses that showed significant and top SCA effects for single fruit weight evolved from parents with either positive x negative, or positive x positive or negative x negative GCA effects. Moreover, the top five hybrids with the highest SCA effects for dry fruit yield per plant and number of fruits per plant (Table 4) were produced from crosses that involved parents with GCA of either negative x positive or positive and positive effects (Table 3). Significant and desirable SCA effects (s_{ii}) of parental lines were expressed by PBC 972 for number of branches per plant and number of nodes on main stem, PBC 602 for stem diameter, PBC 223 and ICPN10#6 for number of nodes on main stem, and 'Bakolocal' for length of internode on primary branch.

Table 2. Estimates of mean squares (MS) and variances of general (GCA) and specific (SCA) combining ability effects for 13 traits of 78 hot pepper genotypes at Melkasa in 2004/2005.

Traits	Mean squares (degrees of freedom)			Variantes of genetic components			
	Genotypes (77)	GCA effects (11)	SCA effects (66)	$\sigma_e^2 = V_e$	$\sigma_g^2 = (1/2)V_A$	$\sigma_s^2 = V_D$	σ_g^2 / σ_s^2 ratio
Number of branches per plant	3.737***	4.077***	0.774***	0.355	0.266	0.419	0.635
Plant height (cm)	259.857***	408.054***	33.047***	10.254	28.414	22.793	1.247
Stem diameter (cm)	0.045***	0.029***	0.013***	0.006	0.002	0.007	0.286
Number of nodes on main stem	11.765***	13.409***	2.340***	0.737	0.905	1.603	0.564
Length of internode on main stem (cm)	0.287***	0.207***	0.077***	0.021	0.013	0.056	0.232
Length of internode on primary branch (cm)	0.863***	0.354***	0.277***	0.051	0.021	0.226	0.092
Number of nodes on primary branch	15.220***	14.721***	3.465***	0.514	1.016	2.942	0.345
Number of fruits per plant	439.146***	457.239***	94.572***	6.168	32.219	88.404	0.364
Days from transplanting to maturity	99.115***	52.485***	29.797***	1.545	3.638	28.252	0.129
Fruit length (cm)	6.087***	9.456***	0.791***	0.170	0.663	0.621	1.067
Single fruit weight (g)	0.264***	0.282***	0.056***	0.013	0.019	0.043	0.442
Canopy diameter (cm)	148.199***	161.018***	30.797***	5.93	11.078	24.867	0.445
Dry fruit yield per plant (g)	1269.330***	431.595***	421.696***	47.197	27.457	374.5	0.073

**** = Significant at $P < 0.001$; V_A = Additive variance; V_D = Dominante variance; σ_g^2 = Variance component due to GCA; σ_s^2 = Variance component due to SCA; $\sigma_e^2 = V_e$ = Environmental variante; figures in [arenthesis = Degrees of freedom.*

Table 3. Estimates of general combining ability (GCA) effects and standard errors (SE) along with the corresponding *per se* performance (indicated in parenthesis) for 13 traits of 12 parental lines of hot pepper genotypes at Melkasa in 2004/2005.

Serial code of parents[a]	GCA effects along with the corresponding *per se* performance for 13 traits[b]												
	B/P	PH	SD	NN/S	LI/S	LI/B	NN/B	F/P	DM	FL	FW	CD	FY/P
P1	0.04	10.21*	0.06*	0.48*	-0.13*	0.02 (3.48)	2.10*	-3.38*	0.89*	1.29*	-0.01	0.78	-5.07* (60.85)
	(6.44)	(62.07)	(1.30)	(15.17)	(1.34)		(18.17)	(40.95)	(90.00)	(12.32)	(1.49)	(47.93)	
P2	0.88*	-6.26*	0.00	-0.04	-0.06	-0.32	0.45*	3.49*	1.10*	-0.87*	-0.15*	-1.73*	-1.23 (46.36)
	(7.16)	(34.33)	(1.33)	(11.67)	(1.36)	(2.80)*	(14.50)	(51.83)	(87.00)	(9.15)	(0.90)	(42.00)	
P3	0.84*	-1.33	0.06*	0.22	-0.06	0.07 (2.71)	-0.10	15.80*	1.10*	-0.13	-0.20*	1.15	12.19* (87.08)
	(5.03)	(42.13)	(1.03)	(13.83)	(1.45)		(10.83)	79.00)	(91.67)	(9.29)	(1.10)	(45.90)	
P4	-0.21	-4.01*	-0.07*	-0.85*	-0.14*	-0.01	-1.17*	-5.65*	2.18*	0.01	0.04	-0.25	-7.75* (36.11)
	(3.83)	(32.00)	(0.90)	(9.67)	(1.19)	(3.57)	(7.83)	(23.63)	(91.67)	(9.52)	(1.52)	(48.27)	
P5	0.23	-4.81*	-0.01	-1.01*	0.06	-0.21*	-0.88*	-1.85*	-1.73*	0.06	-0.06	-1.02	-4.50* (54.52)
	(3.97)	(36.17)	(1.06)	(9.83)	(1.89)	(2.59)	(8.17)	(32.00)	(93.00)	(9.81)	(1.70)	(49.67)	
P6	-0.42*	-6.22*	-0.02	-0.81*	-0.06	-0.15*	-1.28*	-0.16	-2.14*	0.04	-0.01	-7.49*	1.78
	(3.56)	(33.00)	(1.05)	(8.67)	(1.83)	(2.39)	(9.00)	(34.67)	(88.33)	(10.37)	(1.36)	(30.00)	(47.06)
P7	-0.22	-1.28	0.06*	1.06*	0.07	-0.06	-0.49*	1.02	1.84*	-1.86*	-0.03	-2.15*	0.74
	(4.39)	(37.67)	(1.18)	(12.67)	(1.53)	(3.00)	(10.83)	(46.93)	(93.00)	(6.35)	(1.59)	(44.27)	(74.35)
P8	-0.44*	-3.56*	-0.06*	-0.51*	-0.12*	0.21* (3.53)	-1.00*	-2.78*	-1.11*	0.82*	0.10*	2.61*	0.76
	(4.40)	(31.63)	(0.99)	(10.50)	(1.48)		(10.83)	(35.93)	(88.67)	(11.45)	(1.80)	(49.30)	(64.94)
P9	0.08	6.25*	-0.02	-0.82*	0.15*	0.11	0.99*	1.23	-3.18*	-0.18	-0.07*	3.67*	-1.39 (68.23)
	(4.83)	(53.73)	(0.98)	(8.83)	(2.01)	(4.19)	(10.83)	(42.60)	(90.00)	(9.68)	(1.61)	(53.77)	
P10	-0.47*	2.99*	0.04	-0.25	0.24*	0.04	0.92*	-1.96*	-1.40*	-0.23*	0.24*	3.51*	6.63* (77.66)
	(3.00)	(56.67)	(1.25)	(8.50)	(2.30)	(3.59)	(14.67)	(34.13)	(83.33)	(9.16)	(2.29)	(55.27)	
P11	0.53*	2.86*	0.01	2.39*	-0.04	0.16* (4.95)	0.18	0.26	2.96*	0.19	-0.12*	-3.19*	-4.99* (40.60)
	(7.75)	(48.60)	(0.91)	(16.00)	(1.54)		(8.33)	(30.73)	(93.00)	(9.33)	(1.33)	(40.13)	
P12	-0.84*	5.11*	-0.04*	0.14	0.10*	0.13* (4.32)	0.27	-6.03*	-0.52	0.86*	0.26*	4.12*	2.82
	(4.28)	(58.00)	(1.10)	(10.00)	(1.82)		(11.17)	(37.33)	(83.33)	(11.06)	(2.01)	(59.07)	(75.63)
SE[gi]	0.15	0.82	0.02	0.22	0.04	0.06	0.18	0.64	0.32	0.11	0.03	0.62	1.76
SE[gi-gj]	0.23	1.21	0.03	0.33	0.06	0.09	0.27	0.94	0.47	0.16	0.05	0.92	2.60

** = Significant at $P < 0.05$; [a]P1 = PBC 972; P2 = PBC 602; P3 = PBC 223; P4 = ICPN10#5; P5 = ICPN10#6; P6 = ICPN9#16; P7 = PBC 731; P8 = PBC 535; P9 = PBC 580; P10 = 'Marekofana; P11 = 'Bakolocal; P12 = 'Marekoshote; [b]B/P = Nnumber of branches per plant; PH = Plant height; SD = Stem diameter; NN/S = Number of nodes on main stem; LI/S = Length of internode on main stem; LI/B = Length of internode on primary branch; NN/B = Number of nodes on primary branch; F/P = Number of fruits per plant; DM = Days to maturity; FL= Fruit length; FW = Single fruit weight; CD = Canopy diameter; FY/P = Dry fruit yield per plant.*

Table 4. Significant desirable SCA effects of the top 5 progenies of 78 genotypes (12 parental selfs and 66 F_1s) along with *per se* performances and the proportion (%) of progenies with significant desirable SCA effects in each of the three groups and standard error of mean for 13 traits in crosses of Asian (A) and Ethiopian (E) genotypes of hot pepper grown at Melkasa in 2004/2005.

Trait[b]	Five top (selfs and F_1s)[a]		Proportion (%) of progenies with significant desirable SCA effects (%)				Standard error of mean	
	Significant and desirable SCA effects	*Per se* performance	Selfs (12)	E x E (3 F_1s)	E x A (27 F_1s)	A x A (36 F_1s)	s_{ii}	s_{ij}
B/P	P3XP10 (2.80), P11xP11 (2.02), P2XP7 (1.74), P5XP9 (1.63), P1xP1 (1.70)	P3XP10 (7.83), P11xP11 (7.75), P2xP2 (7.16),), P2XP7 (7.06), P3XP5 (6.67)	25.0	0.0	7.4	5.6	0.6	0.5
PH	P9XP12 (8.76), P4XP7 (8.38), P6XP11(7.95), P7XP8 (7.36), P5XP9 (7.22)	P1xP1 (62.07), P9XP12 (60.8), P1XP11 (60), P12xP12 (58), P1XP12 (57.33)	25.0	33.3	11.1	16.7	3.0	2.7
SD	P3XP10 (0.40), P2xP2 (0.22), P4XP10 (0.19), P6XP8 (0.14), P11xP12 (0.14)	P3XP10 (1.6), P2xP2 (1.33), P1xP1 (1.30), P5XP7 (1.28), P2XP7 (1.28)	8.3	33.3	7.4	5.6	0.1	0.1
NN/S	P1xP1 (4.17), P3xP3 (3.36), P11xP12 (3.27), P3XP4 (2.10), P5xP5 (1.82)	P11xP11 (16), P11xP12 (15.83), P3xP3 (13.83), P1xP1 (15.17), P1XP11 (14)	41.7	66.7	3.7	2.8	0.8	0.7
LI/S	P2XP4 (0.58), P3XP7 (0.58), P8XP11 (0.51), P3XP9 (0.47), P3XP9 (0.47)	P5XP10 (2.93), P3XP7 (2.33), P3XP9 (2.3), P10xP10 (2.3), P7XP11 (2.28)	0.0	0.0	22.2	16.7	0.1	0.1
LI/B	P11xP11 (1.30), P3XP7 (1.26), P5XP6 (1.25), P2XP4 (1.21), P7XP8 (0.91)	P11xP11 (4.95), P3XP7 (4.59), P7XP8 (4.38), P12xP12 (4.32), P2XP4 (4.21)	41.7	33.3	22.2	41.7	0.2	0.1
NN/B	P6XP11 (3.18), P5XP9 (3.12), P1XP3 (2.90), P7XP9 (2.74), P4XP11 (2.73)	P1xP1 (18.17), P1XP3 (17), P9XP12 (16), P1XP2 (15.67), P7XP9 (15.33)	16.7	0.0	29.6	27.8	0.7	0.6
F/P	P4XP11 (9.95), P6XP11 (9.93), P2XP7 (9.85), P3XP11 (8.87), P5XP7 (8.53)	P3XP12 (80.67) P3XP10 (79.67), P3xP3 (79), P3XP4 (75.73), P3XP11 (75.57)	0.0	0.0	48.1	25.0	2.3	2.1
DM	P8XP10 (-9.330), P5XP6 (-17.64), P2XP7 (-15.12), P8XP9 (-12.88), P3XP9 (-10.09)	P2XP7 (73), P6XP12 (73), P3XP9 (73), P5XP6 (63.67), P8XP9 (68)	0.0	0.0	29.6	25.0	1.2	1.1
FL	P9XP12 (1.69), P6XP8 (1.13), P1XP2 (1.07), P10XP12 (0.96), P4XP9 (0.96)	P1XP12 (13.86), P8XP12 (13.36), P9XP12 (13.3), P1XP5 (12.97), P6XP8 (12.94)	0.0	33.3	40.7	19.4	0.4	0.4
FW	P2XP11 (0.57), P5XP10 (0.41), P4XP12 (0.38), P7XP12 (0.34), P2XP6 (0.33)	P4XP12 (2.32), P8XP12 (2.31), P10xP10 (2.29), P8XP10 (2.28), P5XP10 (2.24)	0.0	0.0	29.6	16.7	0.1	0.1
CD	P9XP12 (9.12), P5XP6 (8.99), P4XP7 (8.58), P3XP7 (8.21), P3XP8 (7.66)	P9XP12 (67), P1XP10 (65.53), P9XP10 (63.38), P3XP8 (61.5), P1XP12 (61.4)	0.0	0.0	37.6	22.2	2.3	2.1
FY/P	P3XP12 (52.00), P5XP10 (33.82), P9XP12 (33.35), P5XP6 (31.84), P7XP12 (26.05)	P3XP12 (149.15), P2XP6 (123.2), P5XP10 (118.31), P9XP12 (117.12), P8XP10	0.0	0.0	51.9	13.9	6.4	5.9

[a]*P1 = PBC 972; P2 = PBC 602; P3 = PBC 223; P4 = ICPN10#5; P5 = ICPN10#6; P6 = ICPN9#16; P7 = PBC 731; P8 = PBC 535; P9 = PBC 580; P10 = 'Marekofana; P11 = 'Bakolocal; P12 = 'Marekoshote;* [b]B/P = N*number of branches per plant;* PH = *Plant height;* SD = *Stem diameter;* NN/S = *Number of nodes on main stem;* LI/S = *Length of internode on main stem;* LI/B = *Length of internode on primary branch;* NN/B = *Number of nodes on primary branch;* F/P = *Number of fruits per plant;* DM = Days *to maturity; FL= Fruit length; FW = Single fruit weight; CD = Canopy diameter; FY/P = Dry fruit yield per plant.*

4. Discussion

Since the parental lines were deliberately selected for specific breeding objectives, combining ability and types of gene action for dry fruit yield per plant and related traits were studied using Griffing's (1956) combining ability analysis, Methods 2 in fixed effect. The highly significant mean squares for both GCA and SCA effects for all the traits suggested existence of large amounts of variability among the genotypes for both additive and non-additive gene actions that might be involved in the expression and inheritance of the traits studied. However, SCA variances (σ_s^2) were larger than the corresponding GCA variances (σ_g^2), i.e. σ_g^2/σ_s^2 ratio less than unity for all the traits except for plant height and fruit length, suggesting that non-additive gene action has been a more important source of variation for all the traits than the additive gene action.

As reported by Melchinger *et al.* (1987), the ratio of variances due to general combining ability to specific combining ability (σ_g^2/σ_s^2) is of central importance for predicting hybrid performance. However, more effective and superior hybrids can be identified and selected mainly on the basis of their SCA effects (Reif *et al.*, 2007). Thus, it could be predicted that the non-additive variance (SCA) might dominate the expression of the majority of the studied traits whereas the additive variance (GCA) might have played more significant roles for expression of both plant height and fruit length. Falconer (1989) defined GCA as the average performance of the progeny of an individual resulting from its mating with a number of other individuals in the population and recognized primarily as a measure of additive gene action. A positive GCA could be an indicator of a genotype that produces above-average progeny, whereas a genotype with a negative GCA could produce progeny that performs below average.

ICPN9#16, PBC 731, PBC 535 and 'Marekofana' parents, which exhibited desirable additive gene actions both for earliness and dry fruit yield per plant, suggested the possibility of simultaneous selection for earliness and high dry fruit yield per plant. Furthermore, the Asian parent PBC 223 and the Ethiopian parent 'Marekofana' showed significant GCA effects for dry fruit yield per plant and some of its related traits. Genotypes that showed good GCA for many desirable traits may be more useful for the simultaneous improvement of multiple traits. Good general combiners have multiple advantages in that they often have high probabilities of good SCAs, allow for the development of synthetic varieties, and are ideal choices as parents in a hybrid program (Welsh 1981). In addition, it is evident from the present study that the parents with good general combining ability possessed high mean values (Table 4). It is also important to note that there appeared to be good relationships between mean performance of parent *per se* and its GCA effect. For example, parents PBC 223, 'Marekofana' and 'Marekoshote' that were the top mean performers for dry fruit yield per plant and earliness also had high GCA effects for the same traits. This revealed that combining ability can be judged to some extent by *per se* performance in hot pepper especially for traits such as dry fruit yield per plant, number of fruits per plant and earliness. The results of the present study indicated that it is important to consider both GCA effects as well as *per se* performances in the improvement program to achieve the desired results. This is in agreement with the observations of Shrivastava and Seshu (1983) and others who reported similar relationships in different crops. Therefore, mean *per se* performance of parents may, to some extent, serve as predictors of GCA of parents in hot pepper. In a systematic breeding program, GCA of the parents is obviously important (Kalloo, 1988).

The hybrids with the highest SCA effects were observed resulting from any possible combination of parents having negative and positive GCA effects (Tables 3 and 4). Therefore, when the breeding interest is to develop synthetic varieties, good general combiners could be very useful. However, when the breeding interest is to develop superior specific hybrids, it may be more effective to search among all possible crosses between elite genotypes, including both good (positive) and poor (negative) general combiners. In view of the above results, due attention must be paid when selecting or rejecting parents in hot pepper breeding programs.

Crosses from Asian x Ethiopian group produced a higher proportion of hybrids with the highest SCA effects with respect to most of the studied traits, suggesting the importance of genetic diversity to obtain superior hybrids. High estimated values for variance of SCA for early and total fruit yield, fruit number per plant and fruit weight were also reported in crosses of homozygous varieties of *Capsicum annuum* (Khalf-Allah *et al.*, 1975). These authors indicated that the inheritances of these four traits are governed by a relatively high degree of non-additive gene action. High estimates of SCA were reported by Sharma and Saini (1977) for fruit yield and plant height in *Capsicum* pepper.

The recorded high SCA effects (s_{ii}) of parental selfs (PBC 972, PBC 602, PBC 223, ICPN10#5 and 'Bakolocal') were good indicators regarding their potential to improve dry fruit yield and related morphological traits in hybrid breeding programs. According to Cruz and Vencovsky (1989), the SCA of a parent with itself (s_{ii}) has great genetic significance and indicates the existence of unidirectional dominance. Negative s_{ii} values indicate that the deviations are predominantly positive and positive s_{ii} values indicate the *vice-versa* (Franco *et al.*, 2001). According to these investigators, the magnitude of s_{ii} is an indicator of varietal heterosis and their additive values express the mean values of such heterosis.

5. Conclusions

Inheritance of the majority of the studied traits appeared to be governed both by additive and non-additive genes. Crosses PBC 223 x 'Marekoshote', ICPN10#5 x 'Marekofana', PBC 580 x 'Marekoshote', ICPN10#6 x ICPN9#16 and PBC 731 x 'Marekoshote' exhibited maximum dry fruit yield per plant and, thus, can be promoted for commercial exploitation of hybrids for higher dry fruit yield in Ethiopia. There seems to be an opportunity to exploit some specific crosses such as ICPN10#6 x ICPN9#16 for earliness and enhanced dry fruit yield as it expressed significant and negative SCA effect coupled with minimum mean value for days to maturity and significant SCA effect for dry fruit yield per plant. However, there is a need to take great care in selecting or rejecting hot pepper parents in breeding programs based on general combining ability as superior specific hybrid could be obtained both from good (positive) and poor (negative) general combiners. An efficient breeding plan for the crop could be based on extensive recurrent selection, progeny tests and cross-breeding using genetically diverse hot pepper genotypes. This study, therefore, revealed a considerable amount of genetic information that can be utilized in hot pepper improvement programs.

6. Acknowledgements

Thanks are due to the Swedish International Development Association - Swedish Agency for Research Cooperation with developing countries and the World Bank - Agricultural Research and Training Project that funded this study through providing funding to the Haramaya University and the Ethiopian Agricultural Research Organization, respectively. The authors thank the Melkasa Agricultural Research Center for providing them with facilities and logistics for the field work.

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Response of Yield and Yield Components of Field Pea to Tillage Frequency, Phosphorus Fertilization and Weed Control on Nitisols of Central Ethiopian Highlands

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Abstract: The effects of tillage frequency, phosphorus fertilizer and weed control on yield and yield components of field pea (*Pisum sativum* L.) were studied in the 2003 and 2004 main cropping seasons on farmers' fields in the Chelia and Welmera Districts of west Shewa, Ethiopia. Four levels of tillage frequency (T4 = April, May, early June and at planting; T3 = May, early June and at planting; T2 = May and at planting and T1= at planting) as main plots and factorial combinations of four levels of phosphorus fertilizer (0, 10, 20 and 30 kg P ha^{-1}) and two levels of weeding (W1 = no weeding and W2 = hand weeding once) were arranged as sub-plots in split-plot design with three replications. The results indicated a highly significant positive response of mean field pea seed yield, total biomass and number of pods per plant to tillage frequency, phosphorus fertilizer and weeding treatments. Plowing twice, three and four times including the last pass for seed covering resulted in mean seed yield advantages of 38, 55 and 43%, respectively, compared to the control. Application of phosphorus fertilizer at the rates of 10, 20 and 30 kg P ha^{-1} increased mean seed yields by 30, 53 and 50%, respectively, compared to the control. Weeding once by hand increased mean seed yield by 16% compared to the unweeded check. Tillage frequency by P fertilizer and weed control interaction significantly affected seed yield. The highest mean seed yield of two years for the tillage, P fertilizer and weed control interaction was obtained from three plowings, 20 kg P ha^{-1} and weeding once by hand. The yield increment was higher by 232% compared to the control, namely planting with the first pass of ox-drawn implement, with no P application and unweeded condition. Seed yield was highly significantly and positively correlated with total biomass ($r = 0.93^{**}$), pods per plant ($r = 0.54^{**}$), plant height ($r = 0.54^{**}$), seeds per pod ($r = 0.41^{**}$) and thousand seeds weight ($r = 0.37^{**}$). The results of economic analysis indicated that the treatment with three times tillage, application of 20 kg P ha^{-1} and weeding once by hand is the best option with a marginal rate of return of 423%, which is economically the most feasible alternative.

Keywords: Field Pea; Nitisols; Phosphorus; Tillage Frequency; Weed Control

1. Introduction

Although field pea is one of the important grain legumes in Ethiopia, its productivity is low due to several factors, among which the major ones are poor seedbed preparation, untimely sowing, poor soil fertility, inadequate weed control and the lack of improved varieties (Alem *et al*., 1990; Asfaw *et al*., 1994). The primary objectives of soil tillage are to provide suitable seedbed and adequate weed control (Rao, 2000). Traditionally, farmers use the local plow for tillage operations to prepare seedbeds. However, the preparation of appropriate weed free seedbeds for crop establishment and production is a problem to field pea and faba bean productions in Ethiopia. Farmers do not practice pre-planting tillage for field pea production compared to most cereals. In most cases, field pea is sown with the first plowing. This leads for uneven germination of seeds, high weed pressure and poor plant stand, which in, the final analysis, results in reduced yields.

Research results showed that plowing frequency and weed control operation significantly increased yield of faba bean (Getachew *et al*., 2005). Hebblethwaite *et al*. (1983) reported that deep loosening of the soil profile to a depth of 90 cm resulted in a considerable increase in yields of faba bean. Increased plowing frequency reduces the occurrence and distribution of weeds (Tolera and Daba, 2004). A review by Amare and Adamu (1994) also indicated that repeated plowings significantly increased yields of field pea. The highest seed yield of field pea with a yield advantage of 62% over the control was obtained from plowing twice followed by plowing three times with a yield advantage of 37% (Amare and Adamu, 1994).

Acidic Nitisols are of wide occurrence in the highlands of Ethiopia where the rainfall intensity is high and the land has been under cultivation for many years. These soils have pH values of less than 5.5, thereby resulting in low yields. The low yields in such soils could mainly be either due to the deficiency of nutrients, such as P, Ca and Mg (Taye and Höfner, 1993; Getachew and Sommer, 2000), or due to toxicity of Al, Fe and Mn (Sharma *et al*., 1990). The growth and grain yield of field pea is affected by fertilizer application. Results of fertilizer trials indicated that field pea grain yield significantly increased over the control due to application of P fertilizer (Getachew *et al*., 2003). The application of 18/20 kg N/P ha^{-1} increased field pea grain yield by 103% compared to the unfertilized plots. Angaw and Asnakew (1994) also reported that the response of field pea to P fertilizer was very high at many locations.

Traditionally, field pea is cultivated under no weeding conditions. Rezene (1986) reported that the major reason for sub-optimal weeding of field pea is the overlapping of farm activities with other crop enterprises. However, experimental evidence indicated that significant reduction in field pea yield potential occurred because of no weeding during the beginning and post-flowering stages of the crop (Rezene, 1986, 1994). Weed competition is high, especially in fields where the land preparation is poor. The efficiency of fertilizer is also low in such fields. Piecemeal research results of these factors have shown positive effects on growth and yield of field pea. However, previous research findings were generated in research centers, with no consideration of differences in soil fertility and weed flora on farmers' fields. Another reason worth mentioning for conducting the current study is to

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ISSN 1992-0407

find out whether the interaction of tillage, fertilizer and weed control exists. Furthermore, economic feasibilities was not considered in recommending the combined results of tillage frequency, fertilizer and weed control for field pea production on Nitisols of the central Ethiopian highlands. Thus, the objectives of the study were to determine the: (1) effects of tillage, phosphorus fertilizer and weed control practice and their interactions on yield and yield components of field pea at two locations in West Shewa Zone, central highlands of Ethiopia, and (2) the economic feasibility of the practice for field pea production.

2. Materials and Methods

2.1. Experimental Site

The trial sites were located on the farmers' fields of Welmera and Chelia Districts of West Shewa, central highlands of Ethiopia, at an altitude of about 2400 and 2700 m above sea level, respectively. In Welmera, the long-term average annual precipitation is 1100 mm, about 85% of which is received from June to September and average minimum and maximum air temperatures are 6.1 and 21.9 °C, respectively. The farming system of the trial sites is crop-livestock mixed farming system. The major soil type of both trial sites is Nitisols.

2.2. Soil Sampling and Analysis

Selected soil chemical properties of the experimental fields, which are shown in Table 1, were determined for samples taken during planting in the soil and plant analysis laboratory of the Holetta Agricultural Research Center. Soil reaction (pH) was measured in H_2O with a liquid to solid ratio of 1:1. Likewise, total nitrogen was determined using the Kjeldahl method (Bremner and Mulvaney, 1982). Available phosphorus was determined using the Bray-II method (Bray and Kurtz, 1945). Exchangeable cations and cation exchange capacity (CEC) were analyzed using the ammonium acetate method (Black, 1965).

Table 1. Some soil chemical characteristics (0-20 cm depth) of the experimental sites at Welmera and Chelia.

Parameter	Welmera	Chelia	Mean
pH (1:1 H_2O)	4.73	4.65	4.69
Total nitrogen (%)	0.19	0.31	0.25
Available P (mg kg^{-1})	8.45	6.72	7.59
Exchangeable Na (cmol(+) kg^{-1})	0.03	0.10	0.07
Exchangeable K (cmol(+) kg^{-1})	1.71	1.25	1.48
Exchangeable Ca (cmol(+) kg^{-1})	8.05	2.47	5.26
Exchangeable Mg (cmol(+) kg^{-1})	1.92	2.17	2.05
CEC (cmol(+) kg^{-1})	21.74	21.48	21.62

2.3. Experimental Design and Procedure

The experiment was conducted to determine the effects of tillage frequency, P fertilizer and weed control and their interactions on field pea for two years (2003 and 2004 main cropping seasons) at two locations. The experimental design was split plot with tillage treatments as main plots, and phosphorus fertilizer and weed control as sub-plots with three replications. The treatments included four levels of tillage frequency (four times tillage = April, May, early June and at planting; three times tillage = May, early June and at planting; twice tillage = May and at planting and one time tillage = at planting) and factorial combinations of four levels of P fertilizer (0, 10, 20 and 30 kg P ha^{-1}) and two levels of weeding (W_1 = no weeding, and W_2 = hand weeding once). Experimental fields were plowed by ox-drawn local plow. Phosphorus fertilizer was applied along with seeds as a single application in the form of triple super-phosphate. Experimental plots received blanket application of 20 kg N ha^{-1} as a starter dressing at planting in the form of urea.

An improved field pea cultivar (*Tegegnech*) was planted at the seed rate of 150 kg ha^{-1}. Sowing took place as per recommendation from 20 to 25 June at Welmera and the first week of July at Chelia each season. The crop rotation followed was field pea after food barley in the first year and after wheat in the second year at Welmera, and field pea after food barley both in the first and second years at Chelia. Plots receiving weed control treatment were weeded once by hand at the proper growth stage of plants.

2.4. Data Collection

Agronomic parameters collected included plant stand counts m^{-2} at complete emergence and harvest, plant height (average of ten plants), weed oven dry weight at weeding and harvesting of plants, number of pods per plant and seeds per pod (average of ten plants), total aboveground biomass, seed yield and thousand seed weight of field pea. To estimate total biomass and seed yield of field pea, sample size of 12 m^2 was harvested from each plot in November at Welmera and in December at Chelia. After threshing, the harvested materials, seeds were cleaned, weighed and adjusted to 10% moisture level. Total biomass and seed yield recorded on plot basis were converted to kg ha^{-1} for statistical analysis.

2.5. Statistical Analysis

The crop data were subjected to analysis of variance using the General Linear Model Procedure of SAS statistical package version 8.2 (SAS Institute, 2001). Data were combined over two years and two locations as the variances were homogenous. The total variability for each trait was quantified using pooled analysis of variance over years and locations. The least significant difference (LSD) test at 5% level of significance was used to compare the means. Pearson's correlation coefficients were also performed using the standard procedures from SAS program.

2.6. Economic Analysis

Data on land preparation and weeding (pair of oxen and labor person-days), fertilizer and seed prices were collected to investigate the economic feasibility of the treatments. Partial budget, dominance and marginal analyses were conducted. The average yield from the on-farm experimental plots was adjusted downward by 10% to reflect the difference between the experimental yield and the yield farmers could expect from the same treatment. This is because experimental yields, even from on-farm experiments under representative conditions, are often higher than the yields that farmers could expect using the same treatments. The two years (2007and 2008) average price (ETB 5.55 kg^{-1}) of field pea was used to convert the adjusted yields into gross field benefits. The costs of tillage for a pair of oxen (ETB 50.00 per day), phosphate fertilizer (ETB 7.48 kg^{-1}) and weeding (ETB 10.00 per person-day) were also taken from the farmers' own practices in the study areas. For a treatment to be considered as a worthwhile option to farmers, the marginal rate of return (MRR) needed to be at least between 50 and 100% (CIMMYT, 1988). Researchers in other parts of the country suggested a MRR of 100% as realistic (Amanuel *et al*., 1991). Thus, to make recommendations to farmers based on analysis, the minimum acceptable rate of return by the farmers was taken to be 100%.

3. Results and Discussion

3.1. Yield and Yield Components

On average, over the two experimental years, the data from this study revealed that the frequency of tillage, P fertilization and weed control treatments had significant effects on yield and yield components of field pea. Analysis of variance indicated that mean field pea seed yield, total plant biomass, number of pods per plant and seeds per pod highly significantly ($P < 0.001$) responded to the frequency of tillage, P fertilization and weed control (Table 2). Experimental locations and cropping seasons also significantly affected field pea growth, yield and weed biomass both at weeding and harvesting.

The mean field pea seed yield record was higher at Chelia (1799 kg ha^{-1}) than at Welmera (1387 kg ha^{-1}). While there was a significant difference between each of the tillage frequency, the highest mean seed yield of two years was recorded from plots plowed three times (Table 3). Plowing twice, three and four times, including the last pass for seed covering, increased mean seed yield of field pea by 38, 55 and 43%, respectively, compared to the control. Likewise, experimental findings at Holetta and Shamboo showed that repeated plowings before planting significantly increased seed yields of field pea and faba bean (Amare and Adamu, 1994; Tolera and Daba, 2004). Bellido *et al.* (2003) also reported that in three rainy years, pre-planting conventional tillage was found to be more productive than no tillage for faba bean production.

Harvest index was significantly different among P levels ($P < 0.001$) and between weed control treatments ($P < 0.01$) but not among tillage frequencies (Table 2). Similarly, thousand seeds weight, plant height and plant stand count at harvesting significantly ($P < 0.05$ to $P < 0.001$)) differed among tillage frequencies, P fertilization and between weed control treatments. Weed over dry weight at weeding was highly significantly ($P < 0.001$) affected by tillage frequency and significantly ($P < 0.05$) by P fertilization but not by weed control. Weed oven dry weight at harvesting also highly significantly ($P < 0.001$) responded to tillage frequency, P fertilization and weed control. Furthermore, total above ground biomass, number of pods per plant and plant height of field pea were highly significantly affected ($P < 0.001$) by the main effects of tillage, P fertilizer rate and weeding (Table 2). Accordingly, the highest mean total field pea biomass, number of pods per plant and plant height were recorded from three times tillage compared to other tillage frequencies (Tables 3 and 4). Similarly, weeding once and P fertilization at the rate of 20 kg P ha^{-1} gave the highest total above ground biomass yield and number of pods per plant among the treatments of the respective factors.

Yield and major yield components of field pea positively and significantly ($P < 0.001$) responded to P fertilizer. The application of P fertilizer at the rates of 10, 20 and 30 kg P ha^{-1} resulted in seed yield advantages of 30, 53 and 50%, respectively, compared to no P fertilizer treatment (Table 3). The results of the study indicated that the highest mean seed yield of field pea was obtained from the application of 20 kg P ha^{-1} although it did not differ significantly from the yield with 30 kg P ha^{-1}. Experimental findings on Nitisols and Alfisols of different locations of the country also showed that the application of phosphate fertilizer increased seed yields of field pea (Angaw and Asnakew, 1994; Getachew *et al*., 2003; Amare *et al*., 2005). The optimum dose of P for attaining an economic yield of field pea was found to be 20 kg ha^{-1}. Total biomass, harvest index, number of pods per plant and seeds per pod, plant stand count at harvesting, and weed biomass at weeding and at harvesting increased as P level increased up to 20 kg P ha^{-1} but decreased at 30 kg P ha^{-1} (Tables 3 and 4). In contrast, thousand seeds weight and plant height consistently increased as P rate increased.

The results of soil analysis were found to be sub-optimal for the production of field pea (Table 1). The soil pH and available P were below the optimum range. This had a direct relationship with the response of yield to applied phosphorus. In most cases, soils with pH less than 5.5 are deficient in available P, Ca and/or Mg (Cooke, 1986; Marschner, 1995; Getachew and Sommer, 2000). In such soils, the proportion of P fertilizer that could immediately be available to a crop becomes inadequate and residues of the fertilizer may be released very slowly (Sikora *et al*., 1991). Legume species differ widely in their ability to grow in soils of low P status. Mahler *et al.* (1988) reported that, in terms of nutrient availability, field pea, lentil, chickpea and faba bean grow best in soils with pH values between 5.7 and 7.2 and require between 13 and 35 kg P ha^{-1} for adequate yields, which agrees with the findings of this study. When pulse crops are grown on soils with pH values of less than 5.6, they give low yields (Mahler *et al*., 1988).

Table 2. Significance of mean squares for yield, yield components and agronomic traits of field pea analyzed for the effects of tillage frequency, P fertilizer rate and weeding at two locations for two years.

Source of variation	df	Yield, yield components and agronomic traits of field pea and weed biomass[a]									
		SY	BY	HI	TSW	SPP	PPP	PH	SC	WDM_1	WDM_2
Year (Y)	1	***	***	**	**	*	ns	**	**	**	***
Location (L)	1	*	***	**	**	ns	**	**	**	***	***
Y×L	1	***	***	***	***	ns	ns	ns	*	***	***
Tillage (T)	3	***	***	ns	*	**	***	***	**	***	***
Y×T	3	*	*	ns	ns	ns	ns	**	ns	*	***
L×T	3	*	***	ns	ns	ns	ns	ns	ns	***	***
Y×L×T	3	ns	***	ns	ns	ns	ns	ns	ns	***	***
Phosphorus (P)	3	***	***	***	***	***	***	***	**	*	***
Y×P	3	*	*	ns	ns	ns	ns	ns	*	*	ns
L×P	3	ns	*	*	ns	ns	ns	ns	ns	ns	ns
T×P	9	***	**	ns	ns	*	ns	*	*	***	***
Y×L×P	3	*	ns	ns	ns	ns	ns	ns	ns	ns	ns
Y×T×P	9	ns	**	***	ns	*	ns	ns	ns	ns	***
L×T×P	9	ns	ns	ns	ns	ns	ns	ns	ns	ns	***
Y×L×T×P	12	ns	ns	ns	ns	ns	ns	ns	ns	ns	***
Weeding (W)	1	***	***	**	**	***	***	***	***	ns	***
Y×W	1	***	ns	**	ns	ns	ns	ns	ns	ns	***
L×W	1	***	***	ns	ns	ns	ns	*	ns	ns	***
T×W	3	**	*	*	ns	ns	ns	*	*	ns	***
Y×L×W	1	**	**	ns	ns	ns	ns	*	ns	ns	***
Y×T×W	3	ns	ns	*	ns	ns	ns	ns	ns	***	ns
L×T×W	3	ns	ns	ns	ns	ns	ns	ns	ns	**	***
Y×L×W	3	ns	ns	ns	ns	ns	ns	ns	ns	*	***
P×W	3	ns	ns	ns	ns	ns	***	ns	**	**	***
Y×P×W	3	ns	**	***	**	ns	ns	ns	ns	ns	***
L×P×W	3	ns		ns	ns	ns	ns	ns	ns	ns	***
T×P×W	9	*	**	*	ns	*	ns	*	*	*	***
Y×L×P×W	3	ns	ns	ns	ns	ns	ns	ns	ns	ns	***
Y×T×P×W	9	**	**	*	ns	ns	ns	ns	**	ns	*
Y×L×T×P×W	21	ns	ns	ns	ns	ns	ns	ns	ns	ns	***
CV (%)		12.2	12.4	11.4	4.8	13.8	15.6	7.2	12.5	24.7	14.5

[a], ** and *** = Significant at $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively; ns = Not significant at $P > 0.05$; df = Degrees of freedom; SY = Seed yield; BY = Biomass yield; HI = Harvest index; TSW = Thousand seeds weight; SPP = Number of seeds per pod; PPP = Number of pods per plant; PH = Plant height; SC = Plant stand count at harvesting; WDM_1 = Weed dry mater at weeding; WDM_2 = Weed dry mater at harvesting; CV = Coefficient of variation.*

Weed control had a significant ($P < 0.001$) effect on seed yield, total biomass, number of pods per plant and seeds per pod, plant height, plant stand count and weed oven dry matter weight at harvesting and at $P < 0.01$ on harvest index and thousand seeds weight (Table 2). Nevertheless, weed oven dry matter weight at weeding was not significantly affected ($P > 0.05$) by weeding. Weeding once by hand at the proper growth stage of the plant resulted in mean seed yield advantage of 16% compared to the unweeded control treatment (Table 3). Similarly, a review by Rezene (1994) indicated that weed control operation at the proper growth stages of plants significantly increased seed yield and major yield components of field pea. Results of studies have shown that full-season weed competition caused yield reduction up to 15.3% in field pea (Rezene, 1986). The presence of weeds during the first 4, 7 and 10 weeks after sowing accounted for respective yield reduction of 0, 43.3 and 66.9% in field pea (Rezene, 1986). Knott and Halila (1988) also reported substantial yield reduction in food legumes due to weed competition. As depicted in the economic analysis, pre-planting tillage decreased to a great extent the amount of labor required to control weeds. The intensity and distribution of weeds decreased consistently as the frequency of tillage increased.

The critical period of weed competition in cool-season food legumes varies from 3 to 8 weeks after crop emergence. The extent to which the yield is reduced by weeds depends not only on the weed species and density, but also on the period for which the crop is exposed to weeds. The results of the study revealed that the weight of weed biomass at harvesting decreased to a great extent by 35% due to weeding compared to the weed biomass recorded in the unweeded conditions (Table 4). Weed biomass both at weeding and harvesting were higher at Chelia than at Welmera, in which field pea was grown after barley at Chelia, and after barley and wheat at Welmera. The plant groups most affected by tillage were the broadleaved weeds. The intensity of weed infestation was dependent not only on the soil tillage treatment but also on the herbicide level used on the preceding cereal crop (Rao, 2000). The higher the herbicide level, the lower the total dry matter production measured.

Table 3. Response of mean yield and yield components of field pea to the main effects of the factors.

Factor	Mean field pea yield and yield components [a]					
	SY (kg ha^{-1})[b]	BY (kg ha^{-1})	HI (%)	TSW (g)	PPP (No.)	SPP (No.)
Location:						
Welmera	1387b	3840b	36.0a	173b	6.5b	4.3
Chelia	1799a	5436a	34.0b	203a	6.8a	4.5
LSD (0.05)	39.16	114.22	0.77	1.88	0.22	Ns
Tillage frequency:						
Once	1187d	3449c	34	192a	5.6b	4.1b
Twice	1642c	4872b	34	187bc	6.9a	4.5a
Three times	1841a	5259a	35	188b	7.1a	4.5a
Four times	1702b	4974b	35	185c	6.9a	4.4a
LSD (0.05)	55.38	161.53	Ns	2.66	0.30	0.18
Phosphorus fertilization (kg ha^{-1}):						
0	1195c	3575c	33c	185c	5.4c	4.1b
10	1551b	4594b	34bc	187bc	6.7b	4.5a
20	1830a	5236a	36a	189ab	7.3a	4.6a
30	1796a	5149a	35ab	191a	7.1a	4.5a
LSD (0.05)	55.38	161.53	1.10	2.66	0.30	0.18
Weeding frequency:						
Unweeded	1474b	4369b	34.0b	190a	6.2b	4.2b
Once weeded	1712a	4908a	35.0a	186b	7.1a	4.6a
LSD (0.05)	39.16	114.22	0.77	1.88	0.22	0.13

[a]*Means within a column of the same factor followed by the same letter(s) are not significantly different at P < 0.05.*
[b]*SY = Seed yield; BY = Biomass yield; HI = Harvest index; TSW = Thousand seeds weight; PPP = Pods per plant; SPP = Seeds per pod; ns = Not significant at P > 0.05.*

Table 4. Response of some agronomic traits of field pea and weed biomass to the main effects of the factors.

Factor [d]	Plant height (cm)	Stand count m^{-2}	WDM_1 (g m^{-2})[e]	WDM_2 (g m^{-2})
Location:				
Welmera	107b	50b	41b	39b
Chelia	111a	53a	57a	61a
LSD (0.05)	1.41	1.29	2.56	1.68
Tillage frequency:				
Once	102c	47b	82a	108a
Twice	110b	51a	48b	43b
Three times	113a	53a	34c	23c
Four times	112ab	52a	32c	24c
LSD (0.05)	2.00	1.82	3.62	2.38
Phosphorus fertilization (kg ha^{-1}):				
0	99c	49b	46b	48b
10	111b	52a	49ab	48b
20	113ab	53a	51a	51a
30	114a	53a	50a	51a
LSD (0.05)	2.00	1.82	3.62	2.38
Weeding frequency:				
Unweeded	107b	50b	48	60a
Once weeded	112a	53a	50	39b
LSD (0.05)	1.41	1.29	ns	1.68

[d]*Means within a column of the same factor followed by the same letters are not statistically different at P > 0.05.*
[e]*WDM_1 = Weed dry matter at weeding; WDM_2 = Weed dry matter at harvesting; ns = Not significant at P > 0.05.*

The combined analysis of variance over the two cropping seasons showed that there were significant ($P < 0.05$; $P < 0.01$ and $P < 0.001$) year by location (Y×L), tillage by P fertilization (T×P), location by weeding (L×W), tillage by weeding (T×W), tillage by P fertilization and weeding (T×P×W), and year by tillage, P fertilization and weeding (Y×T×P×W) interactions for mean field pea seed yield, total biomass and weed biomass at harvesting (Table 2).

The seed yield of field pea obtained from the control (once tillage and no P) treatment was significantly ($P < 0.05$) lower compared to yields obtained from any of the remaining combinations of tillage frequency and P fertilizer rates (Table 5). Twice and three times tillage frequency brought about seed yield increments of 1181 and 1229 kg ha^{-1} at 20 kg P ha^{-1} compared to field pea seed yield obtained from once tillage and no P application with yield advantages of 149 and 155%, respectively. Similarly, sowing field pea at the second and third tillage frequencies with 20 kg P ha^{-1} and weeded once condition resulted in yield increases of 1419 and 1617 kg ha^{-1}, respectively, compared to once tillage, no P treatment and unweeded conditions (Table 6). The yield increments due to these treatments were 203 and 232%, respectively, compared to the control that is planting with the first pass of ox-drawn implement and with no P application and unweeded condition. In general, the highest mean seed yield (2314 kg ha^{-1}) of the two years was recorded from three times tillage, application of 20 kg P ha^{-1} and weeding once by hand. Likewise, Getachew *et al.* (2005) reported that the highest faba bean seed yield for the tillage and weed control interaction was obtained from three times tillage and weeding once by hand.

Table 5. Interaction effects of tillage frequency and P fertilization on mean field pea seed yield (kg ha^{-1}).

Tillage frequency	Phosphorus fertilization (kg ha^{-1})			
	0	10	20	30
Once	794	1190	1376	1389
Twice	1153	1533	1975	1908
Three times	1449	1840	2023	2052
Four times	1383	1641	1947	1836
LSD (0.05)	126.60			

Seed yield was significantly positively correlated with total biomass, number of pods per plant, plant height, number of seeds per pod, thousand seeds weight and plant stand count at harvesting (r = 0.93***, 0.54***, 0.54**, 0.41**, 0.37** and 0.34**, respectively) (Table 7). Total plant biomass and number of pods per plant were strongly correlated with seed yield, which indicates that high total aboveground biomass and number of pods per plant are essential for high seed yield production.

Table 6. Interaction effects of tillage, P fertilizer and weeding on mean field pea seed yield (kg ha^{-1}).

Tillage Frequency	P (kg ha^{-1})	Weeding	
		Unweeded	Weeded once
Once	0	697	892
Once	10	1141	1239
Once	20	1288	1465
Once	30	1267	1511
Twice	0	1122	1184
Twice	10	1347	1720
Twice	20	1834	2116
Twice	30	1808	2007
Three times	0	1295	1604
Three times	10	1697	1983
Three times	20	1732	2314
Three times	30	1901	2202
Four times	0	1291	1476
Four times	10	1589	1693
Four times	20	1879	2014
Four times	30	1699	1972
LSD (0.05)		179.10	

Table 7. Coefficients of correlation (r) among yield and agronomic parameters of field pea for mean values of two locations and two cropping seasons.

Character^{ƒ}	SY	BY	HI	TSW	SPP	PPP	PH
SC	0.34**	0.31**	-0.05ns	0.26*	0.24*	-0.004ns	-0.02ns
PH	0.54**	0.53**	0.02ns	-0.09ns	0.42**	0.73***	
PPP	0.54**	0.52**	0.05ns	-0.08ns	0.25*		
SPP	0.41**	0.42**	-0.05ns	0.03ns			
TSW	0.37**	0.45**	-0.27**				
HI	0.06ns	-0.27*					
BY	0.93***						

, ** and * = Significant at P < 0.05, P < 0.01 and P < 0.001, respectively; ns = Not significant at P > 0.05; SY = Seed yield; BY = Biomass yield; HI = Harvest index; TSW = Thousand seeds weight; SPP = Number of seeds per pod; PPP = Number of pods per plant; PH = Plant height; SC = Plant stand count at harvesting.*

3.2. Economic Analysis

Economic analysis was conducted for tillage frequency, P fertilizer and weed control experiments taking mean seed yields of two years. As farmers attempt to evaluate the economic benefits of shifts in practice, partial budget analysis was done to identify the rewarding treatments. It is one of the concerns of the farmers to find options of field pea management that can provide better economic advantages. The farmers produce field pea without application of inorganic fertilizer, planting with the first pass and without weed control. These practices cannot, however, enable the farmers to produce as high a yield as possible and to earn the highest number of net benefits as possible. To fill this gap, 32 different management options were compared on farmers' fields to select the best options that can bring the greatest economic advantages.

According to net benefit analysis, positive net benefits ranging from 3179.85 to 9832.65 Ethiopian Birr (ETB) were obtained from producing field pea on a hectare of land (Table 8). The option with three times tillage, application of 20 kg P ha^{-1} and weeding once by hand gave the highest net benefit of 9832.65 ETB. Farmers' practice of once tillage, no fertilizer application and no weeding gave the lowest yield and net benefit of 3179.85 ETB ha^{-1}. Out of the total 32 treatments considered for economic analysis, 21 of them were dominated, indicating that the value of the increase in yields due to these treatments is not enough to compensate for the increase for costs. Hence, no farmer would choose treatments that incur additional costs. The dominated treatments were, therefore, eliminated from further economic analysis.

In the end, marginal analysis was conducted for the non-dominated eleven treatments, including the control treatment. In order to make recommendations to farmers based on analysis, the minimum acceptable rate of return by the farmers was assumed to be 100% for this experiment (Amanuel *et al*., 1991). This implies that the farmers will not be willing to change their traditional practice of once tillage, no inorganic fertilizer and no weeding unless they get a minimum of 100% rate of return. If the minimum rate of return is below 100%, the change from one treatment to another will not be acceptable.

According to the results of the marginal analysis, the treatment with three times tillage, application of 20 kg P ha^{-1} and weeding once was identified to be the best option with a marginal rate of return of 423%, well above the minimum acceptable rate of return of 100% (Table 9). From this treatment, a marginal benefit of 804.00 ETB ha^{-1} was obtained from investing an extra 190.00 ETB ha^{-1}. Seven other treatments have also given a marginal rate of return well above the minimum rate of return (100%), but lower than the rate of return obtained from a treatment with a MRR of 423%. Nonetheless, they can be used as options for farmers with different income levels, in as far as they give a better rate of return than the traditional (control) practice. Therefore, the farmers can get the highest rate of return if they follow an improved agronomic practice with three times tillage, application of 20 kg P ha^{-1} and weeding once by hand for the production of field pea.

Table 8. Net benefit analysis results of field pea production as influenced by tillage, P fertilizer and weed control pooled over the two (Chelia and Welmera) locations.

Treatment[c]	Mean yield (kg ha^{-1})	Adjusted yield-10% (kg ha^{-1})	Gross benefit (ETB ha^{-1})	Costs that vary (ETB ha^{-1})				Net benefit (ETB ha^{-1})
				Tillage	P (kg ha^{-1})	Weeding	Total cost	
T1P1W1	697	627	3479.85	300	0	0	300	3179.85
T1P1W2	892	803	4456.65	300	0	370	670	3786.65
T1P2W1	1141	1027	5699.85	300	374	0	674	5025.85
T1P2W2	1239	1115	6188.25	300	374	370	1044	5144.25
T1P3W1	1288	1159	6432.45	300	748	0	1048	5384.45
T1P3W2	1465	1318	7314.90	300	748	370	1418	5896.90
T1P4W1	1267	1140	6327.00	300	1072	0	1372	4955.00
T1P4W2	1511	1360	7542.45	300	1072	370	1742	5800.45
T2P1W1	1122	1010	5605.50	500	0	0	500	5105.50
T2P1W2	1184	1066	5916.30	500	0	290	790	5126.30
T2P2W1	1347	1212	6726.60	500	374	0	874	5852.60
T2P2W2	1720	1548	8591.40	500	374	290	1164	7427.40
T2P3W1	1834	1651	9157.50	500	748	0	1248	7909.50
T2P3W2	2116	1904	10567.20	500	748	290	1538	9029.20
T2P4W1	1808	1627	9029.85	500	1072	0	1572	7457.85
T2P4W2	2007	1806	10023.30	500	1072	290	1862	8161.30
T3P1W1	1295	1165	6465.75	700	0	0	700	5765.75
T3P1W2	1604	1444	8014.20	700	0	280	980	7034.20
T3P2W1	1697	1527	8474.85	700	374	0	1074	7400.85
T3P2W2	1983	1785	9906.75	700	374	280	1354	8552.75
T3P3W1	1732	1559	8652.45	700	748	0	1448	7204.45
T3P3W2	2314	2083	11560.65	700	748	280	1728	9832.65
T3P4W1	1901	1711	9496.05	700	1072	0	1772	7724.05
T3P4W2	2202	1982	11000.10	700	1072	280	2052	8948.10
T4P1W1	1291	1162	6449.10	900	0	0	900	5549.10
T4P1W2	1476	1328	7370.40	900	0	220	1120	6250.40
T4P2W1	1589	1430	7936.50	900	374	0	1274	6662.50
T4P2W2	1693	1524	8458.2	900	374	220	1494	6964.20
T4P3W1	1879	1691	9385.05	900	748	0	1648	7737.05
T4P3W2	2014	1813	10062.15	900	748	220	1868	8194.15
T4P4W1	1699	1529	8485.95	900	1072	0	1972	6513.95
T4P4W2	1972	1775	9851.25	900	1072	220	2192	7659.25

[c]T1 = Control; T2 = Twice tillage; T3 = Three times tillage; T4 = Four times tillage; P1 = No P fertilizer; P2 = 10 kg P ha^{-1}; P3 = 20 kg P ha^{-1}; P4 = 30 kg P ha^{-1}; W1 = No weeding; W2 = Weeding once by hand.

Table 9. Marginal analysis of field pea response to tillage, P fertilizer and weed control for the mean of the two locations (Chelia and Welmera).

Treatment[f]	Adjusted yield - 10% (kg ha^{-1})	Total cost that vary (ETB ha^{-1})	Marginal cost (ETB ha^{-1})	Net benefit (ETB ha^{-1})	Marginal benefit (ETB ha^{-1})	Marginal rate of return (%)
T1P1W1	627	300	-	3180.00	-	-
T2P1W1	1001	500	200	5105.00	1925.00	962
T3P1W1	1165	700	200	5766.00	661.00	330
T2P2W1	1212	874	174	5853.00	87.00	50
T3P1W2	1444	980	106	7034.00	1181.00	1114
T3P2W1	1527	1074	94	7400.00	366.00	389
T2P2W2	1548	1164	90	7427.00	27.00	30
T2P3W1	1651	1248	84	7909.00	482.00	574
T3P2W2	1785	1354	106	8553.00	644.00	607
T2P3W2	1904	1538	184	9029.00	476.00	259
T3P3W2	2083	1728	190	9833.00	804.00	423

[f]*T1 = Control; T2 = Twice tillage; T3 = Three times tillage; P1 = No P fertilizer; P2 = 10 kg P ha^{-1}; P3 = 20 kg P ha^{-1}; W1 = No weeding; W2 = Weeding once by hand.*

4. Acknowledgements

The authors gratefully acknowledge the Ethiopian Institute of Agricultural Research (EIAR) for funding this experiment. They are also thankful to Mr. Beyene Ofa, Mr. Chanyalew Mandefro and Miss Asnakech Dubale for their assistance in the execution of the field experiments. Appreciation is also due to the Soil Laboratory of Holetta Agricultural Research Center for analytical services.

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ustard (Brassica carinata A. Braun)

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Abstract: A field experiment was conducted at Kulumsa Agricultural Research Center in order to estimate the extent of genetic variation in Ethiopian mustard (*Brassica carinata* A. Braun). In this study, genetic diversity in 60 Ethiopian mustard genotypes, collected from 16 regions of Ethiopia, were assessed using the techniques of cluster and principal component analyses based on 16 traits. All traits were significantly ($P < 0.01$) different and the genotypes were grouped into seven clusters. The largest and the smallest clusters comprised about 28.3 and 1.7%, respectively, of the studied genotypes. Genotypes in clusters II and VII showed better performance for the majority of traits of interest: seed yield/plot, seed yield/plant, biomass/plot, biomass/plant, plant height, number of pods/plant, 1000 seeds' weight and oil content. The clustering pattern of the tested genotypes indicated no relationships between genetic diversity and geographic origins since genotypes from the same origin were grouped into different clusters or vice versa. The average inter-cluster distances were significant for all clusters. The D^2 statistics analysis showed that the distance between clusters IV and V was minimum ($D^2 = 22.085$) while distance between clusters VI and VII was maximum ($D^2 = 1239.00$), suggesting the existence of diversity among the genotypes, and hence, parental materials can be selected and used for hybridization and subsequent improvement of Ethiopian mustard. Maximum variations in subsequent generations is expected if there is crossing of parents selected from clusters II and VII with those from clusters III, IV, and VI since the inter-cluster distances between these groups were large. On the other hand, crossing between clusters I, IV and V; I and II, and III and IV might not produce desirable recombinants since the inter-cluster distance between these groups was very small, indicating similarity of their genetic make-up. The first six principal components accounted for 92% of the total variations encountered. The first three principal components accounted for 36, 22 and 19% of the variations, respectively. Days to flowering, days to maturity, seed yield/plot, oil yield/plot and biomass/plot were the most important traits contributing to the total variation of the first principal component, implying the existence of great potential to improve these traits through selection.

Keywords: *Brassica carinata;* Cluster Analysis; Ethiopian Mustard; Genetic Diversity

1. Introduction

Brassica carinata is an amphidiploid species (BBCC, n = 17) containing the BB genome of *B. nigra* (n = 8) and CC genome of *B. oleracea* (n = 9) (Hemingway, 1995; Gomez-Campo and Prakash, 1999). It is believed to have originated in the plateaus of Ethiopia and has been cultivated there as an oilseed and vegetable crop since antiquity. In Ethiopia, the crop is traditionally used for many purposes, such as greasing traditional bread-baking clay pans, curing certain ailments and preparing beverages (Alemayehu, 2001). Furthermore, boiled and chopped leaves are mixed with butter, and served along with cheese and '*kitifo*' (slightly cooked, heavily chopped, and buttered beef). The bottom stalks remaining after harvest can be used for fences or as firewood. Similarly, the upper-branched parts are often used for making brooms for cleaning floors. Ethiopian mustard is also very beneficial in farming systems, as a potential rotational-crop for cereals and pulses. In its homeland, *B. carianata* is found to be better yielding, more tolerant to drought, more resistant to diseases and insect pests and seed shattering than *B. napus* (Tadesse and Bayeh, 1992; Alemayehu and Becker, 2002; Singh, 2003; Teklewold, 2005).

The industrial value of *Brassica carinata* oil is indeed immense in leather tanning, the manufacture of varnishes, paints, lubricants, soap and lamps (Doweny, 1971; Bhan, 1979). Recent investigations have witnessed that after transesterification, the oil exhibits physical and chemical properties suitable for bio-diesel (Cardone *et al.*, 2003). The crop has the potential to be used as feedstock for oleochemicals (due to high erucic and linolenic acids) and bio-fumigant (due to its high glucosinolate) industries.

Genetic diversity measures individual variation and reflects the frequency of different types in a population (Frankel *et al.*, 1995). Analysis of genetic relationships in crop species is an important component of crop improvement. It helps to analyze genetic variability of cultivars (Singh, 1983), select parental materials for hybridization for making new gene recombinations, select inbred parents or testers for maximizing heterotic response and identify materials that should be maintained to preserve maximum genetic diversity in germplasm sources (Thormann and Osborn, 1992).

Genetic diversity in crop plants arises as a consequence of inter-play of evolutionary forces (mutations, selections, migrations and random genetic drift) and the influence of man through selection and domestication (Allard, 1988). The genetic variation within a taxon is not uniformly distributed throughout the geographic area where it is growing (Frankel *et al.*, 1995) and populations from areas very distant from each other are normally expected to accumulate higher genetic diversity than the population from the same vicinity (Chandel and Joshi, 1983). In diversity study, the inclusion of genotypes collected from different geographic areas has been adopted to capture maximum allelic diversity of a particular crop species.

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ISSN 1992-0407

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Divergence analysis is usually performed by using D^2 techniques to classify genotypes for hybridization purposes. The genetic improvement through hybridization and selection depends upon the extent of genetic diversity between parents. The D^2 statistics is one of the important biometrical techniques used for assessing genetic divergence present in a population (Sharma, 1996). The D^2 values represent the index of genetic divergence among the genotypes both at intra-cluster and inter-cluster levels. It would, therefore, be logical to make crosses between genotypes belonging to the clusters which are separated by greatest generalized distance and show maximum divergence (Singh, 1983).

Information on genetic diversity is useful for making choices of parental materials of potential use in the breeding programs and it also enhances the efficienc of gene banks (Jain, 1977; Arunachalam, 1981). Although there are a large number of collections, thorough studies have not been carried out on genetic diversity in Ethiopian mustard genotypes. Therefore, an attempt is made in the present study to assess genetic divergence in Ethiopian mustard genotypes.

2. Materials and Methods

The field experiment was conducted at Kulumsa Agricultural Research Center (8° 01' N latitude and 39° 09' E longitude) in Arsi zone, southeastern Ethiopia, in the 2005/2006 cropping season using 60 Ethiopian mustard genotypes collected from 16 different parts of the country (Table 1). The genotypes were intentionally taken to represent different collections of the country (i.e., purposive sampling). Three released varieties (S-67, Yellow Dodolla and Holetta-1) were included for comparison and to see their position in the diversity pattern. Randomized complete block design with three replications was used in this study. Each genotype was planted in a plot consisting of two rows 5 m long with a spacing of 30 cm between rows. The recommended cultural practices were followed to raise the crop.

Data were recorded on 16 characters, including days to flowering, days to maturity, plant height, number of primary branches per plant, number of secondary branches per plant, number of pods per plant, number of seeds per pod, biomass per plant, biomass per plot, seed yield per plant, seed yield per plot, harvest index per plant, harvest index per plot, thousand seeds weight, oil content and oil yield per plot. Fresh biomass weights were recorded and samples were also taken and dried to constant weight. Then total above ground dry matter and harvest index were calculated. Seed yield per plot was measured after the moisture of the seed was adjusted to 7%. Oil content (%) is the proportion of oil in the seed to the total oven dried seed weight as measured by Nuclear Magnetic Resonance Spectroscope. Oil yield per plot is the amount of oil obtained by multiplying seed yield per plot by corresponding oil percentage. The 16 characters were subjected to analysis of variance following the standard statistical analysis methods (Gomez and Gomez, 1984). Clustering of genotypes into different groups (i.e., based on 16 traits) was carried out using the average linkage method and the appropriate number of clusters were determined from the values of Pseudo F and Pseudo T statistics using the SAS computer software facilities (SAS, 2001). By employing the same software, F statistics and other test statistics were used to test the significances of the generalized squared distances between clusters and that of the clusters versus the traits, respectively.

The Mahalanobis generalized distances were utilized to estimate the distances between and within clusters using the SAS computer software package as per the following formula:

$$D^2ij = (Xi-Xj)'\ S^{-1}(Xi-Xj).$$

where, D^2ij = the distance between any two groups i and j; Xi and Xj are the vector mean of the traits for the ith and jth groups, respectively, and S^{-1} = the inverse of the pooled covariance matrix. In order to assess the total variations and supplement the cluster analysis, principal component analysis was also carried out using the SAS computer software facilities (SAS, 2001), involving all the 16 quantitative traits.

3. Results and Discussion

3.1. Analysis of Variance

Highly significant ($P < 0.01$) differences were noted for all traits measured (Table 2). The significance of genotype difference indicates the presence of variability for each of the characters among the tested genotypes. In characterizing genotypes of *B. carinata* collected from different parts of Ethiopia, Abebe *et al.* (1992) observed the presence of wide variation for morphological and agronomic traits. Alemayehu (2001) also evaluated 36 genotypes of Ethiopian mustard for agronomically important traits and reported the existence of an enormous amount of genetic variability. This wealth of diversity can be used for improving yield, quality and resistance to various biotic and abiotic stresses in future breeding programs. In this study, the total variations were assessed by carrying out principal component analysis by considering all 16 quantitative traits.

3.2. Cluster Analysis

Data on total variations which were assessed by carrying out principal component analysis by considering all the 16 quantitative traits are presented in Table 3. The 60 Ethiopian mustard genotypes were grouped into seven clusters (Table 4 and Figure 1) and the D^2 statistics were computed for all possible pairs of clusters as shown in Table 5. Cluster I, the largest of all seven, included 17 (28.3%) genotypes that comprised one released variety (Yellow Dodolla), one accession collected from the market, three accessions whose areas of collection were unknown and some accessions collected from seven different areas of Ethiopia. Similarly, the second cluster constituted 12 (20%) genotypes, one released variety (S-67), a selection from Kulumsa and some accessions collected from seven different regions. Cluster III was the

...even (11.7%) ...s the second ...contained 14 ...ns were from Hararghe, three from Shewa, and the remaining accessions were from Illubabor, Sidamo, Welayita, Hediya, Wello and Arsi. Cluster V included eight (13.3%) accessions, two each from Shewa and Hararghe and the remaining four from Bale, Gojam, Gonder and Jimma each. Clusters VI and VII, the smallest clusters, constituted one (1.7%) genotype each. The genotype under cluster VI was collected from Gamo and that of Cluster VII was the recent variety (Holetta-1) that was released nationally in 2005. All the three released varieties were grouped under different categories, showing their distinct diversity. Generally speaking, this cluster analysis revealed that the Ethiopian mustard genotypes originating from different sources were randomly distributed into various subgroups with no definite pattern. Teklewold (2005) also reported similar results by grouping 43 accessions into four groups. This author reported that both dendrogram of cluster analysis and principal coordinate of analysis grouped the accessions in a very similar manner.

Table 1. List of the 60 Ethiopian mustard genotypes used in the diversity study of Ethiopian mustard.

Accession number	Area of collection[a]	Altitude
PGRC/E 211501	*	*
PGRC/E 208410	*	*
PGRC/E 21373	*	*
PGRC/E 20211	*	*
PGRC/E 21079	Arsi/Abomsa	2520
PGRC/E 21080	Arsi/Arba Gugu	3090
PGRC/E 21081	Arsi/Arba Gugu	2780
PGRC/E 21005	Arsi/Dodota	2450
PGRC/E 21002	Arsi/Shirka	1910
PGRC/E 21068	Bale/Adaba	2500
PGRC/E 215351	Bale/Ginir	*
PGRC/E 20109	Gamo	*
PGRC/E 20108	Gamo/Gardula	2100
PGRC/E 20162	Gojam/ Bahir Dar	1900
PGRC/E 208421	Gojam/Dangla	1950
PGRC/E 20110	Gojam/Inemay	2450
PGRC/E 208419	Gojam/Mecha	2050
PGRC/E 21257	Gojam/Shikudad	2090
PGRC/E 20112	Gojam/Tehnan	1980
PGRC/E 21033	Gonder	1930
PGRC/E 208004	Gonder/Dembiya	*
PGRC/E 21245	Gonder/Dembiya	1850
PGRC/E 208589	Hararghe/Chiro	2260
PGRC/E 208594	Hararghe/Goro gutu	1750
PGRC/E 20031	Hararghe/Habro	1750
PGRC/E 208596	Hararghe/Kersa	*
PGRC/E 208600	Hararghe/Kombolcha	2600
PGRC/E 208599	Hararghe/Kombolcha	2100
PGRC/E 212894	Hadiya/Angacha	2180
PGRC/E 20035	Illubabor/Chora	1800
PGRC/E 21358	Illubabor/Gumay	1820
PGRC/E 207928	Illubabor/Imboro Gechi	*
PGRC/E 21369	Jimma/Mana	1720
PGRC/E 213168	Kefa	*
PGRC/E 21058	Mentaweha market	*
Yellow Dodolla	Released in 1986	
S-67	Released in 1976	
Holetta-1	Released in 2005	
KARC-2000	Selection	
PGRC/E 20052	Shewa/Adis Alem	2540
PGRC/E 20068	Shewa/Ambo	2010
PGRC/E 20066	Shewa/Ambo	1950
PGRC/E 20125	Shewa/Ambo	1950
PGRC/E 208585	Shewa/Boset	1600
PGRC/E 20059	Shewa/Chaliya	1630
PGRC/E 20130	Shewa/Girar Jarso	2750
PGRC/E 20062	Shewa/Merhabete	1800
PGRC/E 21001	Shewa/Minjar	2755
PGRC/E 20159	Sidamo/Awasa	1750
PGRC/E 20076	Sidamo/Wenago	1853
PGRC/E 20168	Tigray	*
PGRC/E 20163	Tigray/Zal Anbesa	2300
PGRC/E 208860	Welayita/Sodozuriya	1820
PGRC/E 21328	Wellega/Arjo	2280
PGRC/E 21194	Wellega/Horo	1980
PGRC/E 21163	Wellega/Jima Arjo	2340
PGRC/E 208960	Wellega/Jima Genet	2280
PGRC/E 20090	Wellega/Naqamte	2140
PGRC/E 208717	Wellega/Seyo	1920
PGRC/E 21278	Welo/Desezuriya	*

[a]* = *Information not available*

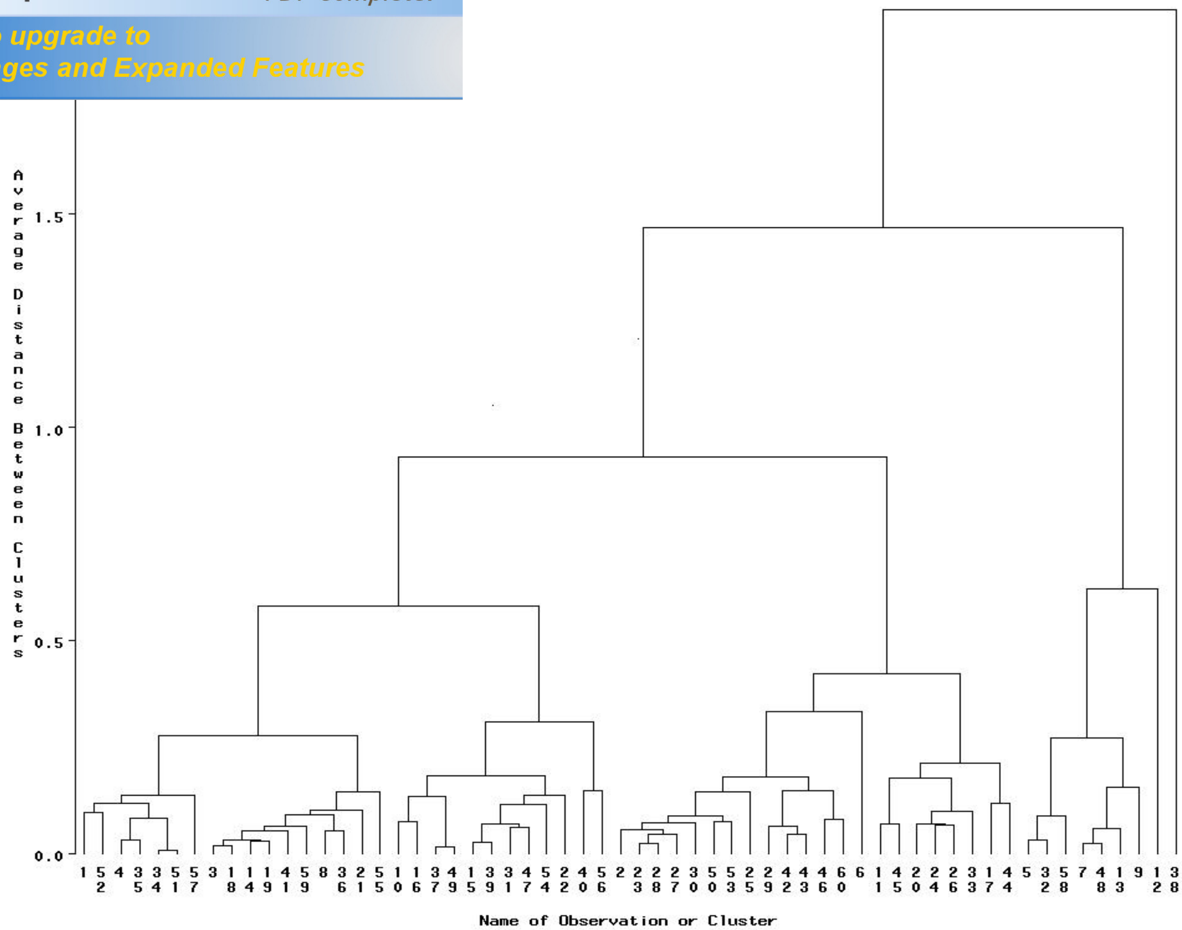

Figure 1. Dendrogram showing the clusters of 60 Ethiopian mustard genotypes.

Table 2. Mean squares of genotypes and error and the corresponding coefficient of variation for 16 characters studied.

Characters	Genotype (59)[b]	Error (118)	CV (%)
Days to flowering	125.258**	5.508	2.6
Days to maturity	324.254**	12.377	2.3
Plant height	529.660**	81.521	5.09
Primary branches per plant	4.892**	1.463	9.06
Secondary branches/plant	88.949**	52.727	23.80
Pods per plant	6547.463**	5963.013	24.42
Seeds per pod	1.238**	0.592	5.23
Biomass per plant	144.057**	106.723	21.66
Biomass per plot	3028892.429**	478780.452	20.69
Seed yield/plant	7.799**	6.147	25.26
Seed yield per plot	164861.548**	27782.425	24.20
Harvest index per plant	0.002**	0.001	13.26
Harvest index per plot	0.002**	0.001	11.78
1000 seeds weight	0.235**	0.035	6.06
Oil content	3.608**	1.174	3.13
Oil yield per plot	19312.379**	3278.271	24.04

[b]*** = Significance at P = 0.01; CV =* Coefficient of variation; *Figures in parenthesis are degrees of freedom*

3.3. Principal Component Analysis

In order to assess the total variations, principal component analysis was carried out by considering all 16 quantitative traits. The first six principal components accounted for 92% of the total variations encountered (Table 3). The first three principal components accounted for 36, 22 and 19% of variations, respectively. Among the traits considered in the study, days to flowering, days to biomass/plot … g to the total … Harvest index … ight on this component. Similarly, in the second principal component, seed yield/plant, number of pods/plant, number of secondary branches/plant and biomass/plant depicted a significant contribution. The third component emphasized plant height and 1000-seed weight, which increased but charged on harvest index/plant and plot.

The maximum variation (36%) depicted by the first principal component was based on quantitative traits such as days to flowering, days to maturity, seed yield/plot, oil yield/plot and biomass/plot. This emphasizes the importance of these traits for assessment of genetic diversity in Ethiopian mustard.

Table 3. Eigenvalues, total variance and cumulative variance for the 16 quantitative traits.

Character[a]	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6
Days to flowering	-0.38	0.10	0.15	0.05	0.13	-0.11
Days to maturity	-0.35	0.10	0.22	0.15	0.12	-0.16
Plant height	0.13	-0.06	0.48	-0.14	-0.08	-0.05
Primary branches per plant	-0.28	0.16	-0.02	-0.41	0.23	0.50
Secondary branches per plant	-0.16	0.42	-0.10	-0.19	0.10	0.26
Number of pods per plant	0.05	0.43	-0.18	-0.22	-0.40	-0.17
Number of seeds per pod	-0.29	0.08	-0.04	0.52	0.07	-0.31
Biomass per plant	-0.15	0.40	0.24	-0.07	-0.25	-0.21
Seed yield per plant	0.03	0.50	0.05	0.15	-0.12	-0.05
Harvest index per plant	0.22	0.23	-0.27	0.38	0.21	0.28
Biomass per plot	0.33	0.09	0.28	-0.12	0.14	-0.12
Seed yield per plot	0.37	0.14	0.18	-0.03	0.13	-0.09
Harvest index per plot	0.27	0.21	-0.23	0.29	0.03	0.13
Thousand seed weight	-0.03	0.14	0.44	0.19	0.45	0.21
Oil content	-0.06	-0.10	0.34	0.35	-0.61	0.56
Oil yield per plot	0.36	0.13	0.22	0.02	0.05	-0.03
Eigenvalues	5.75	3.56	3.11	1.06	0.66	0.64
%Total variance	36.0	22.0	19.0	7.0	4.0	4.0
%Cumulative variance	36.0	58.0	78.0	84.0	88.0	92.0

[a]*PC 1, PC 2, PC 3, PC 4, PC 5 and PC 6 are the first six principal components*

Table 4. Distribution of 60 Ethiopian mustard genotypes in different clusters.

Cluster I	PGRC/E 211501	PGRC/E 20162	PGRC/E 213168	PGRC/E 20168	PGRC/E 208717
	PGRC/E 21373	PGRC/E 21257	PGRC/E 21058	PGRC/E 20163	
	PGRC/E 20211	PGRC/E 20112	Yellow Dodolla	PGRC/E 21194	
	PGRC/E 21005	PGRC/E 208004	PGRC/E 20068	PGRC/E 208960	
Cluster II	PGRC/E 21068	PGRC/E 21245	KARC-2000	PGRC/E 20159	
	PGRC/E 208421	PGRC/E 21358	PGRC/E 20052	PGRC/E 21328	
	PGRC/E 20110	S-67	PGRC/E 20062	PGRC/E 21163	
Cluster III	PGRC/E 21079	PGRC/E 21002	PGRC/E 207928	PGRC/E 20090	
	PGRC/E 21081	PGRC/E 20108	PGRC/E 21001		
Cluster IV	PGRC/E 208410	PGRC/E 20031	PGRC/E 212894	PGRC/E 20125	PGRC/E 208860
	PGRC/E 21080	PGRC/E 208600	PGRC/E 20035	PGRC/E 20130	PGRC/E 21278
	PGRC/E 208589	PGRC/E 208599	PGRC/E 20066	PGRC/E 20076	
Cluster V	PGRC/E 215351	PGRC/E 21033	PGRC/E 208596	PGRC/E 208585	
	PGRC/E 208419	PGRC/E 208594	PGRC/E 21369	PGRC/E 20059	
Cluster VI	PGRC/E 20109				
Cluster VII	Holetta-1				

3.4. Distances among Different Clusters

Maximum generalized squared distance was observed between clusters VI and VII (D^2 = 1239), followed by that of clusters II and VI (D^2 = 757.217), and Clusters III and VII (D^2 = 734.628). In contrast, the smallest squared distance was obtained between clusters IV and V (D^2 = 22.085), indicating their close similarity. The average intra-cluster distance ranged from 2.522 (Cluster I) to 8.189 (Clusters VI and VII) as shown in Table 5. In fact, there was highly significant ($P < 0.01$) difference between the analyzed inter-cluster distances. This is additional proof of for the presence of wide diversity among the studied genotypes to be exploited in future variety improvement schemes.

...aracters for

...luster II, with ..., whereas the shortest with mean height of 159.05 cm was included in cluster III that had seven genotypes (Table 6). Others were grouped in cluster VII (181.00 cm) and cluster I (184.10 cm). Cluster VII exhibited the highest harvest index on a plant and plot basis (0.225 and 0.220, respectively) against the lowest of cluster VI, 0.184 and 0.164, respectively. The range of days to maturity was between 144 for cluster VII to 171 days for cluster VI. Genotypes grouped under cluster V and cluster II were relatively early maturing, with mean days to maturity of 146 and 148 days, respectively. However, genotypes classified under cluster III were relatively late maturing.

The highest biomass on plot basis was recorded for cluster VII (5950 g), while the lowest was for cluster VI (867 g). The second highest and lowest biomass per plot were recorded for cluster II and cluster III. On a plant basis, highest biomass was also recorded for cluster VII (58.17 g), whereas the lowest was registered for cluster V (42.48 g). The highest seed yields per plant (13.17 g) and per plot (1304.91 g) were recorded for cluster VII. The lowest seed yields per plant and plot were recorded for cluster VI (9.13 g and 151.38 g, respectively) compared to cluster II with high seed yield of 961.49 g/plot (Table 6). Genotypes in cluster III were low yielders, with mean seed yield per plot of 334.37 g.

Generally, clusters that contained early maturing genotypes such as clusters VII and II produced relatively high yield, more biomass and long stature but clusters with late maturing genotypes such as clusters VI and III were relatively shorter and produced low biomass. The general performance of genotypes was largely affected by the moisture stress occurring during the grain filling period and the effect was more pronounced on seed yield, 1000-seed weight and oil content. Early maturing genotypes in clusters II and VII relatively escaped moisture stress and produced better seed yield and yield components, suggesting that earlier reproductive development is obligatory for high yield and yield components in areas of terminal moisture stress. Among the genotypes, Holetta-1, PGRC/E 21068, 21163, 20052, 20110 and 21245 were the promising ones due to their better yielding ability and could be selected as parents to be crossed with genotypes in distant clusters, which were better in biomass, 1000-seed weight and oil content. The highest oil content (37.6%) was recorded from PGRC/E 21358 in cluster II and it could be a good candidate for crossing with distant genotypes for improving oil content. In short, cluster analysis showed the presence of high genetic divergence among the Ethiopian mustard genotypes collected from different agro-ecologies of Ethiopia. Hence, hybridization of these genetically divergent parents could lead to the development of desirable recombinants and transgresive segregants, that in turn, may lead to the development of better performing varieties than the released varieties. Crossing genotypes belonging to distant clusters for wide Mahalanobis distance (D^2) could maximize transgresive segregation (Amsalu and Endeshaw, 1999).

In conclusion, the current study has shown that there is sufficient evidence for the existence of ample diversity among the genotypes of Ethiopian mustard for optimizing the conservation and utilization of the mustard genetic resources which could have major impacts on the diverse needs of growers and consumers in view of future climatic, edaphic and biotic challenges.

4. Acknowledgment

The authors would like to acknowledge the germplasm provided by the Institute of Biodiversity Conservation, Ethiopia. The research was funded by the Ethiopian Institute of Agricultural Research.

…cluster divergence D² value in 60 Ethiopian mustard genotypes.

[illegible]	[illegible]	II	III	IV	V	VI	VII
[illegible]	[illegible]	28.95500	200.47509	65.55999	24.05488	528.60367	188.37942
[illegible]	[illegible]	**3.21888**	360.03439	163.36467	86.17360	757.21718	85.12234
III			**4.29687**	46.54070	111.89223	118.44844	734.62849
IV				**2.91057**	22.08478	250.60659	439.52415
V					**4.02981**	376.12252	306.09072
VI						**8.18869**	1239.00
VII							**8.18869**

Table 6. Mean values of seven clusters for 13 characters of the 60 genotypes.

Cluster[b]	DF	DM	PH(cm)	PB/PL	SB/PL	PD/PL	SD/PD	BM/PL(g)	SY/PL(g)	HI/PL	BM/P(g)	SY/P(g)	HI/P
I	89.59	153.33	184.10	12.94	28.32	307.45	14.78	48.47	9.95	0.205	3765.88	780.68	0.207
II	87.17	148.19	187.94	12.71	29.13	314.76	14.22	47.43	10.14	0.213	4539.72	961.49	0.211
III	98.38	162.95	159.05	14.40	32.70	310.23	15.54	49.26	9.79	0.202	1730.00	334.37	0.194
IV	92.74	155.76	172.12	14.13	33.73	329.30	14.80	48.25	9.46	0.198	2675.24	528.33	0.197
V	85.17	145.67	173.46	12.75	28.53	314.05	14.36	42.48	9.36	0.220	3220.42	666.06	0.206
VI	100.33	171.00	162.00	14.00	31.93	265.60	15.80	49.67	9.13	0.184	866.67	151.38	0.164
VII	84.00	143.67	181.00	13.77	38.50	410.30	14.07	58.17	13.17	0.225	5950.00	1304.91	0.220

[b]*DF = Days to flowering; DM = Days to maturity; PH = Plant height; PB/PL = Number of primary branches per plant, SB/PL = Number of secondary branches per plant; PD/PL = Number of pods per plant; SD/PD = Number of seeds per pod; BM/PL = Biomass per plant; BM/P = Biomass per plot; SY/PL = Seed yield per plant; SY/P = Seed yield per plot; HI/PL = Harvest index per plant; HI/P = Harvest index per plot.*

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nt and Monitoring Epidemics of Stem Rust (*Puccinia graminis* heastern Ethiopia

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Abstract: Stem rust caused by *Puccinia graminis f.sp.tritici* is a significant wheat production constraint in southeastern Ethiopia. Burkard 7-days volumetric spore trap was mounted in a field at Sinana Agricultural Research Center to examine the seasonal movement of urediospores of *P. graminis f.sp.tritici* during the cropping seasons of 2001-2006. Disease trap plots were also established to monitor the epidemics of stem rust on durum wheat at three major wheat growing and rust prone districts of Bale highlands viz., Sinana, Agarfa and Herero. Results showed that urediospores exist in the air throughout the year though the concentration considerably varied among the months and seasons, possibly because of the variation in weather condition and cropping time. The highest urediospores catch (613.8 - 2629.7 urediospores per m^3 of air) was observed during the months of October/November-January. Number of urediospores per m^3 of air was generally low but was rarely reduced to zero during the months of crop free period. Low to moderate levels of stem rust epidemics (not exceeding 30%) were recorded on durum wheat cultivars used for traps. Exceptions were at Sinana in 2001 and at Herero in 2002 and 2005 cropping seasons during which up to 60% stem rust severity levels were recorded. On the other hand, the level of stem rust severity (up to 80%) on some commercial bread wheat varieties included in this study for comparison revealed the development of high disease pressure. Durum wheat cultivars Cocorit 71, Gerardo, DZ 1928-2, DZ-2234 and CD 95759-11M showed resistant reaction to stem rust consistently over locations and years. This points to the existence of a high level of durable resistance in the tetraploid wheat species to the existing stem rust pathotypes in the most suitable environment for the development of the disease.

Keywords: Durum Wheat; Epidemics; Stem Rust; Urediospores

1. Introduction

Cereal rusts are the most destructive diseases of wheat worldwide (Shaw, 1963; Haldore *et al.*, 1982). Stem rust, also known as black rust caused by the fungus *Puccinia graminis f.sp.tritici* Eriks, and E. Henn, is the most significant of all wheat diseases under favorable conditions. Ethiopia is one of the hot spot areas for the development of the existing stem rust complex (Leppik, 1970). Invariable epidemics of wheat stem rust have occurred in the major wheat growing areas of Ethiopia. It became a major threat for Ethiopian wheat production after the epidemics of 1974 and 1992/1993 that eliminated bread wheat varieties known as *Lacketch* and *Enkoy* from production. Stem rust races prevalent in Ethiopia are among the most virulent races in the world (van Ginkil *et al.,* 1989) with wide virulence spectrum and most frequent change in pathogenecity. This is more commonly observed in Arsi and Bale highlands, which are the wheat belt of eastern Africa.

The use of genetically resistant cultivars has been the major strategy to control wheat stem rust in Ethiopia. Several bread wheat (*Triticum aestivum*) and durum wheat (*Triticum durum*) varieties have been released since the commencement of wheat breeding in the country. Many of the high yielding and resistant bread wheat cultivars released at national and regional levels became susceptible to either stem rust or yellow rust or both within a short period after their release for large-scale production (SARC, 2006). These changes in response to disease were associated with inadequate knowledge of the virulence present in the pathogen population and the existence of unsatisfactory durable resistance in major commercial bread wheat cultivars.

Durum wheat, on the other hand, has been regarded as one of the major sources of resistance to cereal rusts in Ethiopia (Bekele, 2003; Naod, 2004; Naod *et al.,* 2007). The country is known to be the center of diversity for the tetraploid wheat species, which present high genetic diversity for disease resistance and other merits (Porceddu and Perrino, 1973; Ephrem *et al.*, 2000). Sewalem *et al* (2000) also reported the existence of stability of stem rust resistance in some durum wheat varieties in the highlands of central Ethiopia. The status of stem rust epidemics on durum wheat in southeastern Ethiopia has not been well reported so far. Currently, durum wheat is widely cultivated in Bale highlands, replacing the introduced semi-dwarf bread wheat cultivars. Such a shift is mainly due to the high risk of rust epidemics on bread wheat and consideration of food complex factories to utilize locally produced durum wheat grains. Stem rust epidemics should, therefore, be monitored regularly to understand the status and shift in the disease situation on durum wheat in the Bale highlands.

Survival of the wheat stem rust fungi through the off-season period is an essential component of the stem rust disease cycle as it is a factor for epidemic persistence and subsequent disease development. Barberry (*Berberris vulgaris L.*) does not occur naturally in the Bale highlands (Sorokina *et al.*, 1980; Zerihun and Abdella, 2000), indicating that teleospores are non-functional. Wheat in this region is grown twice a year, during the main season (August-December) and the second season (March–July). This cereal belt of eastern Africa is also characterized by wheat-based monocropping which presents a green bridge between two succeeding seasons. Epidemic persistence is therefore achieved by successive uredial generations carried from volunteer wheat growing in

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ISSN 1992-0407

transport of
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east African
Determining
the pattern of seasonal dynamics of the pathogen propagules causing epidemic persistence and disease monitoring in relation to the prevailing weather conditions are essential components for predicting disease epidemics. This study was undertaken to investigate the importance of seasonal pattern and the dynamics of wheat stem rust urediospores as well as to monitor its epidemic on durum wheat cultivars in southeastern Ethiopia.

2. Materials and Methods

2.1. Experimental Sites

The experiments were conducted at three major wheat growing and rust prone districts of Bale: Sinana Agricultural Research Center (SARC), Agarfa and Herero during the 2001-2006 cropping seasons. The locations represent the highland wheat growing areas of Bale with bimodal rainfall pattern except at Herero, which is characterized by unimodal rainy season.

The SARC is located at 7° 7' N and 40° 10' E, at 2400 meters above sea level (masl) and 463 km southeast of Addis Ababa in Bale zone. It receives an average annual rainfall of 808 mm. The monthly averages of minimum and maximum temperatures are 9.3 and 20.9 ºC, respectively. The dominant soil type is pellic Vertisols with slightly acidic soil reaction. Agarfa is located at 7° 17' N and 39° 49' E and 2530 masl in a cool, sub-humid agro-climatic zone of Bale. Its average annual rainfall is 833 mm. The dominant soil type is pellic Vertisols. Herero is located at 2365 masl with a unimodal rainfall pattern and average annual rainfall of 781 mm.

2.2. Urediospore Trapping

Monthly total urediospore counts for *Puccinia graminis* were determined using Burkard 7-days volumetric spore trap (Burkard Scientific Instrument Rickmanswork, Hertfordshire) during the cropping seasons from 2001 to 2006. The device was mounted on a stand so that the intake orifice was at a height of 1.9 m from the ground surface. The diameter of the orifice was 2 mm x 14 mm, oriented towards the direction of the wind led by the vane. Air was drawn in through a slot at a rate of 10 liters per minute. The air passed by an adhesive coated tape attached to a drum rotated by a clock. One strip of tape was sufficient for one week of collection. The tape was surface coated with a mixture of 35 g gelvatol (1000 ml distilled water, 50 ml glycerol and phenol). Daily trapped spores were determined on the basis of 48 mm of the exposed tape per day. The daily exposed tape was divided into five sections and mounted on a light microscope slide to inspect the spore with magnification of 400x. The actual area of 15 magnification field was 2.3866 mm^2. Representing the number of spores counted on 2.3866 mm^2 by "K", the total number of daily trapped spores (T) was estimated from the total area, 48 mm x 14 mm = 672 mm^2 of the adhesive tape exposed to spores by the formula $T = (K \times 672\ mm^2)/2.3866\ mm^2$.

Given that 10 liters of air was sucked per minute and 1 m^3 of air represents 1000 liters, the amount of air sucked per day was determined to be 14.4 m^3. With this assumption, the adjusted number of spores (A) per m^3 of air was estimated by the formula; $A = K \times 672\ mm^2)/2.3866\ mm^2 \times 14.4 \times 70$.

2.3. Disease Monitoring Using Trap Plots

Epidemics of stem rust were monitored using disease trap plots established at the three major wheat growing and rust prone districts of Bale. The nurseries consisted of 15 to 21 durum wheat advanced lines and commercial cultivars with different degrees of resistance to stem rust. Thirty-two stem rust differential lines with known Sr genes were also planted at Sinana to monitor effective genes against stem rust pathotypes. About 22 commercial bread wheat varieties were included for comparisons. The genotypes were planted in non-replicated nursery in two rows of 1 m long and 0.4 m wide plots. A seed rate of 150 kg ha^{-1} was used. Fertilizer rate of 41-46 kg N-P_2O_5 ha^{-1} was applied at planting. Weeds were removed manually as needed. Stem rust severity and reaction were recorded using the Modified Cobb scale (Peterson *et al.*, 1949). Terminal levels of rust severity were used to measure stem rust variability among the cultivars.

3. Results

3.1. Urediospore Movement

In each season, traps of urediospores of *P. graminis* at Sinana were more abundant during the months of October-January than during the other months (Figure 1). The exception was in 2002 and 2006 during which urediospores were trapped in large quantities as of November. This peak catch corresponds with crop growth stage when stem rust infection is normally apparent in the field (Table 1). Number of urediospores per m^3 of air was generally low during the off-season months. However, it tended to slightly increase during the months of May to mid-June during 2002, 2004 and 2006 cropping seasons, while this increase was extended towards mid July to August during the 2001 cropping season. In 2005, the load of urediospore concentration was extremely low during the months of March to August. Spore concentration started to increase as of September during this season. Peak concentration of urediospores during this year was also comparatively lower, which is about 613.8 urediospores per m^3 of air trapped in the month of December (Figure 1). A similar pattern of urediospore movement was observed in 2003 with that of 2005, except that a slight increase in urediospore concentration was observed during 2003 in July. Urediospore was trapped all through the year in the 2002 cropping season. Overall, the highest spore movement was obtained in the 2001 cropping season. The peak number of urediospores count during this season was about 2629.7 per m^3 of air. In all years except 2002, concentration of the pathogen entity trapped during the months of March to May was very low, approaching zero. The highest urediospore concentration was trapped in the month of December during 2002 and 2006 and in November and January during 2003 and 2004, respectively (Figure 1).

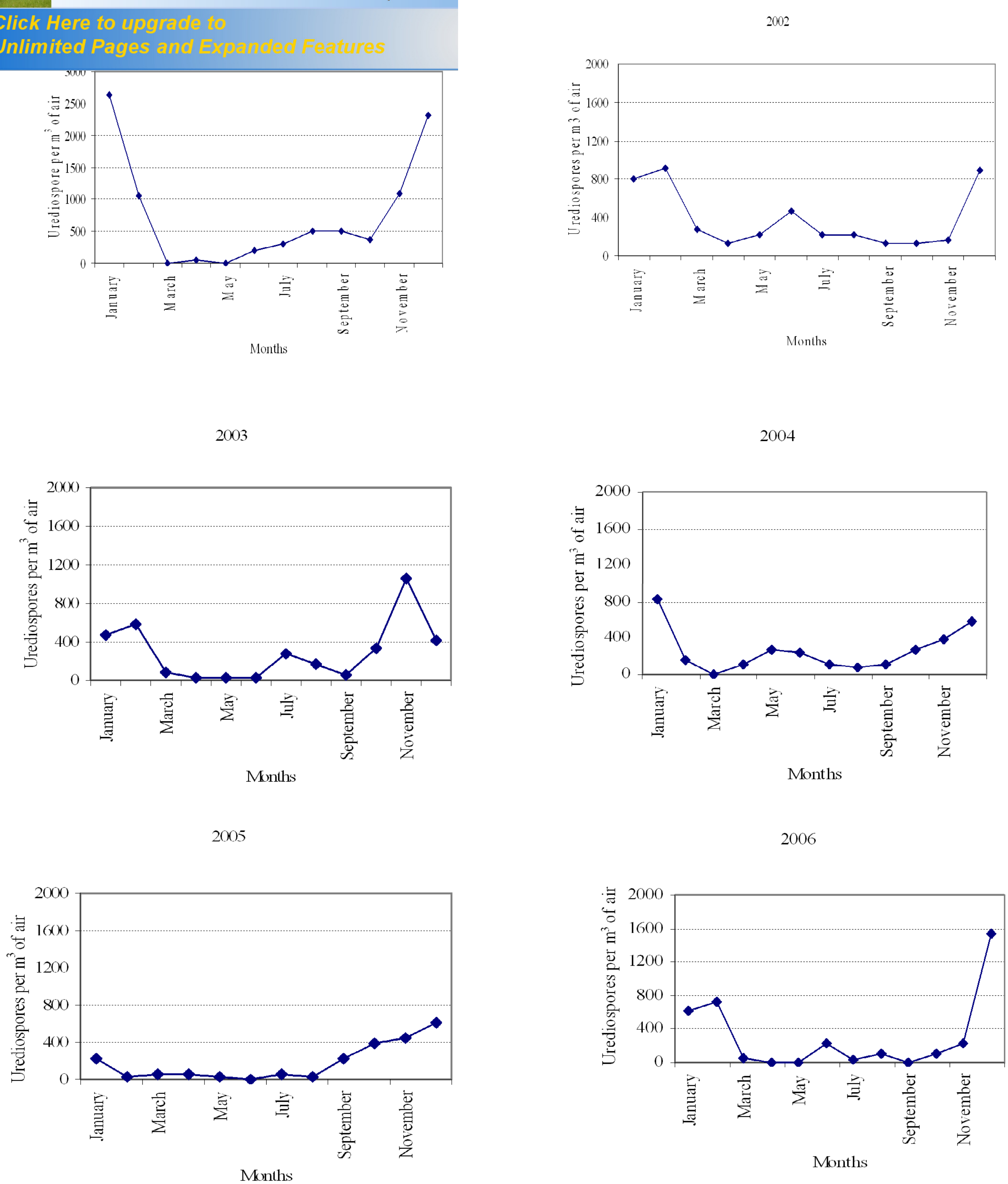

Figure 1. Patterns of seasonal distribution of urediospores of *Puccinia graminis* at Sinana during 2001-2006 cropping season.

In the 2001 cropping season, the first stem rust symptom was apparent in the field on susceptible cultivars in nursery plots during the last week of September while it appeared very late in 2002, during late November (Table 1). In 2003 and 2004, the first stem rust uredinium was observed during the early week of November. It was observed very early in 2005 and 2006, during the first week of October.

tem rust on susceptible wheat cultivars at Sinana during the main cropping

[illegible]	[illegible]	Date of first uredia appearance	Crop growth at first uredia appearance
2001	August 21	September 23	Tillering
2002	August 26	November 27	Booting
2003	August 18	November 3	Early flowering
2004	August 24	November 8	Complete flowering
2005	August 29	October 7	Heading
2006	August 08	October 4	Stem elongation

3.2. Stem Rust Epidemics

During the 2001 crop season, high levels of stem rust epidemic were recorded at Sinana in which several commercial and newly released durum wheat cultivars became susceptible to the disease. More than 60% of the tested cultivars exhibited stem rust severity in the range of 30-60% (Modified Cobb Scale) (Table 2). Four durum commercial wheat cultivars; Cocorit 71, Gerardo, DZ 1928-2 and DZ 2234 had a good level of resistance to stem rust during the 2001 season. Moderate levels of stem rust epidemics were present at Herero during this season (Table 3). Maximum stem rust severity of 25% was recorded on cultivars Kilinto, Bichena and Quamy, while more than 73% of the cultivars showed relatively low resistance reaction (less than 15%) to the existing stem rust pathotypes. At Agarfa, low levels of stem rust severity were recorded during the 2001 crop season (Table 4). Only cultivars Foka, DZ 2085 (Asasa) and Kilinto exhibited relatively high levels of stem rust severity, about 20, 20 and 15%, respectively.

As dry conditions prevailed during the entire season of 2002 at Sinana, a moderate level of stem rust epidemics was observed. Cultivar DZ 04-118 exhibited the highest stem rust severity (40%) while lower disease severity was recorded on the other cultivars (Table 2). At Herero, weather conditions during 2002 appeared to be conducive for stem rust development as evidenced by the high level of stem rust epidemics recorded. About 50% of the test cultivars showed stem rust severity in the range of 25-60% (Table 3). Moderate levels of stem rust epidemics were recorded at Agarfa and Sinana during the 2003 cropping season while a low level of disease epidemic was recorded at Herero during the season. Conversely, low levels of stem rust epiphytotics were observed at Agarfa and Herero and moderate level at Sinana during the 2004 season. Only trace to 5% stem rust severity was observed at Agarfa and Herero. The highest stem rust severity of 30% was recorded on the cultivars DZ 04-118 and DZ 2085 at Sinana during 2004 (Table 2). Reasonable level of disease severity was recorded at Herero during 2005 in which thirteen of the twenty durum wheat cultivars tested exhibited stem rust severity of 20% or higher (Table 3). Stem rust development was low at Agarfa and Sinana during the 2005, while relatively appreciable levels of disease severity were recorded at Sinana and Herero during the 2006 cropping season.

Five durum wheat cultivars, Cocorit 71, Gerardo, DZ 1928-2, DZ-2234 and CD 95759-11M were consistently resistant to stem rust at all locations and over years (Tables 2, 3 and 4). Other cultivars such as DZ 04-118, Boohai, Foka, Kilinto, Bichena, Quamy, Asasa, DZ 1050 and CD 96643-64 were generally susceptible at all locations. Robe and CD-95324 showed differential response over locations perhaps indicating variability in pathogenecity.

3.3. Virulence Status and Effective Genes

Based on their field reaction, virulence for several of the Sr genes (stem rust differential lines) tested was detected at Sinana. However, Sr 6, Sr 18, Sr 22 and Sr 26 + Sr 9g provided relatively better protection to the prevailing stem rust population under field conditions (Table 5). The stem rust resistant gene Sr 31, which has been extensively employed in most wheat germplasms widely cultivated in different parts of the world was found to be ineffective showing severe level stem rust infection.

[illegible] um wheat cultivars at Sinana during the main seasons of 2001-2006.

[illegible]	[illegible]	2002	2003	2004	2005	2006
[illegible]	[illegible]	40s	40s	30s	20s	20ms
Cocorit 71	5ms	Trs	20ms	5ms	Tms	0
Gerardo	5s	Trs	10s	tms	Tms	0
LD 357	25mr	5s	25s	5s	Tms	15s
Boohai	40s	20s	15s	tms	10s	30s
Foka	30s	20s	20s	15s	10s	25s
Kilinto	40s	10s	25s	5s	20s	30s
Bichena	40s	15s	10ms	15s	Tmr	25s
Quamy	40s	10s	25s	15ms	20ms	30s
TOB 66	25ms	Trs	20s	5ms	15ms	20s
DZ 2085 (Asasa)	60s	25s	40s	30s	10ms	trs
DZ 1928-2	tms	Trs	25s	15s	10ms	-
DZ 1640 (Robe)	40s	10s	15ms	5s	5ms	10ms
DZ 1050 (Ginchi)	40s	20s	20s	10s	15ms	10s
DZ 1052	40s	10s	15ms	10s	NT	NT
DZ-2234	0	5s	tmr	0	NT	NT
CD-95324	40ms	5s	10ms	5s	NT	NT
CD-95759-11M	15mr	Trs	5ms	0	NT	NT
CD-95924-IV	20ms	5s	5s	5s	NT	NT
CD-96643-6Y	30ms	5s	25s	15s	NT	NT
Ude	NT[a]	NT	15ms	trs	0	10s
Yerer	NT	NT	10s	0	0	20s
DZ-1838-3dzr-/dz05	NT	NT	5ms	5s	tms	0

[a] *Terminal stem rust severity was assessed using the Modified Cobb's scale (Peterson et al., 1949)*

Table 3. Levels of stem rust severity[a] on different durum wheat cultivars at Herero in the main seasons of 2001-2006.

Durum wheat cultivars	2001	2002	2003	2004	2005	2006
DZ 04 - 118	10ms	25s	10s	0	50s	40s
Cocorit 71	5ms	10ms	10s	0	25s	25s
Gerardo	0	5s	5s	0	15ms	5s
LD 357	0	15ms	10s	0	30s	20s
Boohai	10s	40s	trs	0	20ms	10s
Foka	15s	40s	10s	0	25ms	30s
Kilinto	25s	30s	5s	0	20s	30s
Bichena	25s	30s	trs	0	tmr	20s
Quamy	25s	30s	trs	0	15ms	15s
TOB 66	5ms	20s	trs	0	tmr	10s
DZ 2085 (Asasa)	5ms	25s	5s	trs	30ms	15s
DZ 1928-2	0	5s	5s	0	15ms	-
DZ 1640 (Robe)	15s	60s	10s	0	30ms	10s
DZ 1050 (Ginchi)	10s	60s	trs	-	30ms	10s
DZ 1052	20s	60s	5s	0	30ms	NT
DZ-2234	NT	0	15s	0	10ms	NT
CD-95324	NT	10ms	5s	0	20ms	NT
CD-95759-11M	NT	15ms	trs	0	15ms	NT
CD-95924-IV	NT	40mr	5s	0	60s	NT
CD-96643-6Y	NT	40mr	20s	0	30s	NT

[a] *Terminal stem rust severity was assessed using the Modified Cobb's scale (Peterson et al., 1949)*

…erent durum wheat cultivars at Agarfa in the main cropping seasons of 2001-

	…1	2003	2004	2005	2006
Cocorit 71	trs	5ms	trs	tms	-
Gerardo	0	tms	0	0	0
LD 357	10ms	30ms	0	5ms	0
Boohai	0	15ms	5s	0	5mr
Foka	20s	20s	0	10s	10ms
Kilinto	15s	10ms	0	0	10s
Bichena	0	5s	0	0	10s
Quamy	5ms	10ms	0	tms	5s
TOB 66	0	5ms	0	0	5s
DZ 2085 (Asasa)	20ms	60s	0	15ms	0
DZ 1928-2	10ms	15ms	0	5ms	0
DZ 1640 (Robe)	0	5ms	0	5ms	trs
DZ 1050 (Ginchi)	0	5ms	0	5ms	0
DZ 1052	10ms	5ms	0	tms	NT
DZ-2234	NT	tms	0	-	NT
CD-95324	NT	5ms	-	tms	NT
CD-95759-11M	NT	tms	trs	tms	NT
CD-95924-IV	NT	5ms	0	tms	NT
CD-96643-6Y	NT	5ms	0	-	NT

[a] *Terminal stem rust severity was assessed using the Modified Cobb's scale (Peterson et al., 1949)*

4. Discussion

The study indicated that stem rust urediospores exist in the air almost throughout the entire year, although the concentration varied depending on the time of cropping season and weather conditions. During the months of crop free period, the number of urediospores per m^3 of air was generally low but was rarely reduced to zero. This is in agreement with previous findings by Saari and Prescott (1985) and Mamuluk (2000) who have reported the existence of local inoculum and endemic disease cycle all year round in the major epidemiological zones of the Africa south of the Sahara and southwestern Arabian Peninsula which includes Ethiopia, Kenya, Yemen, Tanzania and many other African countries. It has also been reported that the Ethiopian highlands are particularly unique from other countries in the zone as these are centers of diversity for rust fungal populations providing much of the inoculum for cereals grown in other countries (Saari and Prescott, 1985).

Appreciable quantities of urediospores were evident much earlier before the first stem rust uredia apparently observed during the season. This substantiates the probability that the majority of spores caught originated locally. Urediospores from volunteer or self-sown plants may, therefore, remain the principal source of primary inoculum for annual infection of wheat by stem rust in southeastern areas of Ethiopia. The bimodal rainfall pattern and wheat-based monocropping practice in the Bale highlands provides a green bridge between two seasons and allows availability of volunteer wheat plants. This makes the pathogen generate successful successive uredial stage and also enables it to effectively over season within the main wheat growing areas of southeastern Ethiopia (Roelfs, 1985; Bekele, 2003). Such foci provide initial inoculum which can dependably provoke stem rust epidemics each year in Bale. Roelfs (1985) and Saari and Prescott (1985) also reported that the stem rust fungus mainly persists on volunteer cereal plants or on successive crops as they are planted at different times of the year depending mainly on altitude and rainfall pattern in the area and the role of berberies and grasses as reservoirs of inoculum for the main crop, where wheat is not important.

Urediospore concentration tended to increase slightly during the second (*ganna*) season, which indicates that this season can provide a viable source of primary inoculum for infection during the main (*bona)* season, although the second season is not generally conducive for the development of cereal rust epidemics in Bale (Bekele, 2003). Hence, it can be concluded that the occurrence and distribution of stem rust epidemics in the Bale highlands are largely determined by suitable weather conditions and availability of susceptible hosts.

The importance of long distance transported spores also cannot be ruled out as similarities exist in race patterns between Ethiopia and some other African countries such as Kenya, Uganda and Tanzania which represent the common sub-epidemiological zone for cereal rusts in East Africa (Saari and Prescott, 1985). Mamuluk *et al.* (2000) reported the existence of optimum conditions for crop growth and spore movement among some African countries such as Ethiopia, Sudan, Kenya and Tanzania. In Ethiopia, Johnson *et al.* (1967) reported that there is no evidence for the transport of spores from outside the country. Guthrie (1966) also reported evidence that the rapid turnover of wheat stem rust races in Kenya is related to the dispersal of spores from Ethiopia due to the northeast monsoon wind, which

...ng stem rust ...iopia to those ...ent region of ... pool of rust genes for virulence which could be regarded as the major sources of inoculum of wheat stem rust pathogen in eastern Africa. Long-distance transported urediospores have actually little effect on the subsequent development of the epidemic (Peterson, 2001). Rees (1971) also reported that stem rust epidemics developed from spores transported over longer distances is of minor importance while small sources of inoculum from close proximity to the young crop are normally of greater importance in the development of a particular epidemic. Primary infection from long-distance transported urediospores occurs much later than when primary infections occur from urediospores locally produced from over-wintered mycelium and subsequent development of uredinia and will have the advantage of several more generations of spore-to-spore development before the host plants mature (Eversmeyer and Kramer, 2000). However, long-distance transported spore appears to be of particular importance in the distribution of genetic novelty in the rust organisms over vast areas (Rees, 1971).

Table 5. Performance of stem rust resistance (Sr) genes at Sinana during the main cropping seasons of 2001-2004.

		Stem rust severity			
Differential line	Sr gene	2001	2002	2003	2004
ISR5-Ra	Sr 5a	40s	-	-	-
PDSr6KY58	Sr 6	25s	20s	-	0
MEDINOS/W2691/?/W3498	Sr 7a + 10	40s	60s	60s	30s
ISR7B-Ra	Sr 7b	60s	40s	60s	40s
BARNETA BENBENUTO	Sr 8b	20s	20s	40s	60s
W2691Sr9D	Sr 9d	60s	60s	60s	-
VERNESTEIN	Sr 9e	40s	40s	60s	40s
Sr9g(J2N)N.N.SEL	Sr 9g	40s	60s	60s	60s
W2691Sr10	Sr 10	60s	60s	60s	60s
ISr11-Ra	Sr 11	40s	60s	60s	60s
BtSr12TC	Sr 12	40s	30s	40s	60s
W2691Sr13	Sr 13	30s	25s	40s	50s
LINE A SELECTION	Sr 14	40s	40s	60s	40s
W2691SR15NK	Sr 15	60s	40s	60s	40s
CONBINATION VII	Sr 17+Sr 13	80s	25s	25s	60s
LCSr 18RL	Sr 18	5ms	0	20s	25s
LCSR 19MG	Sr 19	60s	40s	60s	15s
T.MONOCOCUM DERIV	Sr 21	30s	25s	30s	40s
SWSR 22Tb	Sr 22	10ms	30s	20s	-
LCSr25 Ars	Sr 25	80s	20s	40s	20s
EAGLE	Sr 26+Sr 9g	25ms	trs	10s	20s
WRT238-5	Sr 27	60s	40s	60s	25s
W2691Sr28KT	Sr 28	80s	60s	60s	60s
PUSA *4/ETOIL DE CHOISY	Sr 29	60s	40s	40s	40s
BtSr30Wst	Sr 30	40s	25s	60s	40s
LINE E/KBZ	Sr 31	60s	20s	60s	30s
ER5155	Sr 32	5s	25S	60s	30s
TETRACANTHATCH/AE-SQ[AL5045]	Sr 33 + Sr 5	30s	40s	60s	40s
W2691SrTt-1	Sr 36	60s	30s	80s	60s
W2691SrTt-2	Sr 37	15s	50s	60s	60s
FED*2/SrTt-3	SrTt3+ Sr 10	40s	30s	40s	30s

Large quantities of urediospores of the pathogen were generally trapped during the months of October/ November – January. This period normally corresponds with the main cropping season and crop growth when stem rust infection is normally apparent in the field. In Bale, main season planting takes place from mid to late August and crop growth may extend to December. Infection of new wheat crops by stem rust commonly tober or may the prevailing can occur till ty (until late December), which can result in generations of large quantities of inoculum during the growing season. Low concentrations of urediospores per m^3 were trapped during the crop free months. The exception was during the months of May to mid June during which concentration tended to rise as planting of wheat also occurs during the second season (March to July). This season is not actually conducive for rust development, but low levels of infection may occur which contributes to the increase in urediospores concentration during this period.

Variable levels of stem rust epidemics were recorded on durum wheat varieties planted at each location depending on the weather condition, inoculum and the genetic background of the cultivar. In general, only low to moderate levels of stem rust epidemics were recorded on the durum wheat cultivars included in the trap. The only exceptions were at Sinana in 2001 and at Herero in the 2002 cropping seasons during which relatively severe epidemics of stem rust were observed. Some of the cultivars showed dependable resistance to the existing pathogen population, even during the seasons of heavy epidemic. The Arsi-Bale highlands have actually been described as a hot spot for the *Triticum-Puccinia* system (Mulugeta, 1986). Heavy epidemics of stem rust have been recorded in this region each year, particularly on bread wheat (Bekele *et al.,* 2002; Bekele, 2003).

The levels of stem rust severity on susceptible bread wheat varieties (Table 6) and stem rust resistance genes described in this study and the concentrations of urediospores trapped are cases in point for the occurrence of severe stem rust epidemics in Bale. The commercial bread wheat cultivars most widely cultivated in Ethiopia such as HAR604, HAR1685, HAR727, HAR1407, included for comparisons (Table 6), exhibited severe levels of stem rust (up to 80%) and thus confirmed the occurrence of high disease pressure in the area. The high levels of stem rust severity recorded on most of the differential lines, on the other hand, indicated that most of the known Sr genes are not effective in the area which could be due to the most frequent changes in virulence of the stem rust population in the Bale highlands. Only a few Sr genes (Sr 6, Sr 18, Sr 22 and Sr 26+Sr 9g) provided relatively better protection to the prevailing stem rust population. Van Ginkil *et al.* (1989) reported that stem rust races prevalent in Ethiopia are among the most virulent races in the world with wide virulence spectrum and frequent changes in pathogencity. Sr 31 gene, that has been extensively deployed in most wheat germplasms widely cultivated in different parts of the world, was found to be ineffective, bearing witness to the speculation that race Ug99 is widely distributed in eastern Africa (CIMMYT, 2005).

Table 6. Levels of stem rust severity[a] on some commercial bread wheat cultivars at Agarfa during the main seasons of 2000-2004.

Cultivars	Year of release	2000	2001	2002	2003	2004
HAR1685	1995	40s	80s	80s	80s	60s
HAR710	1994	15ms	30s	40s	80s	30s
HAR1709	1994	trs	15ms	10s	30s	30s
HAR604	1995	5ms	25s	40s	60s	40s
HAR1407	1997	5ms	40s	30s	80s	70s
HAR1595	1997	10ms	80s	40s	80s	60s
HAR1522	1997	0	60s	40s	60s	50s
HAR416	1987	0	5s	50s	40s	10s
HAR719	-	trms	60s	30s	60s	60s
HAR727	-	trms	40s	40s	60s	80s
HAR720	-	5ms	30s	40s	60s	20s
HAR627	-	5ms	30s	50s	60s	30s
HAR729	-	0	0	0	trs	0
HAR1899	1999	20s	60s	30s	80s	40s
Batu	1984	tmr	25s	10s	30s	-
Gara	1984	5ms	25s	40s	80s	-
Dereselign	1974	trms	10s	10s	30s	5s
Enkoy	-	0	0	5s	10s	0
Pavon-76	1982	10s	40s	30s	80s	60s
Lakech	1970	25s	60s	25s	60s	30s
Dashen	1984	5ms	20ms	20s	40s	15s
ET-13	1981	trms	60s	30s	80s	60s

[a] *Terminal stem rust severity was assessed using the Modified Cobb's scale (Peterson et al., 1949)*

Environmental conditions in Bale are in the range of conducive weather requirements for stem rust development (Table 7 and Figures 3). From the 17 years weather data, it is evident that the average maximum (21.7

ring the main erage of 19.5 *al.*, 1992). In ise from early November to December (Table 7), which creates a conducive environment for sporulation of the pathogen. Average relative humidity also tended to rise during the months of mid October to early November (Figure 2) while the peak rainfall occurs in September followed by October (Figure 3), generally indicating suitability for infection of stem rust pathogen during these periods. In 2002 at Sinana, low to moderate levels of stem rust severity and also low concentration of urediospores per m^3 of air were recorded.

The performance of durum wheat cultivars under such epidemic occurrence of the disease provides evidence for the existence of satisfactory durable resistance within the tetraploid wheat species. Ethiopia is known to be the center of diversity of tetraploid wheat species, which presents high genetic diversity for disease resistance and other merits (Ephrem *et al.*, 2000; Naod *et al.,* 2007). Sewalem *et al.* (2000) also reported the existence of stability of stem rust resistance in some durum wheat cultivars in Ethiopia. Such potentials need to be considered in the development of cultivars with broad genetic basis.

In conclusion, the present study showed that the occurrence and distribution of wheat stem rust are largely determined by suitable weather conditions and availability of susceptible hosts as inoculum of local origin in sufficient quantity exists all year round. Weather conditions in the Bale highlands are mostly within the range of optimum requirements for the epidemic occurrence of the disease when susceptible cultivars are used. On the other hand, wheat stem rust management strategy in Ethiopia should focus on the development of resistant cultivars with a wide genetic base. Breeders should consider the sources of resistance existing within the tetraploid wheat species, particularly durum wheat, and incorporation of effective genes in the development of resistant cultivars with a wider genetic basis.

Table 7. Monthly average (1990-2006) minimum and maximum temperatures (August to December) at the Sinana Agricultural Research Center.

	Monthly temperature (^{0}C)	
Month	Minimum	Maximum
August	9.7	20.8
September	9.9	20.1
October	8.7	19.4
November	8.2	20.1
December	8.3	21.7
Mean	9.0	20.4

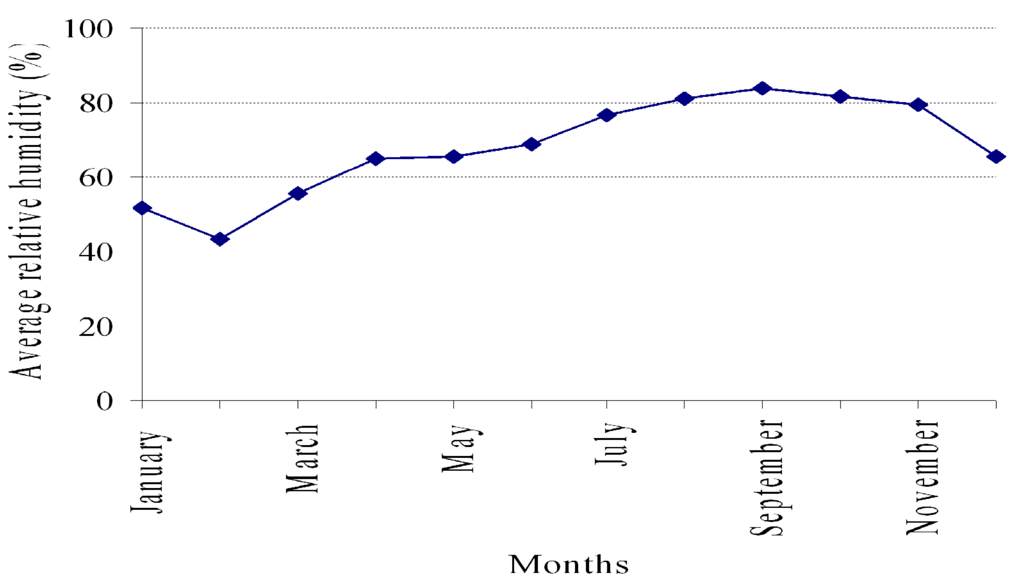

Figure 2. Average (2001-2005) relative humidity (%) at the Sinana Agricultural Research Center.

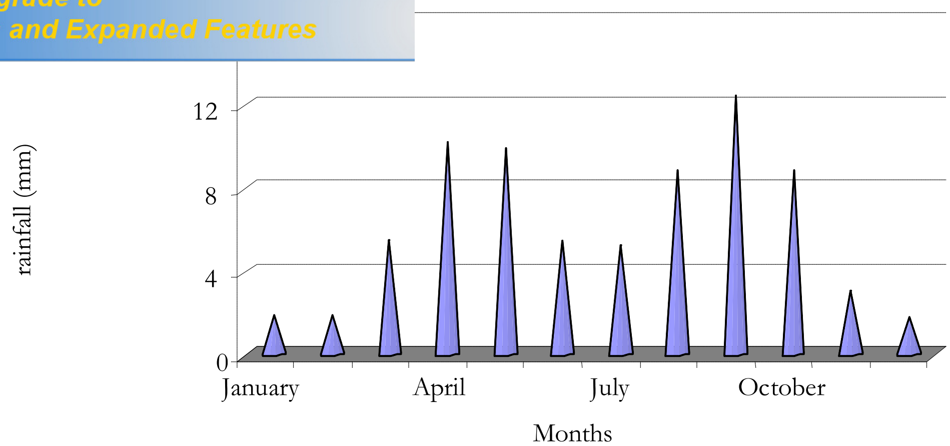

Figure 3. Monthly average (1990-2006) rainfall (mm) at the Sinana Agricultural Research Center.

5. Acknowledgment

The Burkard 7-days volumetric spore trap machine was purchased by aid from The International Center of Agricultural Research in the Dry Areas (ICARDA). We gratefully acknowledge the Oromia Agricultural Research Institute (OARI) for funding the research.

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…nd Volatile Oil Contents of Five Pepper (Pepper nigrum L.) Cultivars as Influenced by Maturity

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Abstract: The experiment was undertaken to identify the appropriate stage of harvesting of berries to prepare quality pepper for whole use or for extraction purpose to get better oleoresin and essential oil yield. Harvesting of berries from five pepper cultivars was carried out at 3.5, 4.5, 5.5, and 6.5 months after 70% set of the berries. The experiment was arranged in a randomized complete block design with three replications at Teppi Agricultural Research Sub-center, South-western Ethiopia. Generally, peppercorn boldness and color improved with delayed harvest; 5.5 months after fruit set being the optimum. Five of the cultivars showed comparable oleoresin and volatile oil contents. The oleoresin content ranged from 13.63 to 16.01% whereas the volatile oil content ranged from 3.18 to 3.53%. Both were found to be within the acceptable ranges. The highest oleoresin (19.41%) and volatile oil (4.95%) yields were obtained from earlier harvest (3.5 months after fruit set) and decreased as harvest stages delayed. In general, it is recommended that the spikes be harvested 3.5 months after 70% fruit set to get higher oleoresin or volatile oil yield and 5.5 months after fruit set if it is intended for use as whole or in ground form.

Keywords: Black Pepper; Essential Oil; Oleoresin; Peppercorn; Volatile Oil

1. Introduction

Pepper (*Pepper nigrum* L.) in the botanical family Piperaceae is among the oldest and the most widely used spices throughout the world. Nybe and Peter (2003) pronounced that black pepper enjoys a distinction of 'King of Spices' for its varied uses and dominance in the global spice trade and is also known as "black gold" , valued for its multiple uses. It alone accounts for about 35% of the world's total spice trade (Majeed and Prakash, 2000). Major products of pepper are whole dried immature fruit (black pepper) and washed dried ripe fruit (white pepper) (Purseglove *et al*., 1981; I-San Lin, 1994).

Black pepper is the spiciest of all spices and is the most important and authoritative of all spices. It has extensive culinary uses, and is used in meats, soups, fish, pickles and sauces, while white pepper is used primarily in cases where dark particles are undesirable, such as in light-colored sauces, mayonnaise and cream soups. The essential oils and oleoresins obtained from black pepper are mainly used for flavoring purposes; in perfumery and in pharmaceutical products (Purseglove *et al*., 1981; Borget, 1993; I-San Lin, 1994). The quality of pepper products (black, white or green pepper) is influenced by intrinsic characteristics of the variety, the stage of maturity of berries at harvest, processing methods and conditions, and duration of storage (Pruthi *et al*., 1976). The authors stressed that cultivar and the maturity stage of berries at harvest have a great impact on the quality of pepper, and the former can be improved by continuous selection and propagation of suitable strains. Risch (1997) also pointed out that a number of factors, including climatic conditions, can influence the abundance of the active components in spices.

The main components of product quality are type, size, shape, color, texture, composition, maturity, freedom from damage, disease, pest, and/or disorders (Jackson *et al*., 1985). Black pepper quality is evaluated on the basis of its appearance, pungency level, aroma and flavor and the relative importance of these quality characteristics is dependent upon the intended end-use of the spice. When it is intended for direct use as a spice in whole or ground form, the appearance is of primary importance to the buyers. In general, bold-sized dried peppercorn with a uniform dark-brown to black color fetches the best prices. In contrast, the appearance of the spice has lesser importance when it is intended for processing into black pepper oleoresin or essential oil. According to Purseglove *et al*. (1981), the quality of white pepper is evaluated based on its appearance (color and size) and flavor properties (pungency and aroma).

Black pepper is used to produce oleoresin and essential oils (volatile oils) which are utilized in many ways. Oleoresin is the total pungency and flavor constituent of pepper marketed as spice drops which are in great demand in all countries (Nybe and Peter, 2003). It is produced by solvent extraction of pepper powder using a suitable organic solvent such as acetone, ethanol, ethyl acetate or ethylene dichloride, whereas black pepper oil is extracted by using steam distillation (Purseglove *et al*., 1981; Nybe and Peter, 2003).

Diverse agro-ecology in Ethiopia allows the production of pepper particularly in the hot humid lowlands. Dry black pepper yield ranging from 1970 to 2850 kg ha^{-1} was recorded for different cultivars at Teppi Agricultural Research Sub-center. Although the crop is becoming important in the Ethiopian spice industry, the appropriate harvesting stage (time) of berries to produce quality pepper has not been identified. Hence, the current experiment was initiated with the objective of identifying the optimum harvesting stage of berries to produce quality black pepper that can be used as whole or in ground form or for extraction purposes to acquire high oleoresin and volatile oil yields.

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ISSN 1992-0407

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d 35° E at an altitude of 1200 m above sea level in the hot humid lowland area of south western Ethiopia. The site receives mean annual rainfall of 1750 mm and the mean minimum and maximum temperatures are 15.6 and 29.9 °C, respectively. The soil of the experimental area is generally fertile forest soil, very suitable for coffee and perennial spices production. It is grouped as Dystric Nitosol which is fertile, clay loam in texture with clay content of 30%, silt 42%, sand 28% and a pH (KCl) value of 6.8. It has an organic carbon content of 5.99%, total N of 0.98% and available P of 25.99 ppm. Furthermore, the exchangeable K content was 1.4, Ca 35.4, Mg 6.4 and cation exchange capacity was 46.8 all expressed in meq/100 gram of soil. The carbon to nitrogen ratio of the soil was 10 and percentage base saturation was 93%.

2.2. Experimental Material and Treatments

The experiment was conducted on the already established plantation of five pepper cultivars (Bra. 32/79, SR. 3/80, Pan. 4/80, Kuch. 5/80 and T_4. 228 17/79) which were arranged in randomized complete block design and replicated three times. Harvesting was done at 3.5, 4.5, 5.5, and 6.5 months after 70% fruit setting occurred. At each harvesting stage, spikes with uniform size (similar maturity stage) were picked. Berries were detached from spikes and sun-dried on stretched clothes by continuously turning over by hand until the recommended or safe moisture level (11%) was attained. At night, the samples were kept in a room to protect them from night moisture or rain.

2.3. Physical and Chemical Evaluation

After drying, 1 kg of dried berries was taken for each treatment for physical quality study, and oleoresin and volatile oil extraction. Physical parameters such as peppercorn boldness or shriveledness and color were assessed by visual observation. Samples were sent to KASSK Spices and Herbs Extraction Factory (Addis Ababa) for chemical analysis. Oleoresin yield was determined by using cleavage type apparatus and volatile oil yield was quantified by using acetone in a soxhlet apparatus.

2.4. Statistical Analysis

Data were subjected to analysis of variance (ANOVA) by the General Linear Model procedure using SAS (Statistical Analysis System, 2001). Mean comparison was performed using the least significant difference at 1% level of significance.

3. Results and Discussion

3.1. Physical Parameters

Physical observation of the samples after final drying indicated that there was great variability among samples harvested at different stages of maturity with respect to peppercorn boldness (shriveledness) and color (Table 1). Regardless of the cultivar, dried peppercorns from the first harvest (3.5 months after 70% fruit set) were too shriveled, while those from the final harvest were bold. Fruit collected 3.5 and 4.5 months after 70% fruit set developed a dull black color and delaying harvesting up to 5.5 and 6.5 months resulted in dark and dark brown colored peppercorn, respectively. From the physical observation, it was noted that harvesting 5.5 months after 70% fruit set resulted in less shriveled black colored peppercorns which are much preferred by the consumers (either ground or whole). Delaying harvesting up to 6.5 months encouraged the development of bold and dark brown peppercorn because they are extracted from spikes consisting of a high amount of red ripe berries. In most cases, however, consumers prefer black peppercorn to dark brown ones. Hence, the berries should be harvested 5.5 months after fruit set to produce less shriveled black pepper. To produce quality black pepper, the spikes should be picked as soon as one of the berries on it begins to turn red (Carlos and Balakrishnan, 1991). They also noted that picking unripe berries while green is not advisable for preparing black pepper. Purseglove *et al.* (1981) also reported that, if the spikes of pepper are left un-harvested longer (more than 6 months), the physical parameters of the peppercorn increase while extraction quality tends to decrease.

Table 1. Peppercorn boldness and color of pepper as influenced by harvest stages.

Harvesting stage (month)	Peppercorn boldness	Peppercorn color
3.5	Too shriveled	Dull black
4.5	Shriveled	Dull black
5.5	Less shriveled	Black
6.5	Bold	Dark brown

3.2. Chemical Parameters

There were no significant differences among cultivars with respect to oleoresin and volatile oil yields (Table 2). Oleoresin yield ranged from 13.63% (T_4. 228.17/79) to 16.01% (SR.3/80) while volatile oil yield varied from 3.18% (Kuch. 5/80) to 3.53% (Bra. 32/79). Richard *et al.* (1971) reported that the chemical composition of black pepper varieties varies widely. There was variation in cultivars in quality factors tested at different years-probably due to the variation in agro-climatic conditions (Menon *et al.*, 2002). From the current investigation, it has been observed that the tested cultivars can fulfill the required standard volatile oil if harvested at the right stages. According to Nurdjannah (2003), the steam volatile oil content of some cultivars of the spices could be as high as 3.8%, but for commercial scale, a reasonable quality crushed black pepper can provide yield ranging from 1 to 2.6% through steam distillation. Similarly, the oleoresin yield of the cultivars was in the recommended market standard range. Oleoresin yields of 10-13% have been reported for Indian Malabar pepper; the highest being obtained with Malabar light pepper (Nambudri *et al.*, 1970).

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	(%)	latile oil yield (%)
Bra. 32/79	15.65a	3.53a
SR. 3/80	16.01a	3.52a
Pan. 4/80	13.76a	3.35a
Kuch. 5/80	13.75a	3.18a
T_4. 228.17/79	13.63a	3.50a
SEM	0.730	0.140

Means within columns sharing the same letters are not significantly different (P < 0.01); SEM = Standard error of the mean.

Both oleoresin and volatile oil yields were significantly influenced by harvesting stage (Table 3). Regardless of the cultivars, the highest yields of oleoresin (19.41%) and volatile oil (4.95%) were obtained from peppercorns harvested 3.5 months after fruit set. Harvesting stage was negatively correlated with oleoresin (r=-0.98**) and volatile oil (r=-0.99**) yield indicating that there was a progressive decline both in oleoresin and volatile oil yields in response to delaying harvesting. The volatile oil of immature green pepper reaches a maximum at early stage (4.5 months after fruit setting) for some varieties in India, and diminishes while the piperine content continues to increase for some period (GCSSI, 2003). Similarly, Purseglove *et al.* (1981) reported that pepper quality is significantly influenced by harvesting stage and the highest and lowest volatile oil yields of 10.4 and 3.6% (v/w) were recorded from peppercorn harvested 4.5 and 7.0 months after fruit set, respectively. Jansz *et al.* (2006) also reported most oil synthesis in black pepper appeared to have taken place by 23 weeks. It has been generalized that, for most of the spices, earlier harvesting is recommended to attain a good volume of extraction yield with the exception that high volume of volatile oil yield per hectare bases will be obtained from late harvesting of ginger (Purseglove *et al.*, 1981; KAU, 2002).

Table 3. Oleoresin and volatile oil yields of pepper as influenced by harvest stage.

Harvesting stage (month)	Oleoresin yield (%)	Volatile oil yield (%)
3.5	19.41a	4.95a
4.5	16.72b	3.66b
5.5	11.74c	2.89c
6.5	10.37c	2.15d
SEM (±)	0.650	0.130

Means within columns sharing the same letters are not significantly different (P < 0.01); SEM = Standard error of the mean.

4. Conclusions

The five cultivars exhibited comparable oleoresin as well as volatile oil contents. However, the harvesting stage of the spikes influenced to a grate extent the quality parameters of pepper, such as peppercorn, boldness and color and oleoresin and volatile oil yield. Early harvest (3.5 months after fruit set) gave the highest oleoresin and volatile oil yields while harvesting 5.5 months after fruit set resulted in less shriveled black peppercorns which are much preferred for whole or crushed home-use. Hence, the purpose of pepper production must be clearly known and the harvesting period should be adjusted accordingly.

5. Acknowledgements

The authors would like to acknowledge Dr. Wondyfraw Tefera, Mr. Amsalu Nebiyu, Mr. Woyesa Garedew, Mr. Hayleab Atsbeha, Mr. Mohamod Worku and Mr. Kebede Abera for their unreserved efforts with regard to the successful completion of the experiment.

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09) Volume 3 (2) 193-194

ghum (Sorghum bicolor (L.) Moench) Varieties

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Abstract: *Dano* and *Lalo* are common names for sorghum (*Sorghum bicolor* (L.) Moench) with pedigree names of BRC-378 and BRC-245, respectively. They were developed and released by Bako Agricultural Research Center for western Ethiopia. At early breeding stage, *Dano* and *Lalo* were tested for three years at three locations and the mean grain yield of *Dano* was comparable with all location means of every season. In multi-location trials, *Lalo* was the best with 3.5 ton/ha grain yield. The mean yields of *Dano* and *Abamelko* were 2.7 and 3.2 tons/ha, respectively. Results of stability studies showed that *Dano* had above average and *Lalo* had good general adaptability. *Dano* and *Lalo* have maturity that is synchronized with that of the locals compared to that of standard check, which is earlier than the locals. *Dano* has good popping character, attractive seed color, stays green naturally and has potential for animal feed. *Dano* and *Lalo* have moderate resistance to anthracnose and leaf blight with uniform agronomic traits.

1. Agronomic and Morphological Characteristics

Dano and *Lalo* were selected for their uniform and good agronomic performance out of 195 brown seeded sorghum landraces collected from different districts. They are single stemmed varieties with a strong stalk, which make them better than *Abamelko* in lodging resistance. The maturity of *Dano* and *Lalo* is synchronized with that of the locals compared to that of the standard check, which is earlier than the locals. *Dano* and *Lalo* have low shattering characters and the stalks are dry. The summary of agronomic and morphological characters of *Dano* and *Lalo* is given in Table 1.

2. Yield Performance

Starting at early breeding stage, *Dano* and *Lalo* were tested for three years (2001-2003) at Bako, Gute and Boshe for their grain yield performance. Mean grain yield of *Dano* was comparable with all location means of every season and *Lalo* was the best in its grain yield performance. In multi-location trials for two years (2004 and 2005) across three locations (Bako, Boshe and Gute), *Lalo* was most productive with 3.5 tons/ha. The mean yields of *Dano* and the standard check, *Abamelko*, were 2.7 and 3.2 tons/ha, respectively. In on-farm trials, mean yields of 3.6 and 2.8 tons/ha were recorded for *Lalo* and *Abamelko*, respectively. In on-farm trials during 2006, mean yields of 3.5 tons/ha for *Lalo*, 3.3 tons/ha for *Dano* and 2.8 tons/ha for *Abamelko* were recorded. The results showed that *Lalo* was the most productive.

3. Stability Performance

Yield stability in ten sorghum varieties was studied for two years across three locations. In this study, *Dano* had less than unity regression coefficient, indicating it that has above average stability. *Lalo* had unity regression coefficient associated with high mean grain yield performance implying that it has good general adaptability.

4. Disease and Pest Reaction

Dano and *Lalo* are moderately resistant to the most important foliar diseases in the area, namely anthracnose and leaf blight (Table 2). *Abamelko* is earlier than the local varieties, at Bako it is exposed to bird damage. *Dano* has sweet seed test and needs planting in sorghum dominating areas otherwise it needs bird scaring.

5. Special Merits

Dano has good popping character, attractive seed color, stays green naturally and has potential as animal feed. In addition, it has high local demand.

6. Conclusions

Dano has reasonable grain yield, good agronomic traits, multipurpose uses, and high local demand. It has above average stability and it can be grown in an unfavorable environment. *Lalo* has high grain yield, good agronomic traits with wider adaptability. *Dano* and *Lalo* are moderately resistant to anthracnose and leaf blight. They have good synchronization in maturity with the locals. They are named after *Dano* and *Lalo* Districts known for their sorghum land race diversity and from where these varieties were collected.

7. Reference

Eberhart, S.A. and Russell, W.A. 1966. Stability parameters for comparing varieties. *Crop Science* 6: 36-40.

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ISSN 1992-0407

acteristics of *Dano* and *Lalo* sorghum varieties.

	(*Dano*)	BRC-245 (*Lalo*)
Altitude (masl)	1500 - 1900	1500 - 1900
Rainfall (mm)	1100 - 1200	1100 – 1200
Fertilizer rate:		
DAP (kg/ha)	100	100
UREA (kg/ha)	100	100
Planting date	Late April to early May	Late April to early May
Seed rate (kg/ha)	10 (row planting)	10 (row planting)
Days to heading	132	129
Days to maturity	198	199
Panicle length (cm)	32	26
Plant height (cm)	350	300
Inflorescence compactness	Loose	Loose
Shattering character	Very low	Very low
Stalk juiciness	Dry	Dry
Leaf color after maturity	Stay green	Yellowish
Stalk color at maturity	-	Brown
100 kernels' weight (g)	2.4	2.9
Seed color	Light orange	Red
Popping type	Yes	No
Crop pest reaction	Resistant to major diseases and pests	Resistant to major diseases and pests
Yield (ton/ha):		
Research field	4.0-5.0	4.0-5.2
Farmer field	3.0-4.8	3.5-4.8
Year of release	March 2006	March 2006

Table 2. Sorghum varieties, *Dano* and *Lalo* disease incidences (1-9) scale for the years 2001 and 2002 across different locations.

Genotypes	Anthracnose (1-9)			Leaf blight (1-9)		
	Bako	Gute	Boshe	Bako	Gute	Boshe
BRC-378 (*Dano*)	4 (6)	4 (4)	4 (5)	4 (5)	3 (4)	2 (4)
BRC-245 (*Lalo*)	4 (5)	4 (5)	4 (4)	5 (5)	4 (4)	5 (4)
Abamelko	2 (2)	2 (2)	2 (2)	2 (2)	2 (2)	2 (1)

Numbers in parenthesis are disease incidences for 2002

...rostis tef (Zucc.) Trotter] Variety

...chew Lule, Girma Mengistu, Abeya Temesgen and Firdissa Eticha

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Abstract: *Guduru* is the common name for *teff* [*Eragrostis tef* (Zucc.) Trotter] with the pedigree name of DZ-10-1880. It out-yielded the standard check, *Dukem*, across all on-stations. In on- farm trials, *Guduru* maintained its superiority over the standard check, *Dukem* with 13% grain yield advantage. *Guduru* has wide yield adaptability in its grain yield performance. It has good traits such as uniform agronomic characters, high biomass, and thick stalk and with low lodging problem. It also has very white seeds and high market value as well as, disease resistance.

1. Agronomic and Morphological Characteristics

Guduru is a white seeded variety with a white flower that was evaluated for its agronomic traits across test locations and years. It has thick stalk erect growth habit but bending at maturity. *Guduru* (6.5 tons/ha) has higher mean biomass than that of the standard check, *Dukem* (6.1 tons/ha). This high biomass of *Guduru* was mainly attributed to its high tillering habit and better plant height than that of *Dukem*. On average, *Guduru* heads in 70 days and matures in 132 days after emergence, and the standard check, *Dukem* is earlier than *Guduru* with 4 days for heading and 10 days for maturity. On mean basis, *Guduru* had 115 cm plant height, 46 cm panicle length, a seed size of 0.3 g per 100 seeds and with a fairly loose panicle. The standard check, *Dukem* had plant height of 91 cm. Summary of agronomic and morphological characters of *Guduru* are given in Table 1.

2. Yield Performance

Guduru was tested at early breeding stages from 1999 to 2001 at Arjo, Gedo and Shambu and it out yielded the standard check, *Dukem* throughout the trials. In multi-location trials, where 14 varieties were tested for two years (2002 and 2003) at Arjo, Gedo, Gute, and Shambu, the mean grain yield of *Guduru* was 1.8 tons/ha with 12% grain yield advantage over the standard check, *Dukem*. In on-farm trials, *Guduru* maintained its superiority over the standard check, with the mean yield of 1.7 tons/ha compared to 1.5 tons/ha for *Dukem*.

3. Disease Reaction

Guduru and *Dukem* were resistant for leaf rust (*Uromyces eragrostidis* Tracy) and head smudge (*Helmentosporium miyakei* Nisikado) diseases.

4. Stability Performance

Yield stability in fourteen *teff* varieties was studied for two years across four locations. Stability parameters were calculated by the method of Eberhart and Russel (1966). The result showed that *Guduru* had unity regression coefficient associated with high mean grain yield implying that it has good general adaptability.

5. Conclusions

The *teff* variety, *Guduru* out-yielded the standard check, *Dukem* and local check. It had stable yield across years and locations. *Guduru* has high biomass, which is a very important trait for animal feed. It also has very white seed compared to the standard check, *Dukem*, and has high market value. It is, therefore, released for the highlands of Arjo, Gedo, Gute and Shambu in Western Ethiopia.

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Eberhart, S.A. and Russell, W.A. 1966. Stability parameters for comparing varieties. *Crop Science* 6: 36-40.

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ISSN 1992-0407

acteristics of *teff*, *Guduru* (DZ-10-1880).

	1850 - 2500
Rainfall (mm)	1000 - 1200
Fertilizer rate; DAP (kg/ha)	100
Planting date	July
Seed rate (kg/ha)	25 – 30
Days to heading	70
Days to maturity	132
Panicle length (cm)	46
Plant height (cm)	115
Growth habit	Erect and slight bending at maturity
Flower color	White
Seed color	White
100 seed weight (g)	0.3
Crop pest reaction	Resistant to major diseases and pests
Leaf rust	2
Head smudge	2
Yield (ton/ha):	
Research field	1.5-2.3
Farmer field	1.4-2.0
Year of release	2006